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Under
Graduate Degree Programme NETAJI SUBHAS OPEN UNIVERSITY ZOOLOGY HZO CC-ZO-01 SELF LEARNING MATERIAL NSOU CC - ZO - 01 1
PREFACE In a bid to standardize higher education in the country, the University Grants Commission (UGC) has introduced Choice Based Credit System (CBCS) based on five types of courses viz. core, discipline specefic, generic elective, ability and skill enhancement for graduate students of all programmes at Honours level. This brings in the semester pattern, which finds efficacy in sync with credit system, credit transfer, comprehensive continuous assessments and a graded pattern of evaluation. The objective is to offer learners ample flexibility to choose from a wide gamut of courses, as also to provide them lateral mobility between various educational institutions in the country where they can carry their acquired credits. I am happy to note that the university has been recently accredited by National Assessment and Accreditation Council of India (NAAC) with grade "A". UGC (Open and Distance Learning Programmes and Online Programmes) Regulations, 2020 have mandated compliance with CBCS for UG programmes for all the HEIs in this mode. Welcoming this paradigm shift in higher education, Netaji Subhas Open University (NSOU) has resolved to adopt CBCS from the academic session 2021-22 at the Under Graduate Degree Programme level. The present syllabus, framed in the spirit of syllabi recommended by UGC, lays due stress on all aspects envisaged in the curricular framework of the apex body on higher education. It will be imparted to learners over the six semesters of the Programme. Self Learning Materials (SLMs) are the mainstay of Student Support Services (SSS) of an Open University. From a logistic point of view, NSOU has embarked upon CBCS presently with SLMs in English / Bengali. Eventually,
the English version SLMs

will be translated into Bengali too, for the benefit of learners. As always,
all of our teaching faculties contributed in this process. In addition to this
we have also requisitioned the services of best academics in each domain in preparation of the new SLMs. I am sure they will be of commendable academic support. We look forward to proactive feedback from all stakeholders who will participate in the teaching-learning based on these study materials. It has been a very challenging task well executed, and I congratulate all concerned in the preparation of these SLMs. I wish the venture a grand success. Professor (Dr.) Subha Sankar Sarkar Vice-Chancellor
2 NSOU CC - ZO - 01 Printed in accordance with the regulations of the Distance Education Bureau of the University Grants Commission. Netaji Subhas Open University Under Graduate Degree Programme Choice Based Credit System ((CBCS) Subject : Honours in Zoology (HZO) Course : Animal Diversity,
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Notification All rights reserved. No part of this Study material may be repoduced in any form without permission in writing from Netaji Subhas Open University. Kishore Sengupta Registrar Professor Kajal De Dr. Koushik Ghosh (Chairperson) Associate Professor of Zoology Director, School of Sciences West Bengal State University NSOU Dr. Anirban Ghosh Dr. Santanu Chakraborty Associate Professor of Zoology Principal & Associate Professor of Zoology, WBES NSOU Govt. General Degree College, Singur Dr. Sanjay Mandal Dr. Samir Saha Associate Professor of Zoology Associate Professor of Zoology NSOU West Bengal State University Dr. Bibhas Guha Dr. Paulami Maiti Associate Professor of Zoology Associate Professor of Zoology, WBES NSOU Lady Brabourne College Mr. Ashif Ahamed Dr. Rupa Mukhopadhyay Assistant Professor of Zoology
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NSOU CC - ZO - 01 5 Unit - 1 Study of specimens with proper reasons 7-123 Unit - 2 Study of permanent slides 124-133 Unit - 3 Key to identification of poisonous and non-poisonous snakes 134-135 Unit - 4 Osteology 136-166 Unit - 5 Examination of gametes 167-171 Unit - 6 Chick : developmental stages 172-175 Unit - 7 Demonstration of whole mount preparation of chick embryo 176-177 Unit - 8 Animal album 178-214 Netaji Subhas Open University UG Zoology (HZO) Course : Animal Diversity, Structure and Development (Practical) Code : CC - ZO - 01
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NSOU CC - ZO - 01 7 Units : 1 Study of specimens with proper reasons Structure 1.0 Objectives 1.1 Introduction 1.2 Study of different invetebrate specimens 1.3 Study of different vertebrate and invertebrate chordate speciments with proper reasons 1.0
Objectives
By studying this unit learners would be able to understand about
the
systematic position and indentifying characteristics of different invertebrate and vertebrate species. 1.1 Introduction Species identification has traditionally been based on morphological data and implemented in dichotomous identification keys. With easy access to increasingly affordable DNA sequencing, specimens can also be identified through sequence similarity in taxonomically curated sequence data base. In this unit, study of different invertebrate, invertebrate - chordates and vertebrates has been discussed in details. 1.2 Study of the different invertebrate specimen with proper reasons 1. Amoeba sp. a)
Systematic position (According to Levine et. al., 1980) Sub-kingdom : Protozoa Phylum : Sarcomastigophora
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NSOU CC - ZO - 01 Sub-phylum : Sarcodina Genus : Amoeba Specimen : Amoeba sp. b) Systematic identification with reasons Sub-kingdom : Protozoa (i) Microscopic, single celled eukaryotic organisms. (ii) Nucleus–single or many. (iii) Pseudopodia, cilia and flagella are locmotory organelles. (iv) Chloroplast may or may not be present. (v) Flagella or pseudopodia, or both are present. (vi) The nucleus is monomorphic. Sub-phylum : Sarcodina (i) Pseudopodia present. (ii) Body is naked or with test. Specimen : Amoeba sp. (i) Irregular body shape. (ii) Blunt and finger like lobose type pseudopodia are present. (iii) The body can be divided into an outer ectoplasm and an inner endoplasm. (iv) A single contractile vacuole and several food vacuoles are clearly visible. (v) A single consicuous nucleus is present. (vi) Body naked.

NSOU CC - ZO - 01 9 Figure 1 : Amoeba sp. 2. Euglena sp. a)

Systematic position (According to Levine et.al., 1980) Sub-kingdom : Protozoa Phylum : Sarcomastigophora Sub-phylum :

Mastigophora Genus : Euglena Specimen : Euglena sp. b) Systematic identification with reasons Sub-kingdom : Protozoa Same as amoeba sp. Phylum : Sarcomastigophora Same as amoeba sp. Sub-phylum : Mastigophora (i) Presence of one or more flagella. (ii) Pellicle cover is present in several forms. Cytoplasm Food vacuole (digests food) Pseudopod Contrac vacuole (excretes water and waste) Cell membrane Pseudopods nucleus

10 NSOU CC - ZO - 01 Specimen: Euglena sp. (i) A long fagellum is present. (ii) Photoreceptive eye spot called stigma present. (iii) Chloroplast present. (iv) The nucleus is posterior. (v) The body is spindle shaped. 3. Paramoecium sp. a) Systematic position (According to Levine et.al, 1980) Sub-kingdom : Protozoa Phylum :

Ciliophora Genus : Paramoecium Specimen : Paramoecium sp. b) Systematic identification with reasons Sub-kingdom : Protozoa Same as Euglena sp. Phylum : Ciliophora (i) Presence of cilia that cover the cell surface. (ii) Two types of nuclei present. fagellum stigma (eyespot) Photoreceptor Golgi apparatus contractile vacuole endoplasmic reticulum stored carbohydrate chloroplasts mitrochandrion nucleus nucleus

NSOU CC - ZO - 01 11 Specimen : Paramoecium sp. (i) Slipper like body shape. (ii) Body is uniformly covered by cilia which are equal in length. (iii) Cytopharynx present. (iv) Presence of ventral oral groove. (v) The body consists of food vacuoles, macronucleus, micronucleus, anterior and posterior contractile vacuoles. 4. Plasmodium sp. a) Systematic position (According to Levine et.al.,1980) Sub-kingdom : Protozoa Phylum :

Apicomplexa Genus : Plasmodium Specimen : Plasmodium sp. ANTERIOR END POSTERIOR END Figure 3 : Paramecium sp. Posterior canals (in diestole) Caudal tuft of cilia Fooder canals (in diestole) Newly forming food vacuole Cytopyge Cytopharynx Cytostome Buccal cavity with oral cilla Fooder vacuoles Vestibule Oral groove Micronucleus Endoplasm Ectoplasm Pollicle Trichocysts Cilia Anterior contractile vacuole (in diastole) Fooder canals (in systole) Macronucleus

12 NSOU CC - ZO - 01 b) Systematic identification with reasons Sub-kingdom : Protozoa Same as Euglena sp. Phylum : Apicomplexa (i) Unique form of organelle called apicoplast present, which is a type of special plastid. (ii) An apical complex structure is present. (iii) Pseudopodia or cilia or flagella absent. Specimen : Plasmodium sp. (Trophozoite or Signet ring state) Plasmodium vivax (i) Trophozoite stage is found within the RBC. (ii) Body rounded, ring like with a large central vacuole. (iii) Only one ring like structure is present. (iv) Cytoplasm of one side of vacuole is thick and broad, while the other side is thin and narrow. (v) Nucleus one in number and lies on the thin side. (vi) The haemozoin granules are scattered in the cytoplasm of the trophozoite. (vii) Globular Schuffner's dots are seen in the cytoplasm of RBC. Plasmodium falciparum (i) Trophozoite stage is found within the RBC. (ii) Body rounded, ring like with a large central vacuole. (iii) More than one ring like structures are present.

NSOU CC - ZO - 01 13 (iv) Thickness of cytoplasm is more or less uniform. (v) Nucleus may be found in segmented conditions, segmented nucleus may remain on side by side or may lie in the opposite pole of the ring. (vi) The haemozoin granules form a black mass in the cytoplasm. (vii) Elongated Mourer's dots are seen in the cytoplasm of RBC.

14 NSOU CC - ZO - 01 5. Sycon sp. a) Systematic position (According to Brusca and Brusca, 2003) Phylum : Porifera Class : Calcarea Sub-class : Cacaronea Genus : Sycon Specimen : Sycon sp. b) Systematic identification with reasons Phylum : Porifera (i) Generally marine aquatic organisms, with few fresh water form. (ii) Bodies are asymmetrical. (iii) Body shape can be cylindrical, vase-like, rounded or sac-like. (iv) Diploblastic animals with two layers, the outer dermal layer and the inner gastral layer. Class : Calcarea (i) Skeleton made of calcareous spicules. (ii) Vase- shaped compact structures. (iii) Spicules are not divisible into megaseleres and microselers. Sub-class : Calcaronea (i) Flagella from choanocytes arise directly from nucleus. (ii) Triaxon spicules with one ray characteristically longer than other two. Specimen : Sycon sp. (i) The body is vase shaped be interconnected with each other. (ii) The middle portion of this vase is broad and an osculum is present on the top. (iii) The osculum is encircled by large giant monaxon spicules forming a funnel shaped collar or oscular firnge. (iv) The base is attached to the substratum. (v) Body surface is finely rough with projecting spicules.

NSOU CC - ZO - 01 15 6. Hyalonema sp. a) Systematic position (According to Brusca and Brusca, 2003) Phylum : Porifera Class : Hexactinellida Sub-class : Amphidiscomorpha Genus : Hyalonema Specimen : Hyalonema sp. b) Systematic identification with reasons Phylum : Porifera Same as Sycon sp. Class : Hexactinellida They possess six rayed sillicious spicules. Sub-class : Amphidiscomorpha Presence of amphidis spicules.

16 NSOU CC - ZO - 01 Specimen : Hyaloneama sp. (i) Commonly known as glassrope sponge, since the spicules are often fused to form a lattice like skeleton giving the sponge a glass like appearance. (ii) Cup shaped, measuring 10 to 30 cm in height. The spongocoel is well developed and the osculum contains sieve plate. (iii) There is presence of hold fast organs like root spicules. The root spicules are compact, elongated and twisting giving a rope like appearance. (iv) The middle portion between the cup and root spicules contains symbiotic polyps of Epizoanthus. (v) A large number of a amphidisc spicules are present.

NSOU CC - ZO - 01 17 7. Eupelectella sp. a) Systematic position (According to Brusca and Brusca, 2003) Phylum : Porifera Class : Hexactinellida Subclass : Hexasterophora Genus : Euplectella Specimen : Euplectella sp. b) Systematic identification with reasons Phylum : Porifera Same as sycon sp. Class : Hexactinellida Same as Hyalonema sp. Sub-class : Hexasterophora (i) Skeletons composed of overlapping six-rayed spicules. (ii) The sponge is commonly firmly attached by its base to a hard substratum. Specimen : Euplectella sp. (i) Has a glassy, knitted, basket like appearance and is therefore called venus flower basket. (ii) Knitted appearance is due to the presence of parietal gaps which formed because of interlaced four and six rayed silicious spicules which are fused at the top. (iii) Root tufts made a long silicious spicules are found in the bottom part, being responsible for the attachment of the animal to the mud. (iv) Oscular sieve plate present in the osculum.

18 NSOU CC - ZO - 01 8. Obelia sp. a) Systematic position (According to Ruppert & Barnes 1994) Phylum : Chindaria Class : Hydrozoa Genus : Obelia Specimen : Obelia sp. b) Systematic identification with reasons Phylum : Cnidaria (i) Cnidoblast cells with nematocyst present, hence the name cnidaria. roof tuft imedacel parietal gaps osculut oscular sieve plate

NSOU CC - ZO - 01 19 (ii) Colonies are essentially dimorphic with asexual polyp and sexual medusa. (iii) A single gastrovascular cavity or coelenteron with a single opening called mouth is present. Class : Hydrozoa (i) Either polypoid or medusoid or both are present. (ii) They may be solitary or colonial. Specimen : Obelia sp. (i) The colony of Obelia is dimorphic (both polyp and medusa present) and resemble small seaweed filaments. (ii) The hydrorhiza forms the basal or horizontal portion called stolon, which is responsible for attachment to substratum. (iii) Hydrorhiza gives rise to vertical branches called hydrocaulus, which further gives alternate branches ending in terminal zooids. (iv) The stems and zooids contain a living, hollow, cellular tube called coenosarcs. (v) The medusas are present at the base of the polyp bearing branches and are enclosed in blastostyles. (vi) The polyps are a bell shaped cup, with the lower portion called hydrotheca and the upper portion hypostome. (vii) 24 nematocyst bearing tentacles are present surrounding the hypostome.

20 NSOU CC - ZO - 01 9. Physalia sp. a) Systematic position (According to Ruppert & Barnes, 1994) Phylum : Cnidaria Class : Hydrozoa Genus : Physalia Specimen : Physalia sp. b) Systematic identification with reasons Phylum : Cnidaria Same as Obelia sp.

NSOU CC - ZO - 01 21 Class : Hydrozoa Same as Obelia sp. Specimen : Physalia sp. (i) Commonly known as Portuguese man of war. (ii) The animal is characterized by an upper large crested pneumatophore or float. Below the float lies the coenosarc from which dactylozooids, gastrozooids, gonozooids and gonodendra hang. (iii) Batteries of pneumatocys are present. (iv) The gastrozooids are without tentacles. gonozooids crest or float pneurnatophore or float gas glands smaller dactylozooids large dactylozooid gastrozooids fishing tentacles bearing nematocyst

22 NSOU CC - ZO - 01 10. Jellyfish a) Systematic position (According to Ruppert & Barnes, 1994) Phylum : Cnidaria Class : Schyphozoa Specimen : Jellyfish b) Systematic identification with reasons Phylum : Cnidaria Same as Obelia sp. Class : Schyphozoa (i) Exclusively medusoid. (ii) Velum absent in medusoid umbrella. Specimen : Jellyfish (i) The body is saucer shaped and has a convex ex-umbrellar and concave sub umbrellar surface. (ii) Gastric filaments, sub genital pits and velarium can be seen. (iii) Marginal tentacles having stinging cells are seen along the sub-umbrellar margin. (iv) The four cornered mouth is drawn out into four oral arms. (v) The body is jelly like, transparent, bluish, white, reddish or pinkish in colour. (vi) Four horse-shoe shaped gonads are present.

NSOU CC - ZO - 01 23 11. Sea Anemone a) Systematic position (According to Ruppert & Barnes, 1994) Phylum : Cinidaria Class : Anthozoa Subclass : Hexacorallia Specimen : Sea anemone b) Systematic identification with reasons Phylum : Cnidaria Same as Obelia sp.

24 NSOU CC - ZO - 01 Class : Anthozoa (i) Exclusively polypoid, with no medusa. (ii) Eight or more mesenteries divide the gastrovascular cavity. Subclass : Hexacorallia Tentacles and mesenteries are six or in multiples of six in number. Specimen : Sea anemone (i) Body of animal divided into oral disk, column and pedal disc. (ii) The body is short cylindrical and radially symmetrical. (iii) The oral disk is expanded as a flat disc called capitulum, which bears several marginal tentacles. (iv) The coloumn or the body is a thick walled structure called scapus. (v) The capitulum and scapus is separated by a collar which is a prominent fold. (vi) Cinclides or small openings perforate the wall of the scapus. (vii) The pedal disc which attaches the body to the substratum is a broad disc which is separated from scapus by limbus. Figure : 11: Sea anemone

NSOU CC - ZO - 01 25 12. Taenia sp. a) Systematic position (According Ruppert & Barnes, 1994) Phylum : Platyhelminthes Class : Cestoda Genus : Taenia Specimen : Taenia sp. b) Systematic identification with reasons Phylum : Platyhelminthes (i) Dorsoventrally flattened leaf like or ribbon like body. (ii) Attachment organs are present. (iii) Mouth may or may not be present. (iv) Anus absent. Class : Cestoda (i) Ribbon like segmented body. (ii) Mouth absent. (iii) Suckers present. (iv) Cuticle present surrounding the body. Specimen : Taenia sp. (i) The body can be divided into the head/scolex, neck, immature, mature and gravid segments called proglottids. (ii) Scolex serves as organ for attachment, containing four suckers and a rounded rostellum. (iii) The size of the progtottids increase gradually towards the posterior end. (iv) Mature segments contain well developed male and female reproductive organs. (v) The gravid segments contain branched uterus filled with oncospheres.

26 NSOU CC - ZO - 01 Figure : 12 : Taenia sp 13. Male and female Ascaris sp. a) Systematic position (According to Ruppert & Barnes, 1994) Phylum : Nematoda Class : Phasmida Genus : Ascaris Specimen : Ascaris sp. b) Systematic identification with reasons Phylum : Nematoda (i) Unsegmented worm like body with their ends tapering. (ii) Body is generally covered with thick, flexible cuticle. (iii) Mouth and anus are at opposite end. (iv) Presence of caudal phasmid which are sensory structures. (v) The labial amphids are pore like acting as chemosensory organ.

NSOU CC - ZO - 01 27 Specimen : Ascaris sp. (i) Elongated body with no distinct head. (ii) Four longitudinal streaks are present on the cuticle. Male Ascaris Female Ascaris (a) Tail is curved and pointed. (a) Tail is straight and blunt. (b) A pair of penial setae or (b) No penial setae are present. cloacal spicules are present near the cloaca. Figure : 13: Male (a) and Female (b) Ascaris sp.

28 NSOU CC - ZO - 01 14. Aphrodite sp. a) Systematic position (According to Ruppert & Barnes, 1994) Phylum : Annelida Class : Polychaeta Genus : Aphrodite Specimen : Aphrodite sp. b) Systematic identification with reasons Phylum : Annelida (i) Bilaterally symmetrical and metamerically sengmented body. (ii) Mouth and anus are at opposite ends. (iii) Setae present or parapodia or suckers present. (iv) Appendages, when present, are unjoined. Class : Polychaeta (i) Well developed parapodia with numerous setae in each segment. (ii) Distinct head with appendages and eyes. (iii) Clitellum absent. (iv) Sucker absent. Specimen : Aphrodite sp. (i) Ovoid body with 30 to 35 segments. (ii) Felt like setae cover the body. (iii) Anterior end has prostomium bearing a small median tentacle and two lateral palps. (iv) The structure of the parapodia is greatly modified. (v) The notopodia contains stiff setae, soft setae and irridescent setae. (vi) The soft notopodial setae form the felt. (vii) Neuropodial setae are brown and stiff.

NSOU CC - ZO - 01 29 Figure : 14: Aphrodite sp. 15. Nereis sp. a) Systematic position (According Ruppert & Barnes, 1994) Phylum : Annelida Class : Polychaeta Genus : Nereis Specimen : Nereis sp. b) Systematic identification with reasons Phylum : Annelida Same as Aphrodite sp. Class : Polychaeta Same as Aphrodite sp. Specimen : Nereis sp. (i) Elongated and cylindrical body which is divided into several metameres or segments. (ii) The first segment is the prostomium which bears the prostomial tentacles, palps and ocelli. setal setal staff chaetae iridelent bristles palp tentacles

30 NSOU CC - ZO - 01 (iii) The second segment observedis the peristomium which carries anterolaterally four pairs of peristomial tentacle. (iv) Paired parapodia on either side present on all segments except the peristomium and prostomium. (v) Anal segment cotains a pair of anal cirri. Figure : 15: Nereis sp. anus anal cirri inter segmental grooves parapodia metameres peristomium peristomial tentacle prostomium

NSOU CC - ZO - 01 31 16. Earthworm a) Systematic position (According Ruppert & Barnes, 1994) Phylum : Annelida Class : Oligochaeta Specimen : Earthworm b) Systematic identification with reasons Phylum : Annelida Same as Aphrodite sp. Class : Oligochaeta (i) Setae are present in each segment. (ii) Distinct cliteuum present. (iii) Suckers absent. Specimen : Earthworm (i) External and internal segmentation are distinct. (ii) On the ventral body wall of all the segments except the first and the last rows of setae present. (iii) The dorsal surface has a dark median line which is the dorsal blood vessel. (iv) The first segment is the prostomium which contains the ventral mouth. (v) Thickened region called the clitellum is present from the 14th to 16th segment. (vi) Spermathecal pores are found in the intersegmental grooves of 5/6th, 6/7th, 7/8th and 8/9th segments. (vii) Female genital pores reside in the 14th segment and a pair of male genital pore lies on 18th segment on ventral side. (viii) Two pairs of genital papillae lie on the ventral surface in the 17th and 19th segment.

32 NSOU CC - ZO - 01 Figure : 16: Earthworm (A) ventral view and (B) dorsal view 17. Hirudinaria sp. a) Systematic position (According to Ruppert & Barnes, 1994) Phylum : Annelida Class : Hirudinea Genus : Hirudinea Specimen : Hirudinaria sp. b) Systematic identification with reasons Phylum : Annelida Same as Aphrodite sp. mouth prostomium peristomiun clitellum genital papillae female genital opening mate genital opening ring of setac anus segments 14-16 segments dorsai blood vessel A B

NSOU CC - ZO - 01 33 Class : Hirudinea (i) There is definite number of body segments. (ii) Segments are marked externally by secondary rings or annuli. (iii) The clitellum is prominent during the reproductive season and is made of three segments. (iv) A small suctorial anterior sucker and a large and powerful posterior sucker are present. (v) The clitellum is prominent during the reproductive season and is made of three segments. (vi) Body has three segments. (vii) Three toothed and well developed jaw is present. Specimen : Hirudinaria sp. (i) The body is soft, vermiform, elongated dorsoventrally flattened. (ii) Small anterior and large posterior suckers are well developed. (iii) Dorsal surface is olive green and ventral surface is orange-yellow or red. (iv) Both sides have black stripes. (v) Body divided into cephalic, preclitellar, clitellar, middle, caudal and posterior sucker region. (vi) The body has 33 segments, with each segment being superficially divided into 5 annuli. (vii) Five pairs of eyes are present dorsally. (viii) Four pairs of dorsal segmental receptor organs and three pairs of ventral segmental receptor organs are present.

34 NSOU CC - ZO - 01 Figure : 17 : Hirudinaria sp. (a) dorsal view and (b) ventral view 18. Palaemon sp. a) Systematic position (According to Ruppert & Barnes, 1994) Phylum : Arthropoda Sub-phylum : Crustacea Class : Malacostraca Sub-class : Eumalacostraca Genus : Palaemon Specimen : Palaemon sp.

NSOU CC - ZO - 01 35 b) Systematic identification with reasons Phylum : Arthropoda (i) The body is segmented and shows bilateral symmetry. (ii) Externally jointed appendages are present. (iii) Body is externally covered with a thick, tough and non-living, chitinous cuticle, forming the exoskeleton. (iv) Body is generally divided into head, thorax and abdomen. (v) The compound eyes are present. Sub-phylum : Crustacea (i) Head bears five pairs of appendages which comprise of two pairs of antennae (first pair being the antennules), one pair of mandibles and two pairs of maxillae. (ii) The cylindrical or leaf-shaped appendages are all typically biramous, the two branches are of different size and shape. (iii)
Head bears a pair of compound eyes, sometimes located on movable stalks and a small median dorsal naupliar eye. Class : Malacostraca (i) Body comprises of a head, an eight segmented thorax and a six segmented abdomen. (ii) All the fourteen segments bear appendages. (iii) The posterior thoracic limbs beint walking legs (pereiopods), the first five pairs of abdominal ones forming swimming organs (pleopods). (iv) Carapace usually present. (v) The compound eyes are present.

36 NSOU CC - ZO - 01 Subclass : Eumalacostraca (i) Anennae without three flagella. (ii) No seventh abdominal segment. Specimen : Palaemon sp. (i) Young stages are transluscent and white but the adults are usually dull pale- blue or greenish with orangered patches. (ii) Body divided into cephalothorax , abdomen, and telson. (iii) Cephalothorax is formed by the union of head and thorax region and consists totally of 13 segements. (iv) All segments of cephlalothorax bear jointed appendages. (v) The abdomen is jointed region with 6 distinct movable segments and a terminal conical piece, the telson. (vi) The abdominal segments are dorsally rounded, laterally compressed and normally bent under the cephalothorax, so that the animal looks like (‘) cooma shaped. (vii) Each abdominal segment bears a pair of jointed appendages called pleopods or swimmerets. (viii) Carapace anteriorly produced into rostrum.

NSOU CC - ZO - 01 37 Figure : 18 : Palaemon sp. 19. Scylla sp. (a) Systematic position (According to Ruppert of Barnes, 1994) Phylum : Arthropoda Subphylum : Crustacea Class : Malacostraca Subclass : Eumalacostraca Genus : Scylla Specimen : Scylla sp. b) Systematic identification with reasons Phylum : Arthropoda Same as Palaemon sp. Class : Malacostraca Same as Palaemon sp.

38 NSOU CC - ZO - 01 Sub-class : Eumalacostraca Same as Palaemon sp. Specimen : Scylla sp. (i) Carapace smooth, broad with strong transversal rides. (ii) Anterior zone on the carapace with a deep H-shaped groove. flexed beneath caphalothorax. (iii) Broad teeth like structures on each anterolateral margin carapace all them with similar size and projecting obliquely outwards. (iv) Strong chelipeds with well developed spines. (v) Rostrum and uropod absent. Figure : 19 : Scylla sp. (Crab) 20. Carcinoscorpius sp. a) Systematic position (According Ruppert & Barnes, 1994) Phylum : Arthropoda Subphylum : Chelicerata

NSOU CC - ZO - 01 39 Class : Merostomata Sublclass : Xiphosura Genus : Carcinoscorpius Specimen : Carcinoscorpius sp. b) Systematic identification with reasons Phylum : Arthropoda Same as Palaemon sp. Subphylum : Chelicerata (i) Body divided into an anterior cephalothorax or prosoma, carapace, and a posterior abdomen or opisthosoma without legs. (ii) Chelicera and pedipalp present. (iii) Antenna and mandible absent. (iv) Median ocellii are present. Class : Merostomata (i) Abdominal appendages are modified into gills. (ii) Twelve segmented abodmen is subdivided into a seven segmented mesosoma and a five segmented metsoma. (iii) A prominent spike like caudal spion or telson is present at the end of the body. Subclass : Xiphosura (i) Prosoma and opisthosoma are separated by a hing. (ii) A large horseshoe shaped carapace covers the prosoma. (iii) An elongated, pointed and slender caudal spine is present. (iv) Carapace has one median end two lateral rides. (v) A pair of median eye and a pair of lateral eye are present on the carapace. (vi) Five pairs of book gills are present on and from the ninth to the thirteenth segment. Specimen : Carcinoscorpius sp. (mangrove horseshoe crab) (i) The prosoma is the large, dome-shaped frontal part at the carapace. (ii) The smaller rear carapace with spines on the edge is the opisthosoma.

40 NSOU CC - ZO - 01 (iii) The telson or the tail is rounded. (N.B. It is essentially triangular in the other species of horse shoe crabs.) (iv) Each individual has six pairs of appendages. The first pair, the chelicerae, is relatively small and placed in front of the mouth of which the first pair is and the pusher legs remaining four pairs. (v) Most of the appendages have straight, scissor-like claws. (N.B. in males the first and second pair of walking legs have strongly hooked "scissors".) (vi) Located behind their legs are book gills. Figure 20: Carcinoscorpius sp. (A) Dorsal view and (B) Ventral view 21. Penaeus sp. a) Systematic position (According Rupper & Barnes 1994) Phylum : Arthropoda Subphylum : Curstacea

NSOU CC - ZO - 01 41 Class : Malacostraca Subclass : Eumalacostraca Genus : Penaeus Specimens : Penaeus sp. b) Systematic identification with reasons Phylum : Arthropoda Same as Palaemon sp. Subphylum : Crustacea same as Palaemon sp. Class : Malacostraca Same as Palaemon sp. Subclass : Eumalacostraca same as Palaemon sp. Specimen : Penaeus sp. (i) The carapace and abdomen are transversely banded with alternative red bluish black and white. (ii) Ventral surface of rostrum bears teeth. (iii) Pleopods are biramous. (iv) The cephalotorax is relatively smaller.

42 NSOU CC - ZO - 01 Figure 21 : Penaeus sp. 22. Scolopendra sp. a) Systematic position (According to Ruppert & Barnes, 1994) Phylum : Arthropoda Subphylum : Uniramia Class : Chilopoda Subclass : Epimorpha Genus : Scolopendra Specimen : Scolopendra sp. b) Systematic identification with reasons Phylum : Arthropoda Same as Palaemon sp. Sub-phylum : Uniramia (i) The body can be divided into a head and trunk. Third maxillped Pereopod (Walking leg) Antennal flagelum Pleopod (Swimmeret) Uropod (Tall tan) Telson Sixth abdominal segment Abdominal segment Hepatic carina Hepatic spine Epigastic spine Adrostral carina Gastro-orbital carina Antennal spine Rostrum Antennular flagellum Anternal scale

NSOU CC - ZO - 01 43 (ii) Head appendages are one pair each of antennae, mandibles and maxillae. In addition, it has an upper lip or labrum. (iii) The trunk bears pairs of walking legs. (iv) Appendages uniramous. (v) Head also comprises of compound eyes. Class : Chilopoda (i) Dorsoventrally flattened and elongated body. (ii) The number of leg bearing segments varies from 15 to more; with the last two segments have no legs. (iii) Poison claws or forcipules are the first pair of legs, which terminates in a pointed fang from which poison is released. Subclass : Epimorpha 21 or more pairs of legs are present. Specimen : Scolopendra sp. (i) They are commonly known as centipede. (ii) Body elongated, dark-greenish brown in colour. (iii) A distinct head is present with a long segmented trunk or body. (iv) The head bears long antennae, ocelli, maxillae and mandibles, with the maxillae being somewhat reduced. (v) 21 pairs of walking legs are present on the body segments. (vi) Last segment bears ventral anus, genital atrium and a pair of anal style. (vii) Walking legs are seven segmented.

44 NSOU CC - ZO - 01 Figure 22 : Scolopendra sp. 23. Millipede sp. a) Systematic position (According to Ruppert & Barnes, 1994) Phylum : Arthropoda Subphylum : Uniramia Class : Diplopoda Subclass : Helminthomorpha Specimen : Millipede sp. b) Systematic identification with reasons Phylum : Arthropoda Same as Palaemon sp. Subphylum : Uniramia Same as Scolopendra sp. Class : Diplopoda (commonly called millipedes) (i) Presence of two pairs of jointed legs on most body segments. The first segment (collum) is legless, the next three segments bear a single pair of legs and the following segments have two pairs of legs. (ii) A plate-like mouth structure comprising of fused maxillae and labium called gnathochilarium is present.

NSOU CC - ZO - 01 45 (iii) Pressence of diplosomites which are double trunk sigments formed from the fusion of two segments Poison claw absent. Subclass : Helninthomorpha Segments are cylindrical. Specimen : Millipede (i) Body differentiated into head, thorax and abdomen. (ii) The head is covered by cephalic shields and is bent downwards. (iii) The head contains antennae, simple eyes (ocelli), and only a single maxilla. (iv) Thorax has four segments and each of the last three segments is provided with one pair of walking legs. (v) Anennae are seven segmented. (vi) More than 200 pairs of legs present. Figure 23 : Millipede sp. 24. Periplaneta sp. a) Systematic position (According to Ruppert & Barnes, 1994) Phylum : Arthropoda Subphylum : Uniramia Class : Insecta Subclass : Ectognatha Genus : Periplaneta Specimen : Periplaneta sp. b) Systematic identification with reasons Phylum : Arthropoda Same as Palaemon sp.

46 NSOU CC - ZO - 01 Subphylum : Uniramia Same as Seolopendra sp. Class : Insecta (i) Three pairs of thoracic legs are present. (ii) The head is formed by the fusion of six segments and bears one pair of antennae, one pair of mandible and two pair of maxillae. (iii) The thorax is divided into prothorax, mesothorax and metathorax. (iv) The mesothorax and the metathorax, bear a pair of wings. Sub-class : Ecognatha (i) Mouth parts are not sunk into a pouch. (ii) Presence of compound eyes. Specimen : Periplaneta sp. [Commonly called the cockroach] (i) Body is elongated and dorsoventrally flattened with reddish brown colour. (ii) The head is movable and

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contains a pair of long sensory antennae and a pair of

compound eye. (iii) The thorax contains a pair of anterior forewings and a pair of posterior hindwings. (iv) The abdomen consists of ten segments. (v) The mouth parts are of the chewing type. (vi) Each leg is made up of coxa, trochanter, femur, tibia, tarsus, claws and pulvillus. (vii) A pair of anal cerci present. (viii) In male, a pair of anal style is present which is absent in female.

NSOU CC - ZO - 01 47 Figure 24 : Male and female Periplaneta sp. 25. Apis sp. a) Systematic position (According to Ruppert & Barnes, 1994) Phylum : Arthropoda Subphylum : Uniramia Class : Insecta Subclass : Ectognatha Genus : Apis Specimen : Apis sp. b) Systematic identification with reasons Phylum : Arthropoda Same as Palaemon sp. Subphylum : Uniramia Same as Scolopendra sp.

48 NSOU CC - ZO - 01 Class : Insecta Same as Periplaneta sp. Subclass : Ectognatha Same as Periplaneta sp. Specimen : Apis sp. [commonly known as honey bee] (i) The body is divisible into head, thorax and abdomen. (ii) Three castes exist in honey bee, the largest fertile queen, the sterile workers and the male drones. (iii) In the lateral position clypeus, labrum and other mouth parts are visible. (iv) The mouth parts are rasping and lapping type. (v) Prothoracic leg contains eyebrush, velum, and antenna comb and pollen brush. (vi) Mesothoracic legs contain spur, pollen brush and pulvillus. (vii) Meathoracic legs contain pollen basket and pollen comb. (viii) Wax plates and wax glands are present on the ventral surface of the last four segments. Figure 25 : Apis sp. Prothoracic leg Mesothoracic legs Methoracic leg (Outer view) pulvillus claws antenna comb Mouthparts eye brush velum or fibula pollen brush Metathoracic leg (Outer view) clypous labrum antenna cleaner in use compound eye ocelli anleena THORAX fore and hindwings hooked together ABDOMEN pollen basket spiracles wax plates or scales sting pollen packer pocten auricle pollen combs larsus pollen brush spur coxa trochanter femur tibia metarasus

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NSOU CC - ZO - 01 49 26. Chiton sp. a) Systematic position (According to Ruppert & Barnes, 1994) Phylum : Mollusca Class : Polyplacophora Genus : Chiton Specimen : Chiton sp. b) Systematic identification with reasons Phylum : Mollusca (i) The body is soft, unsegmented. (ii) A thick muscular mass called the mantle encloses the visceral mass. (iii) Generally external shell is present but in some caces it is internal or reduced or lost. (iv) A muscular ventral foot is a diagnositc feature. Class : Polyplacophora (i) Body oval, elongated and dorsoventrally flattened. (ii) Eight plates cover the dorsal surface. (iii) A number of gills are present in the pallial groove between muscular ventral foot and mantle cavity. (iv) The surrounding mantle froms a thick 'gridle', the cuticle. (v) Eyes and tentacles are absent. Specimen : Chiton sp. [commonly known as sea mouse] (i) The elliptical body can be divided into an indistinct head, a large flat foot and a dorsal mantle. (ii) The body is convex dorsally and flattened ventrally.

50 NSOU CC - ZO - 01 (iii) The head contains ventral mouth and labial palps. (iv) Eyes and tentacles are absent. (v) Mouth and anus on opposite ends. Figure 26 : Chiton sp. (A) dorsal view (B) ventral view 27. Dentallium sp. a) Systematic position (According to Rupper & Barnes, 1994) Phylum : Mollusca Class : Scaphopoda Genus : Dentallium Specimen : Dentalium sp. b) Systematic identification with reasons Phylum : Mollusca Same as Chiton sp. Class : Scaphopoda (i) A tubular tusk like shell is present which is open at both ends. (ii) The mantle completely encloses the elongated body.

NSOU CC - ZO - 01 51 (iii) The foot is cylindrical and projects out of the ventral side of the tusk like shell along with the buccal region. (iv) The head is proboscis like and lacks eyes and sensory tentacles. (v) Presence of captaula. (vi) Gills or ctenidia are absent. Specimen : Dentalium sp. (i) Presence of a tubular but shell slightly curved shell open at both ends. (ii) Body consists of head, foot, mantle and visceral mass. (iii) Foot is long and conical, protrudes through the anterior opening of the shell. (iv) Anus lies behind the base of the foot. Figure 27 : Dentalium sp. 28 Pila sp. a) Systematic position (According to Ruppert & Barnes, 1994) Phylum : Mollusca Class : Gastropoda Mouth Foot Mantle cavity Anus

52 NSOU CC - ZO - 01 Subclass : Prosobrenchia Genus : Pila Specimen : Pila sp. b) Systematic identification with reasons Phylum : Mollusca Same as Chiton sp. Class : Gastropoda (i) Below the digestive system and the visceral mass is present a muscular foot. (ii) The shell is a single piece and is spirally coiled. (iii) One or two pairs of tentacles are present along with eyes. Subclass : Prosobranchia (i) Shell opening is large and generally covered by operculum. (ii) Ctenidia is in front of head. (iii) Anus directed forward. Specimen : Pila sp. (i) Shell is globose, spirally coiled round an axis called the collumella and opens outside by the mouth or aperture. (ii) Operculum is well developed and closes the aperture or the mouth of the shell. (iii) Foot is broad and flat. (iv) Head with two pairs of contractile tentacles and a pair of eyes.

NSOU CC - ZO - 01 53 Figure 28 : Pila sp. 29. Lamellidens sp. a) Systematic position (According to Ruppert & Barnes, 1994) Phylum : Mollusca Class : Bivalvia Subclass : Palaeoheterodonta Genus : Lamellidens Specimen : Lamellidens sp. b) Systematic identification with reasons Phylum : Mollusca Same as Chiton sp. Class : Bivalvia (i) A pair of shell valves encloses a laterally compressed body. (ii) Shell with distinct lines of growth.

54 NSOU CC - ZO - 01 (iii) Head is indistinct without eyes and tentacles. (iv) Foot tongue -shaped. Subclass : Palacoheterodonta (i) Shell is inequilateral i.e. umbo is not at the centre. (ii) Byssus thread absent. (iii) Mentle margins fused posteriorly. Specimen : Lamellidens sp. (i) Body is soft, bilaterally symmetrical and flattened, surrounded externally by a hard calcareous shell. (ii) The shell consists of two separate, equal valves laterally attached by special musculture. (iii) The two valves of the shell are united together along the dorsal side in a straight hinge line. (iv) In front of the hinge there is a whitish knob-like structure called 'umbo', which is the thickest and the oldest portion of the shell. (v) Inhalent and exhalent siphons are present. Figure 29 : Lamellidens sp.

NSOU CC - ZO - 01 55 30. Loligo sp. a) Systematic position (According to Ruppert Barnes, 1994) Phylum : Mollusca Class : Cephalopoda subclass : Coleoidea Genus : Loligo Specimen : Loligo sp. b) Systematic identification with reasons Phylum : Mollusca Same as Chiton sp. Class : Cephalopoda (i) Prehensile arms or tentacles and siphon are present. (ii) Shell may or may not be present. (iii) Head is well developed bearing large eyes. Subclass : Coleoidea (i) Shell internal or reduced. (ii) Tentacles with suckers. Specimen : Loligo sp. (commonly known as squid) (i) Fleshy body which is dorsoventrally flattened. (ii) Head bears ten oral arms and a pair of eyes. (iii) Head and trunk region are separated by a collar. (iv) Lateral fins or parapodia united posteriorly to form a triangular shape.

56 NSOU CC - ZO - 01 Figure 30 : Loligo sp. 31. Sepia sp. a) Systematic position (According to Ruppert & Barnes, 1994) Phylum : Mollusca Class : Cephalopoda Sub-class : Coleoidea Genus : Sepia Specimen : Sepia sp. b) Systematic identification with reasons Phylum : Mollusca Same as Chiton sp. Class : Cephalopoda Same as Loligo sp. lateral line or parapodium suckers trunk or visceral hump hexacotylised arm for capture of prey collar eye head mouth 4 rows of suckers

NSOU CC - ZO - 01 57 Sub-class : Coleridea Same as Loligo sp. Specimen : Sepia sp. [Commonly known as cuttle fish] (i) Body differentiated into anterior head, middle collar or neck and posterior trunk or visceral hump. (ii) The head contains ten oral arms. (iii) Eight oral arms are smaller and have several rows of pedicellate suckers, ventrally surrounding the mouth. (iv) Two arms on each side are elongated, each having several pedicellate suckers at its tips are called hectocotylysed arms. (v) Base of the head contains a pair of eyes. (vi) Lateral fins narrow, present throughout the trunk and not united posteriorly. Figure 31 : Sepia sp.

58 NSOU CC - ZO - 01 32. Octopus sp. a) Systematic position (According Ruppert & Barnes, 1994) Phylum : Mollusca Class : Cephalopoda Subclass : Coleoidea Genus : Octopus Specimen : Octopus sp. b) Systematic identification with reasons Upto Sub-class same as Loligo sp. Specimen : Octopus sp. (i) Body differentiated into head and visceral hump. (ii) The head bears eyes, siphon and eight elongated arms. (iii) Two rows of cupped sessile suckers are present on the arms. (iv) One of the arms of the male octopus is hectocotylised and therefore spoon shaped. (v) Visceral mass and mantle cavity enclosed in mantle. Figure 32 : Octopus sp.

NSOU CC - ZO - 01 59 33. Starfish a) Systematic position (According to Ruppert & Barnes, 1994) Phylum : Echinodermata Subphylum : Asterozoa Class : Asteroidea Specimen : Starfish b) Systematic identification with reasons Phylum : Echinodermata (i) Body show pentamerous radial symmetry. (ii) Body distinguishable into oral and aboral surfaces and is without any distinct head. (iii) Body is a flattened disc with radially projecting arms. (iv) Body is star shaped. (v) Oral surface of the ambulacra project several tube feet. Sub-phylum : Asterozoa (i) A star shaped body. (ii) Radially divergent axes of symmetry. Class : Asteroidea (i) From the central disc the arms are not sharply set off. (ii) The ambulacral grooves are open. (iii) Two to four rows of tube feet are present on the ambulacra. (iv) Anus and madreporite are present on the aboral surface. Specimen : Starfish (i) Star shaped echinoderness having a central disc and usually five arms. (ii) The aboral surface may be smooth, granular or spiny and is covered with overlapping plates. (iii) Many species are brightly coloured with various shades of red or orange, while others are blue, grey or brown.

60 NSOU CC - ZO - 01 Figure 33 : Starfish (A) Aboral view and (B) Oral view 34. Ophiura sp. a) Systematic position (According to Ruppert & Barnes, 1994) Phylum : Echinodermata Subphylum : Asterozoa Class : Ophiuroidea Genus : Ophiura Specimen : Ophiura sp. b) Systematic identification with reasons Phylum : Echinodermata Same as star fish Subphylum Asterozoa Same as star fish Class : Ophiuroidea (i) From the central disc the arms are sharply set off. (ii) Ambulacral grooves are not present.

NSOU CC - ZO - 01 61 (iii) Arms provided with vertebral ossicles. (iv)

Mouth and madreporite are situated on the oral surface of the body.

Specimen : Ophiura sp. (i) It has a circular central disc and five radially arranged narrow arms. (ii) Both the disc and arms are covered with calcareous plates. (iii) Arms are highly fragile. (iv) Small spines on the arms lie flat against the surface. (v) Five large mouth-shield plates are on the underside of the disc which surrounds the central mouth. Figure 34 : Ophiura sp. 35. Echinus sp. a) Systematic position (According Ruppert & Barnes, 1994) Phylum : Echinodermata Subphylum : Echinozoa Class : Echinoidea

62 NSOU CC - ZO - 01 Subclass : Euechinoidea Genus : Echinus Specimen : Echinus sp. b) Systematic identification with reasons Phylum : Echinodermata Same as star fish Subphylum : Echinozoa (i) The body is globoid or discoidal without arms and is radially symmetrical. (ii) Madreporite and anus remain on the aboral side. Class : Echinoidea (i) Body is spherical and the oral and aboral side is flattened. (ii)

Although the ambulacral grooves are absent, the body surface is divided into alternate ambulacral and inter-ambulacral areas. (

iii) The tube feet possess suckers. (iv)

The ambulacral areas extend from the oral to the aboral sides of the body. (

v) Ossicles fused to form an internal test on which moveable spines are mounted. Sub-class : Euechinoidea (i) Test rigid, not flexible. (ii) Spines may be hollow or solid. Specimen : Echinus sp. (commonly known as sea-urchin) (i) Approximately spherical but slightly flattened at both poles. (ii) There are two rows of plates in each of five ambulacral areas. (iii) The test is covered in spines each articulating with a tubercle. (iv) There is a dense covering of secondary spines and a smaller number of longer, primary spines, carried on each second or third ambulacral plate. (v) There is a radially symmetrical pattern of holes in the ambulacral areas through which the tube feet emerge.

NSOU CC - ZO - 01 63 (vi) On the buccal plates round the mouth on the underside are pedicellariae, defensive organs like minute pincers, each with two lateral teeth and one terminal tooth. Figure 35 : (A) Oral view and (B) Test of Echinus sp. 36. Cucumaria sp. a) Systematic position (According to Ruppert Barnes, 1994) Phylum : Echinoermata Subphylum : Echinozoa Class : Holothuroidea Genus : Cucumaria Specimen : Cucumaria sp. b) Systematic identification with reasons Phylum : Echinodermata Same as star fish Subphylum : Echionozoa Same as Echinus sp.

64 NSOU CC - ZO - 01 Class : Holothuroidea (i) Along the oral–aboral axis the body is elongated. (ii) Five ambulacral areas are present on the surface of the body. (iii) Anteriorly directed mouth with circum -oral tantacles. (iv) Skeleton diminished to minute ossicles. Specimen : Cucumaria sp. [commonly known as sea-cucumber] (i) The body is thick and has five double rows of tube feet, separated by smooth, soft skin. (ii) Tentacles are highly brauched. (iii) Presence of a smooth, thin collar like structure at the base of tentacles. (iv) Their mouth and anus are at separate ends of the body. Figure 36 : Cucumaria sp.

NSOU CC - ZO - 01 65 37. Antedon sp. a) Systematic position (According to Ruppert & Barnes, 1994) Phylum : Echinodermata Subphylum : Cinozoa Class : Crinoidea Subclass : Articulata Genus : Antedon Specimen : Antedon sp. b) Systematic identification with reasons Phylum : Echinodermata Same as star fish Subphylum : Crinozoa (i) A cup-shaped theca with arms on a radially symmetrical body. (ii) Either sessile or attached with a stalk. (iii) The oral side faces upwards. (iv) The oral surface bears both mouth and anus. (v) The cup shaped aboral side is called calyx. Class : Crinoidea (i) Both stalked and free moving forms are present. (ii) Arms are branched and bear pinnules. (iii) The ambulacral grooves radiate from the mouth and extend to the tip of the pinnules. Subclass : Articulata (i) Aboral cirri may or may not be present.

66 NSOU CC - ZO - 01 Specimen : Antedon sp. (commonly known as Sea-lilly) (i) Stalk absent. (ii) Presence of 10 feathery arms arising from a central concave disc. (iii) Pinnules are uniserial. (iv) Clawed cirri on the lower surface provide temporary attachment to the substrate. Figure 37 : Antedon sp. 1.3 Study of different vertebrate and invertebrate chordate specimen with proper reason 1. Balanoglossus sp. a) Systematic position (According to Ruppert and Barnes, 1994) Phylum : Hemichordata Class : Enteropneusta Genus : Balanoglossus Specimen : Balanoglossus sp. b) Systematic identifications with reasons Phylum : Hemichordata (i) Presence of a buccal diverticulum or stomochord.

NSOU CC - ZO - 01 67 (ii) Pharyngeal clefts are present. (iii) Body is divided into three basic parts: the proboscis, collar, and trunk. Class : Enteropneusta (i) Proboscis elongated, cylindrical. (ii) Collar is without appendages. (iii) Trunk elongated and differentiated into branchial, hepatic and abdonural zones. Specimen : Balanoglossus sp. (i) Both proboscis and collar are more or less equal in length. (ii) Presence of genital wings. (iii) Pharyngeal clefts are like small pores. (iv) Notochord present at any stage of life history. (v) Pharyngeal gill slits present. (vi) Presence of dorsal hollow tubular nerve cord. (vii) Presence of post anal tail. Figure 38 : Balanoglossus sp.

68 NSOU CC - ZO - 01 2. Herdmania sp. a) Systematic position (According to J.Z Young, 1981) Phylum : Chordata Subphylum : Urochordata Clas : Ascidiacea Genus : Herdmania Specimen : Herdmonia sp. b) Systematic identifications with reasons Phylum : Chordata (i) Presence of notochord. (ii) Presence of dorso-tubular nerve chord. (iii) Presence of pharyngeal gill slits. Subphylum : Urochordata (i) Body is covered by a tunic or tunic test. (ii) Notochord present only in the larval tail. (iii) Presence of an oral aperture. Class : Ascidiacea (i) Sac -like body (ii) Muscles are scattered over the test. (iii) Presence of many pharyngeal gill slits. (iv) Test is thick. Specimen : Herdmania sp. [commonly known as sea squirts] (i) The body can be divided into a soft sac like body proper and a foot. (ii) The foot forms the posterior third of the body and is dirty, leathery with lot of foreign objects attached.

NSOU CC - ZO - 01 69 (iii) On the anterior side there are present two siphons knows as branchial siphon and atrial siphon, which open to the exterior via branchial aperture and atrial aperture respectively. (iv) Both branchial siphon and atrial siphon lie on same line. Figure 39 : Herdmania sp. 3. Branchiostoma sp. a) Systematic postion (According to J.Z Young, 1981) Phylum : Chordata Subphylum : Cephalochordata Genus : Branchiostoma Specimen : Branchiostoma sp. b) Systematic identifications with reasons Phylum : Chordata Same as Herdmania sp. Subphylum : Cephalochordata (i) Notochord present along the entire length of the body. (ii) Numerous gill slits present.

70 NSOU CC - ZO - 01 Specimen : Branchiostoma sp. [commonly known as lancelet or Amphioxus] (i) Body is elongated, flattened, and pointed at both ends. (ii) Mouth is ventral and guarded by oral hood containing oral cirri. (iii) The dorsal, ventral and caudal fins are low and continuous. (iv) There are two lateral fins and metapleural folds. (v) Myotomes are arranged as shaped on the sides of the bodies. Figure 40 : Branchiostoma sp. 4. Petromyzon sp. a) Systematic position (According to J.Z Young, 1981) Phylum : Chordata Subphylum : Vertebrata Superclass : Agnatha Class : Cephalaspidomorphi Order : Cyclostomata Genus : Petromyzon Specimen : Petromyzon sp.

NSOU CC - ZO - 01 71 b) Systematic identifications with reasons Phylum : Chordata Same as Herdmania sp. Subphylum : Vertebrata Presence of a vertebral column which is derived from the notochord. Superclass : Agnatha (i) Jaws are absent. (ii) Paired appendages are absent. Class : Cephalaspidomorphi (i) These animals possess head shield over the brain. (ii) Single nasal aperture is present at the anterior tip. Order : Cyclostomata The mouth is suctorial and circular. Specimen : Petromyzon sp. [commonly known as lampreys] (i) The body is eel like. (ii) Body differentiated into head, trunk and tail. (iii) First dorsal fin, second dorsal fin and caudal fin confluent. (iv) Scales are absent and the body is slimy. (v) Mouth is surrounded by a large suctorial funnel. (vi) Seven pairs of gill slits are present.

72 NSOU CC - ZO - 01 Figure 41 : Petromyzon sp. 5. Sphyrna sp. a) Systematic position (According to J.Z Young, 1981) Phylum : Chordata Subphylum : Vertebrata Superclass : Gnathostomata Class : Chondrichthyes Subclass : Elasmobranchi Genus : Sphyrna Specimen : Sphyrna sp. b) Systematic identifications with resons Subphylum : Vertebrata Same as Petromyzon sp. Superclass : Gnathostomata (i) Jaws present. (ii) Paired appendages are present Class : Chondrichthyes (i) Fin with fin-rays.

NSOU CC - ZO - 01 73 (ii) Mouth Ventral. (iii) External gill slits present. (iv) Tail heterocircal. (v) The scales are usually placoid. (vi) The endoskeleton is cartilaginous. Subclass : Elasmobranchii (i) At the anterior end of the body 5 to 7 gill slits are present in each side. (ii) Firm and hard jaws are provided with numerous sharp teeth. Specimen : Sphyrna sp. (i) The head is hammer shaped and hence called hammer headed shark. (ii) Eyes contain nictitating membrane and placed at the tip of lateral expansions of head. (iii) First dorsal fin is situated ahead of pelvic fin and second dorsal fin is opposite to anal fin. (iv) Five pairs of lateral gill slits present. (v) Lateral line is distinct. Figure 42 : Sphyrna sp.

74 NSOU CC - ZO - 01 6. Pristis sp. a) Systematic position (According to J.Z Young, 1981) Phylum : Chordata Subphylum : Vertebrata Superclass : Gnathostomata Class : Chondrichthyes Subclass : Elasmobranchii Genus : Pristis Specimen : Pristis sp. b) Systematic identifications with reasons Phylum : Chordata Same as Herdmania sp. Subphylum : Vertebrata Same as Petromyzon sp. Class : Chondrichthyes Same as Sphyrna sp. Subclass : Elasmobranchii Same as Sphyrna sp. Specimen : Pristis sp. [commonly known as saw fish] (i) The snout is produced into a saw like rostrum with large and small weakly embedded teeth. (ii) Head contains a pair of eyes and a pair of spiracles. (iii) Dorsal fins are two in number.

NSOU CC - ZO - 01 75 Figure 43 : Pristis sp. 7. Torpedo sp. a) Systematic position (According to J.Z Young, 1981) Phylum : Chordata Subphylum : Vetebrata Superclass : Gnathostomata Class : Chondrichthyes Subclass : Elasmobranchii Genus : Torpedo Specimen : Torpedo sp. b) Systematic identifications with reasons Phylum : Chordata Same as Herdmania sp. Subphylum : Vertebrata Same as Petromyzon sp. Subclass : Elsmobranchii Same as Sphyrna sp. Specimen : Torpedo sp. [commonly known as electric rays] head trunk first dorsal fin adipose fin tail rostrum teeth eye spiracle pectoral fin pelvic fin caudal fin

76 NSOU CC - ZO - 01 (i) Head, trunk and pectoral fins are fused to form a sub-circular disc. (ii) The two large, kidney-shaped electric organs are visible beneath the skin on either side of the head. (iii) The eyes are small and followed by spiracles of comparable size. (iv) The five pairs of gill slits are placed on the underside of the disc. (v) Tail is thick and short with two dorsal fins, a caudal fin and two lateral folds of skin. (vi) Pelvic fins are just below the lower margin of the pectoral fin. (vii) No spines. Figure 44 : Torpedo sp.

NSOU CC - ZO - 01 77 1.4 Scoliodon sp. a) Systematic Position (According to J.Z Young, 1981) Phylum : Chordata Subphylum : Vertebrata Superclas : Gnathostomata Class : Chondrichthyes Subclass : Elasmobranchii Genus : Scoliodon Specimen : Scoliodon sp. b) Systematic identifications with reasons Phylum : Chordata Same as Herdmania sp. Subphylum : Vertebrata Same as Petromyzon sp. Superclass : Gnathostomata Same as Sphyrna sp. Class : Chondrichthyes Same as Sphyrna sp. Subclass Elasmobranchii Same as Sphyrna sp. Specimen : Scoliodon sp. (i) Elongated, spindle-shaped body tapered at the anterior end. (ii) The trunk and tail are laterally compressed, while the head region is dorsoventrally compressed. (iii) It has two rows of homodont or polyphyodont teeth. (iv) Spiracles absent.

78 NSOU CC - ZO - 01 Figure 45 : Scoliodon sp. 9. Labeo sp. a) Systematic position (According to J.Z Young, 1981) Phylum : Chordata Subphylum : Vertebrata Superclass : Gnathostomata Class : Osteichthyes Subclass : Actinopterygii Order : Cypriniformes Genus : Labeo Specimen : Labeo sp. b) Systematic identifications with reasons Phylum : Chordata Same as Herdmania sp. Subphylum : Vertebrata Same as Petromyzon sp. TAIL TRUNK HEAD Pectoral fin Pelvic fin Clasper (males) Anal fin Caudal keel Caudal fin Gill openings Labial furrows Mouth Snout Nostril Eye Spiracle Dorsal fin spine First dorsal fin Second dorsal fin Precaudal pit

NSOU CC - ZO - 01 79 Superclass : Gnathostomata Same as Sphyrna sp. Class : Osteichthyes (i) Fin with fin rays. (ii) Mouth terninal or sub-terminal. (iii) Gills are covered by operculum. (iv) Tail homocercal or diphycercal. (v) Scales are cycloid, ctenoid or ganoid. (vi) Endoskeleton is bony. Subclass : Actinopterygii (i) Fins are webs of skin supported by fin-rays. (ii) No fleshy lobe base of paired fins. Order : Cypriniformes (i) Head without scales. (ii) Single dorsal fin. Specimen : Labeo sp. (i) Both the lips are fleshy and thick with horny covering. (ii) Body is covered by large and overlapping cycloid scales. (iii) Snout projects beyond the narrow mouth. (iv) A small pair of filamentous barbels may arise from upper lips. (v) Lateral line is distinct.

80 NSOU CC - ZO - 01 Figure 46 : Labeo sp. 10. Exocoetus sp. a) Systematic position (According to J.Z Young, 1981) Phylum : Chordata Subphylum : Vertebrata Superclass : Gnathostomata Class : Osteichthyes Subclass : Actinopterygii Order : Beloniformes Genus : Exocoetus Specimen : Exocoetus sp. b) Systematic identifications with reasons Phylum : Chordata Same as Herdmania sp. Subphylum : Vertebrata Same as Petromyzon sp. Superclass : Gnathostomata Same as Sphyrna sp.

NSOU CC - ZO - 01 81 Class : Osteichthyes Same as Labeo sp. Subclass : Actinopterygii Same as Labeo sp. Order : Beloniformes (i) The pectoral fins are enlarged to wing like form. (ii) The body is covered with cycloid scales. (iii) The mouth is wide, and the jaws bear teeth. (iv) The tail has hypobatic fins as the ventral lobe is comparatively enlarged. (v) Lateral line is located low on the body. Specimen : Exocoetus sp. i) ii) iii) Figure 47 : Exocoetus sp. 11. Anguilla sp. a) Systematic position (According to J.Z Young, 1981) Phylum : Chordata Subphylum : Vertebrata

82 NSOU CC - ZO - 01 Superclass : Gnathostomata Class : Osteichthyes Subclass : Actinopterygii Order : Anguilliformes Genus : Anguilla Specimen : Anguilla sp. b) Systematic identifications with reasons Phylum : Chordata Same as Herdmania sp. Subphylum : Vertebrata Same as Petromyzon sp. Superclass : Gnathostomata Same as Sphyrna sp. Class : Osteichthyes Same as Labeo sp. Subclass : Actinopterygii Same as Labeo sp. Order : Anguilliformes (i) Body long and slender. (ii) Gill openings small. (iii) Scales minute or absent. (iv) Dorsal, caudal and anal fins continuous. Specimen : Anguilla sp. (i) Body slender, elongated and snake like.

NSOU CC - ZO - 01 83 (ii) An operculum grooves the gill slits and nostril is present. (iii) Body covered by minute scales which are embedded in the skin. (iv) Gills displaced posteriorly. Figure 48 : Anguilla sp. 12. Tenualosa sp. a) Systematic position (According to J.Z Young, 1981) Phylum : Chordata Subphylum : Vertebrata Superclass : Gnathostomata Class : Osteichthyes Subclass : Actinopterygii Order : Clupeiformes Genus : Tenualosa Specimen : Tenualosa sp. dorsal fin minute scales lateral line trunk operculum head nostril pectoral fin caudal fin gill opening tail anal fin eye mouth

84 NSOU CC - ZO - 01 b) Systematic identifications with reasons Phylum : Chordata Same as Herdmania sp. Subphylum : Vertebrata Same as Petromyzon sp. Superclass : Gnathostomata Same as Sphyrna sp. Class : Osteichthyes Same Labeo sp. Subclass : Actinopterygii Same as Labeo sp. Order : Clupeiformes (i) Fusiform body tapering toward each end. (ii) Typically lack a lateral line. (iii) Presence of dark shading on the back and bright silvery sides. Specimen : Tenualosa sp. (i) It has no dorsal spines but 18-21 dorsal soft rays and anal soft rays. (ii) The belly has 30 to 33 scutes. (iii) There is a distinct median notch in upper jaw. (iv) Gill rakers fine and numerous. (v) The fish shows a dark blotch behind gill opening, followed by a series of small spots along the flank.

NSOU CC - ZO - 01 85 Figure 49 : Tenualosa sp. 13. Uraeotyphlus sp. a) Systematic position (According to J.Z Young, 1981) Phylum : Chordata Subphylum : Vertebrata Superclass : Gnathostomata Class : Amphibia Subclass : Lissamphibia Order : Gymnophiona Genus : Uraeotyphlus Specimen : Uraeotyphlus sp. b) Systematic identifications with reasons Phylum : Chordata Same as Herdmania sp. Anal fin Pelvic fin Pectoral fin Operculum Mouth Eye Dorsal fin Caudal fin

86 NSOU CC - ZO - 01 Subphylum : Vertebrata Same as petromyzon sp. Superclass : Gnathostomata Same as Sphyrna sp. Class : Amphibia (i) The skin is moist, glandular and naked. (ii) A distinct neck is absent. (iii) Forelimbs with four and hind limbs with five clawless digits. (iv) Two nostrils connected with the mouth cavity. Subclass : Lissamphibia (i) Scaleless, smooth-skinned amphibians with glands. (ii) Skull is broad and the orbits are enlarged into the cheek and temporal regions. Order : Gymnophiona (i) Elongated worm like body. (ii) Scales present but under the skin. (iii) Sensory tentacle present between eye and nostril. (iv) Tail absent or very short. Specimen : Uraeotyphylus sp. (i) Skin with numerous transverse grooves. (ii) Eyes are nonfunctional and concealed beneath the slimy skin. (iii) Cloaca prescent at the terminal end.

NSOU CC - ZO - 01 87 Figure 50 : Uraeotyphlus sp. 14. Salamander sp. a) Systematic position (According to J.Z Young, 1981) Phylum : Chordata Subphylum : Vertebrata Superclass : Gnathostomata Class : Amphibia Subclass : Lissamphibia Order : Gymnophiona Genus : Salamander Specimen : Salamander b) Systematic identifications with reasons Phylum : Chordata Same as Herdmania sp. Subphylum : Vertebrata Same as Petromyzon sp. Superclass : Gnathostomata Same as Sphyrna sp. 1.51.2.4 Class Amphibia Same as Uraeotyphlus sp. head nares trunk scaleless head small tentacle reduced sub- cutaneous eye annules tail

88 NSOU CC - ZO - 01 Subclass : Lissamphibia Same as Uraeotyphlus sp. Order : Urodela (i) Body lizard like. (ii) Both fore and hind limbs are equal in size. (iii) Long tail present. Specimen : Salamander sp. (i) Body divided into head, trunk and tail. (ii) Body brilliantly black with irregular patches of yellow. (iii) Head contains eyes, prominent mouth and nostrils. (iv) Eyes provided with movable eyelids. (v) Large parotid glands are present behind the head. Figure 51 : Salamander sp. 15. Bufo sp. a) Systematic position (According to J.Z Young, 1981) Phylum : Chordata Subphylum : Vertebrata Superclass : Gnathostomata

NSOU CC - ZO - 01 89 Class : Amphibia Subclass : Lissamphibia Order : Anura Genus : Bufo Specimen : Bufo sp. b) Systematic identifications with reasons Phylum : Chordata Same as Herdmania sp. Subphylum : Vertebrata Same as Petromyzon sp. Superclass : Gnathostomata Same as Sphyrna sp. Class : Amphibia Same as Uraeotyphlus sp. Subclass : Lissamphibia Same as Uraeotyphulus sp. Order : Anura (i) Body short and broad. (ii) Tail is absent in adult. (iii) Forelimbs shorter than hindlimbs. (iv) Eyelids and tympanum present. Specimen : Bufo sp. (i) Skin is rough with blackish warts dorsally. (ii) Body divided into head and trunk. (iii) Head bears large eyes, mouth, nostrils and tympanum.

90 NSOU CC - ZO - 01 (iv) Large parotid poison gland present behind eyes. (v) Digits are free and without adhesive pads. (vi) Toes are slightly webbed. Figure 52 : Bufo sp. 16. Hyla sp. a) Systematic position (According to J.Z Young, 1981) Phylum : Chordata Subphylum : Vertebrata Superclass : Gnathostomata Class : Amphibia Subclass : Lissamphibia Order : Anura Genus : Hyla Specimen : Hyla sp.

NSOU CC - ZO - 01 91 b) Systematic identifications with reasons Phylum : Chordata Same as Herdmania sp. Subphylum : Vertebrata Same as Petromyzon sp. Superclass : Gnathostomata Same as Sphyrna sp. Class : Amphibia Same as Uraeotyphlus sp. Subclass : Lissamphibia Same as Uraeotyphlus sp. Order : Anura Same as Bufo sp. Specimen : Hyla sp. (i) Body is divided into head and trunk. (ii) Digits of hindlimbs are webbed. (iii) Parotid gland absent. (iv) Terminal base of each digit is claw shaped. (v) Toes contain expanded adhesive discs. (vi) Eyes well developed with horizontal pupils. (vii) The tympanum is distinct. (viii) Skin of belly contains hygroscopic glands. (ix) Upper jaw toothed and lower jaw without teeth.

92 NSOU CC - ZO - 01 Figure 53 : Hyla sp. 17. Turtle sp. a) Systematic position (According to J.Z Young, 1981) Phylum : Chordata Subphylum : Vertebrata Superclass : Gnathostomata Class : Reptilia Subclass : Anapsida Order : Chelonia Genus : Turtle Specimen : Turtle

NSOU CC - ZO - 01 93 b) Systematic identifications with reasons Phylum : Chordata Same as Herdmania sp. Subphylum : Vertebrata Same as Petromyzon sp. Superclass : Gnathostomata Same as Sphyrna sp. Class : Reptilia (i) Dry and cornified skin which is covered by scales and scutes. (ii) Body individed into head, neck, trunk and tail. (iii) Forelimb and hindlimb with five clawed digits. (iv) Longitudinal or transverse cloacal aperture. Subclass : Anapsida (i) The skull roof is solid. (ii) There is no temporal fossa. Order : Chelonia (i) A dorsal carapace and ventral plastron encase the body. (ii) Longitudinal cloacal aperture. (iii) Horny sheaths are present on jaws. (iv) Teeth are absent. Specimen : Turtle (i) Carapace covered with smooth bony shields. (ii) Limbs modified to paddles. (iii) Not all the digits are clawed.

94 NSOU CC - ZO - 01 Figure 54 : Turtle sp. 18. Calotes sp. a) Systematic position (According to J.Z Young, 1981)

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Phylum : Chordata Subphylum : Vertebrata Superclass : Gnathostomata Class : Reptilia Subclass : Lepidosauria Order : Squamata

Genus : Calotes Specimen : Calotes sp. b) Systematic identifications with reasons Phylum : Chordata Same as Herdmania sp. Subphylum : Vertebrata Same as Petromyzon sp. Superclass : Gnathostomata Same as Sphyrna sp.

NSOU CC - ZO - 01 95 Class : Reptilia Same as Turtle sp. Subclass : Lepidosauria (i) Presence of two temporal fossa in the skull. (ii) Body covered with scales. (iii) Shell absent. (iv) No horny sheath in jaws. (v) Teeth present. (vi) Body enlongated. Order : Sqamata (i) Cloacal aperture transverse. (ii) Scales are mostly over lapping. Specimen : Calotes sp. (i) A spinous crest along the mid-dorsal line of the body is present. (ii) Overlapping rough epidermal scales cover the body. (iv) Head is movable and bears one or two spines. (v) The tail is long and cylindrical and larger than trunk with head. Figure 55 : Calotes sp.

96 NSOU CC - ZO - 01 19. Chameleon sp. a) Systematic position (According to J.Z Young, 1981)

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Phylum : Chordata Subphylum : Vertebrata Superclass : Gnathostomata Class : Reptilia Subclass : Lepidosauria Order : Squamata

Genus : Chameleon Specimen : Chameleon b) Systematic identifications with reasons Phylum : Chordata Same as Herdmania sp. Subphylum : Vertebrata Same as Petromyzon sp. Superclass : Gnathostomata Same as Sphyrna sp. Class : Repitilia Same as Turtle sp. Subclass : Lepidosauria Same as Calotes sp. Order : Sqamata Same as Calotes sp. Specimen : Chameleon sp. (i) Head has prominent crest.

NSOU CC - ZO - 01 97 (ii) Body is laterally compressed. (iii) Eyes are large and capable of independent movement. (iv) Clawed digits are opposable in groups of two and three, such that the limbs are of the grasping type. (v) A long prehensile tail is present. (vi) The tongue is sticky and protrusible and shaped like a club. Figure 56 : Chameleon sp. 20. Draco sp. a) Systematic position (According to J.Z Young, 1981)

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Phylum : Chordata Subphylum : Vertebrata Superclass : Gnathostomata Class : Reptilia Subclass : Lepidosauria Order : Squamata

Genus : Draco Specimen : Draco sp.

98 NSOU CC - ZO - 01 b) Systematic identifications with reasons Phylum : Chordata Same as Herdmania sp. Subphylum : Vertebrata Same as Petromyzon sp. Class : Reptilia Same as Turtle sp. Order : Sqamata Same as Calotes sp. Specimen : Draco sp. (i) Tail is long, slender and whip like. (ii) Four or five ribs support a parachute like web on either side. (iii) Flap like structure is present below the neck on either side called the gular pouches. (iv) Neck with three hooks. (v) Eyes have movable eyelids. Figure 57 : Draco sp.

NSOU CC - ZO - 01 99 21. Vipera sp. a) Systematic Position (According to J.Z Young, 1981)

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Phylum : Chordata Subphylum : Vertebrata Superclass : Gnathostomata Class : Reptilia Subclass : Lepidosauria Order : Squamata

Genus : Vipera Specimen : Vipera sp. b) Systematic identifications with reasons Phylum : Chordata Same as Herdmania sp. Subphylum : Vertebrata Same as Petromyzon sp. Superclass : Gnathostomata Same as Sphyrna sp. Subclass : Lepidosauria Same as Calotes sp. Order : Sqamata Same as Calotes sp. Specimen : Vipera sp. (i) Body elongated and slender. (ii) Absense of limbs

100 NSOU CC - ZO - 01 (iii) Deep brown coloured elliptical patches on skin. (iv) The head is triangular with head scales which small, inbricate and keeled. (v) Paired erectile fangs in front of upper jaw. (vi) No pit between nostrils and eyes. (vii) Large nostrils obliquely directed. Figure 58 : Vipera sp. 22. Naja sp. a) Systematic position (According to J.Z Young, 1981)

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Phylum : Chordata Subphylum : Vertebrata Superclass : Gnathostomata Class : Reptilia Subclass : Lepidosauria Order : Squamata

NSOU CC - ZO - 01 101 Genus : Naja Specimen : Naja sp. b) Systematic identifications with reasons Phylum : Chordata Same as Herdmania sp. Subphylum : Vertebrata Same as Petromyzon sp. Superclass : Gnathostomata Same as Sphyrna sp. Class : Reptilia Same as Turtle sp. Sebclass : Lepidosauria Same as Calotes sp. Order : Sqamata Same as Calotes sp. Specimen : Naja sp. (i) Hood is formed from the expanded neck region. (ii) Spectacle mark on the dorsal surface of the hood. (iii) Body is covered by smooth oblique scales. (iv) Caudal scales are paired. (v) The front of the maxilla bears tubular poisonous fangs. (vi) Tympanum is absent.
102 NSOU CC - ZO - 01 Figure 59 : Naja sp. 23. Crocodylus sp. a) Systematic position (According to J.Z Young, 1981) Phylum : Chordata Subphylum : Vetebrata Superclass : Gnathostomata Class : Reptilia Subclass : Archosauria Order : Crocodilia Genus : Crocodylus Specimen : Crocodylus sp. b) Systematic identifications with reasons Phylum : Chordata Same as Herdmania sp. Subphylum : Vertebrata Same as Petromyzon sp.
NSOU CC - ZO - 01 103 Superclass : Gnathostomata Same as Sphyrna sp. Class : Reptilia Same as Turtle sp. Sublclass : Archosauria (i) The skull is diapsid. (ii) Dorsal bony scutes present. (iii) Shell absent. Order : Crocodilia (i) The tail is laterally compressed and has large crests. (ii) Top of the snout bears the valvular nostrils. (iii) Webbed digit. (iv) Cloaca has longitudinal opening. Specimen : Crocodylus sp. (i) Body is elongated. (ii) The head is triangular and the snout is stout. (iii) Teeth sizes are not uniform. (iv) The fourth mandibular teeth fit into a notch in the upper jaw. (v) Body is covered by leathery armour. Figure 60 : Crocodylus sp.
104 NSOU CC - ZO - 01 24. Gavialis sp. a) Systematic position (According to J.Z Young, 1981) Phylum : Chordata Subphylum : Vertebrata Superclass : Gnathostomata Class : Reptilia Subclass : Archosauria Order : Crocodilia Genus : Gavialis Specimen : Gavialis sp. b) Systematic identifications with reasons Phylum : Chordata Same as Herdmania sp. Superclass : Gnathostomata Same as Sphyrna sp. Class : Reptilia Same as Turtle sp. Subclass : Archosauria Same as Crocodylus sp. Order : Crocodilia Same as Crocodylus sp. Specimen : Gavialls sp. (i) Body is elongated. (ii) Snout is long and slender. (iii) Large head having conical teeth.
NSOU CC - ZO - 01 105 (iv) Teeth sizes are more or less same. (v) The first and fourth teeth fit into a notch in the upper jaw. Figure 61 : Gavilis sp. 25. Columba sp. a) Systematic position (According to J.Z Young, 1981) Phylum : Chordata Subphylum : Vertebrata Superclass : Gnathostomata Class : Aves Subclass : Neornithes Superorder : Neognathae Order : Columbiformes Genus : Columbia Specimen : Columbia sp. b) Systematic identifications with reasons Phylum : Chordata Same as Herdmania sp.
106 NSOU CC - ZO - 01 Subphylum : Vertebrata Same as Petromyzon sp. Superclass : Gnathostomata Same as Sphyrna sp. Class : Aves (i) Body covered with feathers. (ii) Forelimbs modified into wings. (iii) Presence of beak. Subclass : Neornithes (i) Teeth are absent. (ii) Tail very short. (iii) Semicircular arrangement of retrices i.e., tail feathers. Superorder : Neognathae (i) Neognathous type of skull. (ii) Well developed reminges i.e., wing feathers and rectrices. Order : Columbiformes (i) Prominet swollen ciric. (ii) Beak is slender and curved at the tip. (iii) Four clawed toes in each foot, with three pointing anteriorly and one pointing posteriorly. (iv) The wings are long and pointed. Specimen : Columba sp. (i) Staty -grey in colour with purple and green mettalic shine on the neck and upper breast. (ii) Two dark bars are present on the wings. (iii) A band is present across the end of the tail.
NSOU CC - ZO - 01 107 eye head external ear opening neck back back bars wing wing feathers tail feathers hind toe leg clawed toes scales abdomen breast throat beak nostril cere (iv) There are 23 pairs of remiges and 12 pairs of rectrices. (v) The nasal opening is slit like. (vi) Cere is white. Figure 62 : Columba sp. 26. Psittacula sp. a) Systematic position (According to J.Z Young, 1981) Phylum : Chordata Subphylum : Vertebrata Superclass : Gnathostomata Class : Aves Subclass : Neornithes Superorder : Neognathae Order : Psittaciformes Genus : Psittacula Specimen : Psittacula sp.

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108 NSOU CC - ZO - 01 b) Systematic identifications with reasons Phylum : Chordata Same as Herdmania sp. Subphylum : Vertebrata Same as Petromyzon sp. Superclass : Gnathostomata Same as Sphyrna sp. Class : Aves Same as Columba sp. Subclass : Neornithes Same as Columba sp. Superorder : Neognathae Same as Columba sp. Order : Psittaciformes (i) Usually have brightly colored plumage (feathers). (ii) Large head, short neck, and curved beak. with narrow hooked end of upper beak overlaps the lower beak. (iii) Feet are zygodactyl, two toes on each foot face forward and two face backward. Specimen : Psittacula sp. (i) Beak is cherry -red coloured towards the tip. (ii) Blue-green, yellow or red coloured feathers. (iii) Elongated tail feathers. (iv) Males have a black or rose pink collar.

NSOU CC - ZO - 01 109 Figure 63 : Psittacula sp. 27. Bubo sp. a) Systematic position (According to J.Z Young, 1981) Phylum : Chordata Subphylum : Vertebrata Superclass : Gnathostomata Class : Aves Subclass : Neornithes Superorder : Neognathae Order : Strigiformes Genus : Bubo Specimen : Bubo sp. elongated tail feathers clawed toes leg abdomen wing breast black throat horny beak nostril eye head neck back moroon patch wing feathers

110 NSOU CC - ZO - 01 b) Systematic identifications with reasons Phylum : Chordata Same as Herdmania sp. Subphylum : Vertebrata Same as Petromyzon sp. Superclass : Gnathostomata Same as Sphyrna sp. Class : Aves Same as Columba sp. Subclass : Neornithes Same as Columba sp. Superorder : Neognathae Same as Columba sp. Order : Strigiformes (i) Loosely arranged contour feathers extend upto the digits. (ii) Large and round frontally directed eyes. (iii) The ear openings are on the lateral sides of the head. Specimen : Bubo sp. (i) Large and round head. (ii) The plumage normally is dark brown. (iii) The claws are sharp and the feet are adapted for grasping. (iv) Large ear openings covered by a flap. (v) The beak is short and strong. (vi) Eyes are large and round.

NSOU CC - ZO - 01 111 Figure 64 : Bubo sp. 28. Alcedo sp. a) Systematic position (According to J.Z Young, 1981) Phylum : Chordata Subphylum : Vertebrata Superclass : Gnathostomata Class : Aves Subclass : Neornithes Superorder : Neognathae Order : Coraciformes Genus : Alcedo Specimen : Alcedo sp.

112 NSOU CC - ZO - 01 b) Systematic identifications with reasons Phylum : Chordata Same as Herdmania sp. Subphylum : Vertebrata Same as Petromyzon sp. Superclass : Gnathostomata Same as Sphyrna sp. Subclass : Neornithes Same as Columba sp. Superorder : Neognathae Same as Columba sp. Order : Coraciformes (i) Beaks are long. (ii) Size is small and coloured. (iii) Three anterior toes united. Specimen : Alcedo sp. (king fisher) (i) The birds have small sizes and coloured plumage. (ii) long and strong beak. (iii) Present short stump like tail. (iv) Short wings. (v) Legs are coral-red in colour. Figure 65 : Alcedo sp. eye beak wing leg tail feathers

NSOU CC - ZO - 01 113 29. Passer sp. a) Systematic position (According to J.Z Young, 1981) Phyum : Chordata Subphylum : Vertebrata Superclass : Gnathostomata Class : Aves Subclass : Neornithes Superorder : Neornithes Superorder : Neognathae Order : Passeriformes Genus : Passer Specimen : Passer sp. b) Systematic identifications with reasons Phylum : Chordata Same as Herdmania sp. Subphylum : Vertebrata Same as Petromyzon sp. Superclass : Gnathostomata Same as Sphyrna sp. Class : Aves Same as Columba sp. Subclass : Neornithes Same as Columba sp. Superorder : Neognathae Same as Columba sp.

114 NSOU CC - ZO - 01 Order : Passeriformes (i) The birds are small with rounded head. (ii) Small and hard beak. (iii) Three toes point anteriorly and one posteriorly helping the birds to perch. Specimen : Passer sp. (i) The body is small and delicate. (ii) Male is deep gray brown in colour with black spots, while the female is ash gray brown and does not have black spots. (iii) The beak is short and hard and conical. Figure 66 : Passer sp. 30. Dinopium sp. a) Systematic position (According to J.Z Young, 1981) Phylum : Chordata Subphylum : Vertebrata Superclass : Gnathostomata

NSOU CC - ZO - 01 115 Class : Aves Subclass : Neornithes Superorder : Neognathae Order : Piciformes Genus : Dinopium Specimen : Dinopium sp. b) Systematic identifications with reasons Phylum : Chordata Same as Herdmania sp. Subphylum : Vertebrata Same as Petromyzon sp. Class : Aves Same as Columba sp. Subclass : Neornithes Same as Columba sp. Superorder : Neognathae Same as Columba sp. Order : Piciformes (i) The tail feathers are stiff. (ii) Long firm and pointed beak is characteristic feature. (iii) Zygodactylous toes with two facing the anterior side and two facing the posterior side. Specimen : Dinopium sp. (i) The dorsal surface shows black spots on a yellow background. (ii) Crimson coloured crown and occipital crest. (iii) The beak is long and hard.

116 NSOU CC - ZO - 01 Figure 67 : Dinopium sp. 31. Sorex sp. a) Systematic position (According to J.Z Young, 1981) Phylum : Chordata Subphylum : Vertebrata Superclass : Gnathostomata Class : Mammalia Superclass : Gnathostomata Class : Mammalia Subclass : Theria Infraclass : Eutheria Cohort : Unguiculata Order : Insectivora Genus : Sorex Specimen : Sorex sp. Tail feathers Wing feathers Back Neck Head Crown Eye Nostril Beak Leg Fore clawed toes Breast Hind clawed toes Wing

NSOU CC - ZO - 01 117 b) Systematic identifications with reasons Phylum : Chordata Same as Herdmania sp. Subphylum : Vertebrata Same as Petromyzon sp. Superclass : Gnathostomata Same as Sphyrna sp. Class : Mammalia (i) Body covered with hair. (ii) Mammary glands present. (iii) External pinna present. Subclass : Theria Mammary gland with teats. Infraclass : Eutheria Anus and uninogenital apertures are seperate. Cohort : Unguiculata Nails and claws present. Order : Insectivora (i) Long Snout present. (ii) There are several mammary glands distributed on the ventral surface. (iii) Testes are internal and scrotum is absent. (iv) Teeth have sharp molar cusps. Specimen : Sorex sp. (i) Body is covered with short and soft fur. (ii) Head contains snout, eyes and vibrissae.

118 NSOU CC - ZO - 01 (iii) Elongated tail is present which is covered in spines. (iv) Eyes are small and rudimentary. Figure 67 : Sorex sp. 32. Megachiroptera sp. Systematic position (According to J.Z Young, 1981) Phylum : Chordata Subphylum : Vertebrata Superclass : Gnathostomata Class : Mammalia Subclass : Theria Infraclass : Eutheria Cohort : Unguiculata Order : Chiroptera Specimen : Megachiroptera b) Systematic identifications with reasons Phylum : Chordata Same as Herdmania sp.

NSOU CC - ZO - 01 119 Subphylum : vertebrata Same as Petromyzon sp. Superclass : Gnathostomata Same as Sphyrna sp. Class : Mammalia Same as Sorex sp. Subclass : Theria Same as Sorex sp. Infraclass : Eutheria Same as Sorex sp. Cohort : Unguiculata Same as Sorex sp. Order : Chiroptera (i) Wings are modified forelimbs. (ii) Bones of the forelimbs are elongated with the exception of pollex. (iii) Interfemoral membrane present between the femurs. (iv) First finger with claw and forwardly directed. Specimen : Megachiroptera (i) The ears are small and the base of pinna forms a complete ring. (ii) Second finger also clawed. (iii) Tail is either short or lacking. (iv) Interfemoral membrane is reduced. (v) Snout long and pointed.

120 NSOU CC - ZO - 01 Figure 69 : Megachiroptera sp. 33. Microchiroptera sp. a) Systematic position (According to J.Z Young, 1981) Phylum : Chordata Subphylum : Vertebrata Superclass : Gnathostomata Class : Mammalia Subclass : Theria Infraclass : Eutheria Cohort : Unguiculata Order : Chiroptera Specimen : Microchiroptera sp. Head Eye Snout Nostril Mouth Claw Fur Pinna Wing Clawed digits Hind limb

NSOU CC - ZO - 01 121 b) Systematic identifications with reasons Phylum : Chordata Same as Herdmanie sp. Subphylum : Vertebrata Same as Petromyzon sp. Superclass : Gnathostomata Same as Sphyrna sp. Class : Mammalia Same as Sorex sp. Subclass : Theria Same as Sorex sp. Infraclass : Eutheria Same as Sorex sp. Cohort : Unguiculata Same as Sorex sp. Order : Chiroptera Same as Megachiroptera sp. Specimen : Microchiroptera (i) Base of pinna does not form a complete ring. (ii) Pinnae are large. (iii) No claws on the second digit. (iv) Snout is not elongated.

122 NSOU CC - ZO - 01 Figure 70 : Microchiroptera sp. 34. Squirrel sp. a) Systematic position (According to J.Z Young, 1981) Phylum :Chordata Subphylum : Vertebrata Superclass : Gnathostomata Class : Mammalia Subclass : Theria Infraclass : Eutheria Cohort : Unguiculata Order : Rodentia Specimen : Squirrel sp. b) Systematic identifications with reasons Phylum : Chordata Same as Herdmania sp. Subphylum : Vertebrata Same as Petromyzon sp. Superclass : Gnathostomata Same as Sphyrna sp. Class : Mammalia Same as Sorex sp.

NSOU CC - ZO - 01 123 Subclass : Theria Sam as Sorex sp. Infraclass : Eutheria Same as Sorex sp. Cohort : Unguiculata Same as Sorex sp. Order : Rodentia (i) One pair of incisors in each jaw (upper and lower). (ii) A large gap (diastema) behind incisors. (iii) No canine teeth present. Specimen : Squirrel sp. (i) Three white and grey stripes on dorsal side. (ii) Small gray hairs present on ventral side and limbs. (iii) Tail is elongated and bushy. (iv) Incisors exposed and chisel like. Figure 71 : Squirrel sp.

124 NSOU CC - ZO - 01 Unit : 2 Study of permanent slides Structure 2.0 Objectives 2.1 T.S. and L.S. of Sycon sp. 2.2 Study of the life history stages of mosquito 2.3 Study of the life history stages of toad 2.4 T.S of male and female Ascaris 2.0 Objectives

By studying this unit learners would be able to learn about (

i) Transverse and longitudinal section Sycon sp. (ii) Life history stage of mosquito and toad. (iii) Transverse section of male and female Ascaris sp. 2.1 T.S. and L.S. of Sycon sp. 2.1.1 Transverse section (T.S.) of Sycon sp. (i) The body wall shows a loose two layered organization, with the outer pinacoderm (with pincaocyte cells) and inner choanoderm (with flagellated choanocyte cells). (ii) Between the pinacoderm and choanoderm is present a layer of mesenchyme or mesohyll. This layer is jelly like and contains monaxon spicules, collenocytes, amoebocytes, archaeocytes and scleroblast cells. Reproductive cells are also present in this layer.

NSOU CC - ZO - 01 125 (iii) Choanoderm containing flagellated chonaocyte cells line the radial canals. (iv) The incurrent canals alternate with the radial canals and these chambers are connected through prosopyles. The radial canal opens into spongocoel through apopyles. Figure 1 : T. S. of Sycon sp. 2.1.2 Longitudinal Section (L. S.) of Sycon sp. (i)A loose two layered organization of outer pinacoderm and inner choanoderm is found. (ii) The pinacoderm is perforated with several ostia. (iii) The mesohyll or mesenchyme containig spicules, collenocytes, amoebocytes, archaeocytes and scleroblasts make up the bulk of the sponge. (iv) The monaxon spicules protrude out from the body wall. (v)The incrrent canals communicate with the radial canals via prosopyles. (vi) The radial canal communicates with the spongocoel through apopyles. (vii) Spongocoel opens to outside through osculum. incurrent canal spongocoel dermal ostium radial canal internal ostium choanocytes spicules

126 NSOU CC - ZO - 01 Figure 2 : L. S. of Sycon sp. 2.2 Study of the life history stages of mosquito The egg, larva, pupa and imago or adult stages make up the total life history of mosquito. 2.2.1 Eggs (i) Shallow and stagnant water is the ideal place where the female mosquito lays a cluster of around 300 eggs, after fertilization. (ii) Eggs of Culex float as a single unit, while the eggs of Aedes and Anopheles float freely. (iii) Two central extensions known as air floats are attached laterally to the individual eggs of the Anopheles. (iv) The eggs float horizontally of the water surface. (v) The larvae hatch from the eggs in two to three days.

NSOU CC - ZO - 01 127 2.2.2. Larva (i) The body of the larva is elongated and divisible into head, thorax and abdomen. (ii) A pair of compound eyes, a pair of antennae and a pair of feeding brush is present on the head. (iii) The thorax is unsegmented and bears a cluster of bristles. (iv) Respiratory siphons are present on the abdomen. (v) For respiration, during its stay in water it comes to the surface. (vi) The larvae are very active and feeds on algae and other microorganisms which are present. (vii) The larva metamorphoses into the pupa in around 8 days. 2.2.3 Pupa (i) The pupa is a comma like structure and the head is comparatively larger. (ii) The dorsal siphon remains above the surface of water for respiration. (ii) Unlike other insects the pupa is not stationary, but is non feeding as they do not have any mouth aperture. (iv) The duration of the pupal stage is around two days. 2.2.4 Adult or Imago (i) Metamorphosis results in the formation of imago or adult. (ii) The adult comes out by breaking of the pupal shell and the adult mosquito remains sometime over the shell and flies away when its wings harden. (iii) The life cycle of a mosquito is usually completed in 15 days and the adult usually lives for about one month.

128 NSOU CC - ZO - 01 Figure 3: (A) Life history stages of Culex (B) Life history stages of Anopheles 2.3 Study of the life history stages of toad 2.3.1 Breeding Breeding occur during the rainy season. The male calls the female with characteristic harsh sounds. The females are attracted and approach the male. The male then firmly clasps the female with forelimbs and hind limbs in a position called axillary amplexus. Post amplexus, the female lays eggs in water. Males possess black vocal sac and nuptial thumb-pad at each innermost finger of the hand. A single female may lay over a thousand eggs in any convenient patch of water. 2.3.2 Germ cells The eggs are spherical cells and mesolecithal type. Each egg has a blackish animal pole and whitish vegetal pole. The animal pole is full of protoplasm and the vegetal pole is full of yolk. Such a type of egg is called telolecithal type. Each egg is surrounded by vitelline membrane. The egg gets a coating of jelly like albumen while passing through the convoluted part of the oviduct. The spermatozoa are highly specialized cells with an oval head containing nucleus, a short neck having centrosome, and a long wavy protoplasmic tail.

NSOU CC - ZO - 01 129 2.3.3 Fertilization Fertilization is external. The female toads lay their pigmented eggs in quiet water inside the weeds or around the stem, leaves within a translucent slimy tube and the males discharge their spermatozoa or milt over the eggs as they are expelled out. The outer membrane of the egg gives an impass to one sperm after which the outer membrane becomes impervious to other sperms. Only the head portion of the spermatozoa enters the cell-body of ovum and the tail is left out. The sperm nucleus is called male pro-nucleaus and the egg nucleus is known as female pro-nucleus. During fertilization, the male and female pro-nuclei fuse to form a single nucleus. The egg, thus fertilized is known as zygote. 2.3.4 Embroyonic development The zygote undergoes rapid division known as cleavage and results in the production of a large number of blastomeres. The cells now arrange to form a cellular ball known as blastula. The blastula then enters into a complicated stage known as gastrula and the process is known as gastrulation. The gastrulation is essentially a process of cell movement when the different cells take up their respective position for future differentiation. During this process three primary germinal layers-ectoderm, mesoderm and endoderm are differentiated. All the structures of the adult are developed out of these three primary germinal layers. After about two weeks a small embryo is seen moving and writing. 2.3.5 Newly

hatched tadpole A freshly hatched tadpole larva has a limbless body. The body is divided into an ovoid head, a short trunk and a slender tail. A small opening situated ventrally at the root of the tail
is known as anus.
An adhesive sucker is present on the ventral side of the head by which the tadpole larva attaches itself to the aquatic weeds. The mouth is
lacking and as a result it cannot take anything from outside.
The yolk material provided the nutrition. The respiratory organs comprise of three pairs of highly vascular and branched feathery external gills. After a few days mouth is
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formed near the sucker. A pair of horny jaws surrounds the mouth. The tail becomes more elongated. The tadpole larva then develops a dorsal and ventral fin. S-shaped myotomes develop on both the sides of the tail. At this time free-swimming tadpole larva ingests aquatic weeds, as a result, the alimentary canal becomes extremely elongated. 2.3.6 Advanced tadpole larva The pharynx of the tadpole larva becomes perforated by gill-slits. External gills disappear and internal gills are formed between the gill slits. The gills and the gill- slits are covered by the operculum.
In the larval stages, the arterial arches show modifications in terms of both external and internal gills. The operculum fuses with the trunk on all sides except a small opening called spiracle on the left side. Water enters into the pharynx through the mouth and goes out through the spiracle. During this transit of water the internal gills are bathed with water containing oxygen dissolved in it. While the internal gills are functioning, a pair of lungs develops as outgrowths from the pharynx on the ventral surface. The hind limbs appear prior to the forelimbs. The forelimbs initially remain hidden under the operculum and subsequently emerge through it. At this stage both the internal gills as well as the newly formed lungs are functional. When the lungs become fully developed, the internal gills become degenerated. At this stage it looks like a miniature toad except having a tail. As the limbs are developing, the animal enters into a period of starvation. The material of the tail becomes eventually absorbed into the body. 2.3.7
Metamorphosis
The young tadpole larva resembles a fish. It leads an independent and self- supporting life. This fish-like tadpole larva completely metamorphoses
to toad is exclusively a progressive process. Development is rapid, being completed in 34-52 days. The metamorphosis is controlled by the thyroid glands. Removal of thyroid glands in the tadpole larva retards metamorphosis. Anterior pituitary indirectly plays an important role during metamorphosis by stimulating and controlling the function of the thyroid glands. NSOU CC - ZO - 01 131 Figure 4: Life history stages of toad. (A) Adult, (B) Older tadpole 2.4 T.S of male and female Ascaris 2.4.1 T.S. of male Ascaris (i) A section through the middle of the body shows sections of alimentary canal (intestine). Testis, seminal vesicle, vas deferens, and other minor structures are visible. (ii) The cuticle, hypodermis, muscle layer and pseudocoelom make up the body wall. (B) GRADUAL ABSORPTION OF FAIL FERTILISED EGG TAIL EGGS SPERM TRUNK RUDIMENTS OF EXTERNAL GILLS SUCKER HEAD TAIL EYE SPOT TAIL GILL MOUTH INTERNAL GILLS (A) FORELIMB DEVELOPING UNDER OPERATION WIND LIMB NOSTRIL TAIL HIND LIMB TRUNK FORE LIMB HEAD EYE SPAWN
132 NSOU CC - ZO - 01 (iii) The hypodermis is a syncytial layer and protrudes into the pseudocoelom middorsally, midventrally and laterally. This forms the four longitudinal chords which is a characteristic feature. (iv) The musculature is also divided into four quadrants. (v) Presence of pseudocoelom which is not a true coelom, between digestive tube and body wall. (vi) Various rounded cut sections of coiled testis are present, which are without lumen but with a central rachis. (vii) Sperm duct and seminal vesicle have a wide lumen filled with spermatozoa. (Viii) Dorsal longitudinal chord harbours the dorsal nerve cord, the ventral longitudinal chord harbours the ventral nerve cord and the two lateral longitudinal chords harbours the lateral nerve chords. Figure 5 : T. S. of male Assaris sp.

NSOU CC - ZO - 01 133 2.4.2 T.S. of female Ascaris sp. (i) A section through the middle of the body shows sections of ovary, oviduct, uterus and the digestive tube. (ii) The cuticle, hypodermis, muscle layer and pseudocoelom make up the body wall. (iii) The hypodermis is syncytial layer and protrudes into the pseudocoelom middorsally, midventrally and laterally. This forms the four longitudinal chords which is a characteristic feature. (iv) The musculature is also divided into four quadrants. (v) Presence of pseudocoelom which is not a true-coelom, between digestive tube and body wall. (vi) Ovary has no lumen, and the section of oviduct is wider than the ovary section. (vii) The uterus has a wide lumen full of eggs. Figure 6 : T. S. of Female Ascaris sp. ventral nerve chord pseudocoel eggs uterus andoderm cell intestine protoplasmic part of muscle cell muscle cell longitudinal muscle layer syncytial hypoderms dorsal nerve cord thick cuticle dorsal longitudinal chord somatic musculature ovary germinal zone oviduct lateral longitudinal chord lateral excretory canal ovary growth zone innervation process ventral longitudinal chord
134 NSOU CC - ZO - 01 Unit : 3 Key to identification of poisonous and Non-poisonous snakes 1. If the small scales are present on the belly and back, it is a non-poisonous snake. 2. If the belly scales are not broad enough to extend right across it, it is a non- poisonous snake. 3. If small scales are present on the head, it is poisonous and a viper. 4. If small scales or shields are present on the head and a pit lies between the eye and the nostril, it is poisonous and a pit-viper. 5. If dorsal side of the head has both small scales and large shields, the snake may or may not be poisonous. 6. If the third supra labial scale touches the eye and the nostril, the snake is a cobra or a coral snake. If the neck is with hood and markings, it is cobra. If neck is without hood and coral spots are present on the belly, it is a coral snake. Both cobra and coral snakes are poisonous. 7. If vertebral (scales on the middle of the back) are hexagonal and larger than other scales over the back and the fourth infra-labial scale is the largest, it is poisonous and a krait. 8. If the snake has small scales and large shields on the head but does not have the characters of cobra, coral snake or krait, then it is non poisonous.
NSOU CC - ZO - 01 135 Key to identification of Poisonous and Non-Poisonous Snakes Snakes Tail laterally compressed and rudder-shaped Tail small and blunt, overlapping scales on the body Tail not laterally compressed, cylindrical and rounded. Distinction of dorsal and ventral scales. Non-poisonous Sea snakes (Fam. Hydrophidae; e.g., Hydrophis, Enhydrina, Laticauda) Land snakes Poisonous and non-poisonous Poisonous Teeth only in upper law (Fam. Typhlopidae (e.g., Typhlops) Teeth only in lower law (Fam. Leptotyphlopidae (e.g., Leptotyphlops) Ventral scales not completely across the abdomen Non-poisonous and poisonous Poisonous Non-poisonous Teeth solid Ventral scales completely across the abdomen Ventral scales completely across the abdomen. Teeth solid or grooved Fangs present. Head shields without loreal Teeth grooved and situated at the rear end of maxilla Non-poisonous (Aglypha) (Fam. Colubridae), in part. Poisonous (Opisthoglypha) (Fam. Colubridae), in part Spiny with a rough shield tail (Fam. Uropeltidae) (e.g., Uropeltis) Terminal part of the tail blunt (Fam. Boidae) Head shield well- developed. Head oblong or elongated. (Fam. Elapidae) Very small head shields. Head triangular. (Fam. Viperidae) Tail elongated with vestigial remnants of the hind limbs at the two sides of the vent. (e.g., Python molurus, P. reticulatus, Boa constrictor, Giant anaconda) Tail end blunt but not rough, (e.g., Eryx conicas, Eryx johni) Central of dorsal scales hexagonal. No hood. [e.g., Krait (Bungarus)] Central row of dorsal scales hexagonal, rhomboid or elliptical Dorsal body scales oblong. Three rows elliptical spots on the body. [e.g., Russell's viper (Vipera russelli)| Dorsal body scales ellipti- cal and serrated (8.28F) e.g., saw scaled viper (Echis carinatus) Body with white cross spots e.g., common krait (B. caeruleus) Body yellow with black cross bands. [e.g., Banded krait (B. fasciatus)] A pit beyond the nasal opening. Keeled scales on body surface, [e.g., Pit vipers (Ancistrodon, Trimeresurus)]
136 NSOU CC - ZO - 01 Unit : 4 ????? Osteology Structure 4.0 Objectives 4.1 Disartienlated skeleton of fowl 4.2 Disarticulated skeleton of white rat 4.3 Carabace and plastron of turtle 4.4 Mammalian skull 4.0 Objectives
By studying this unit learners would be able to learn about (
i) Disarticulated skeleton of fowl. (ii) Disarticulated skeleton of while rat. (iii) Carapace and blastron of turtle. 4.1 Disarticulated skeleton of fowl A. Skull of fowl 1. Numerous bones united together enclosing a central cavity. 2. Foramen magnum, occipital condyle present. 3. Olfactory, optic and otic capsules are present.
NSOU CC - ZO - 01 137 Hence, it is a skull. 1. Light in weight, thin walled structure. 2. Single occipital condyle. 3. Well-developed beak present. 4. Tri-radiate premaxilla. Hence, it is a skull of bird. 1. Teeth absent. 2. Double headed quadrate bone. Hence, it is a neognathous skull. 1. Vomer absent or short. 2. Maxillopalatine processes are slender and not united with one another. Hence, it is a schizognathons skull. 1. Vomer short. 2. External nostril is oval in shape. 3. Short but strong and curved beak. Hence, it is a skull of fowl.

138 NSOU CC - ZO - 01 quadrate quadrato-jugal eustechian opening paramastoid process fenestra rolundrum tympanic cavity fenestra ovalis occipital condyle foramen for V nerve supra occipital lamboidal crest parietal zygomatic process of frontal optic foramen olfactory frontal frontal interorbital septum nasal nasal chamber maxillo-palatine process of maxilla premaxilla maxilla vomer palatine jugal pterygoid zygomatic process of temporal lacrymal supra-occipital occipital condyle foramen magnum basioccipital basitemporal zygomatic process of temporal parietal quadrate quadrate jugal orbit jugal lacrymal maxilla nesal axternal naris premaxilla nasal process of premaxilla nasal process of premaxilla nasal process of premaxilla nesal quadrate jugal zygomatic process of temporal basitemporal basitemporal basitemporal basitemporal basitemporal basitemporal basitemporal basitemporal LATERAL VIEW DORSAL VIEW VENTRAL VIEW

NSOU CC - ZO - 01 139 B) Vertebrae of fowl a) Atlas vertebra 1. Centrum present as bony structure. 2. Neural arch, neural canal, neural spine present. 3. Zygapophysis present. 4. Transverse process present. Hence, it is a vertebra. 1. Light in weight. 2. Centrum heterocoelous. Hence, it is a vertebra of bird. 1. Small, ring like structure. 2. Centrum, neural spine, transverse process, prezygapophysis absent. 3. A ventral piece and two dorsolateral pieces make the structure by uniting middorsally. 4. Ventral part bears a median condylar facet on the antenior face and a median odontoid notch on the posterior face. 5. Very small postzygapophysis present. Hence, it is the first vertebra or atlas of fowl. b) Axis or 2nd vertebra of fowl Upto vertebra of a bird same as atlas.

140 NSOU CC - ZO - 01 1. Elongated centrum. 2. The neural arch is notched and short. 3. Rudimentary neural spine is present. 4. The cervical ribs are short, spine like, directed backwards being fused with the transverse processes. 5. Pre-and post-zygapophyses present. 6. The hypapophysis is a ventral spine like process borne on the centrum. Hence, it is a typical cervical vertebra of fowl. C) Free thoracic vertebra of fowl Upto vertebra of a bird same as atlas. 1. Centrum short and stout. 2. Neural spine is elongated, flat, plate-like. 3. Transverse processes are well-developed and laterally directed. 4. Pre-and post-zygapophyses are well-developed. 5. Facets for ribs are present on centrum and tansverse process. 6. Hypapophysis prominent beneath the centrum. Hence, it is a free thoracic vertebra of fowl.

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142 NSOU CC - ZO - 01 D) Fused thoracic vertebra of fowl Upto vertebra of a bird same as atlas. 1. Several vertebrae united to form a compound structure. 2. Vertical neural spines of vertebrae fuced together to form a dorsal median ridge. 3. Similarly, hypophyses united ventrally to form a ventral median ridge. 4. Laterally directed flat transverse processes fused together to form a pair of wing- like structure on both sides. 5. Inter-vertebral foramens present. 6. Presence of facets for rib attachment. 7. Zygapophyses present. Hence, it is the fused thoracic vertebra of fowl. E) Synasacrum of fowl Upto vertebra of a bird same as atlas. 1. A large thin plate like structure which is narrowa anteriorly but broad and rectangular posteniorly. 2. It includes last thoracic, six lumbers, two sacrals and five antenior caudal vertebrae. 3. Each vertebra prossesses all the characteristic features of a typical vertebra. 4. Anteniormost vertebra clearly shows the heterocoelous centrum. 5. A vertical crest is formed by the fusion of neural spine. 6. Transverse processes, except for the first three vertebrae, fused together to form a thin, plate like structure on each side. 7. Sacral vertebrae with sacral ribs originating from the centrum. Hence, it is the synsacrum of fowl. F) Free caudal vertebra of fowl Upto vertebra of a bird same as atlas.

NSOU CC - ZO - 01 143 1. Small and bifid neural spine. 2. Transverse processes are cylindrical and directed downwords. 3. Zygapophyses are not prominent. Hence, it is a free candal vertebra of fowl. G) Pygostyle of fowl Upto vertebra of a bird same as atlas. 1. Last four caudal vertebrae become fused to form this structure. 2. It is laterally compressed, plough shaped structure. 3. Centra and neural spines are indistinguishable. 4. Zygapophyses are absent. Hence, it is pygostyle of fowl. H) Pectoral girdle of fowl As it is a compound structure consisting of coracoid, scapula, united clavicle and interclavicle, and a large sternum, so all the structures are discussed seperately. (a) Coracoid and scapula: - 1. Two bones are attached together by strong ligament. 2. Coracoid is stout, rod-like with acro-coracoid process anteriorly and a flat, expanded posterior end. 3. Scapula is sword -shaped with an anterior acromion process. 4. At the anterior end of scapula there is a shallow depression called glenoid cavity. 5. Both the bony structures are light and pneumatic. Hence, it is coracoid and scapula of fowl. (b) Fercula: - 1. The bony structure is v-shaped. 2. Very light in weight. 3. It is formed by fusion of clavicles and interclavicle.

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144 NSOU CC - ZO - 01 4. Each limb i.e. clavicle is slender, slightly curved and flattened. 5. Dorsal end of each limb with a concave articular facet. 6. Both the ends of each limb meet ventrally where very reduced interclavicle joins. 7. There is a disc-like structure at the junction point. Hence, it is fercula of fowl. Figure 3: (A) Right half of pectoral girdle of fowl (outer view); (B) inner view of pectoral girdle of fowl. (c) Sternum: 1. Boat-shaped, thin bony structure. 2. Anterior end broad while posterior end narrow. 3. A deep keel or carina sterni present on the ventral surface while dorsal bony plate is known as metasternum. 4. The metasterum is a dorsally concave ventrally convex, broad plate-like structure. 5. Metasternum bears a pair of costal processes, 5 pairs of costal facets and a pair of backwardly directed xiphoid processes from anterior to posterior. 6. Metasternum also bears a pair of coracoid grooves at the anterior end. 7. From the ventral surface of metasternum a small plate-like structure. Hence, it is sternum of fowl, arises vertically from the anterior end, called manubrium. scapula acrocoracoid process glenoid cavity capular tubercle corcoid corcoid acromion process acrocoracoid process foramen triossaum scapula capular tubercle

NSOU CC - ZO - 01 145 I) Pelvic girdle of fowl : The pelvic girdle is formed by two but seperate bones is known as os-innominatum and similar, halves. Each half consists of the following. 1. Thin, broad bony structure and light in weight. 2. It is composed of 3 bones–ilium, ischium and pubis. 3. Ilium is thin, broad, flat, anteriorly concave but posteriorly convex. 4. Ischium broad and fused with ilium at the posterior end. 5. Pubis slender, long, curved, parallel to ischium but extended beyond ischium. 6. At the junction of three bones, there is a cavity called acetabulum. 7. At the junction of ilium and ischium exists ischiadic foramen. 8. An obturator foramen is present at the junction of ischium and pubis. 9. An elongated obturator notch is present in between ischium and pubis. 10. A prepubic process exists near acetabulum. Hence, it is the os-innominatum or half of the pelvic girdle of fowl.

146 NSOU CC - ZO - 01 J) Limb bones of fowl a) Humerus of fowl : 1. A rod-like single, slightly curved bone with a narrow shaft and broadened both ends. 2. A round head present at the proximal end called head of humerus. 3. Deltoid ridge present. Hence, it is humerus bone. 1. The bone is light. 2. Proximal end broad than distal end and bears the head. 3. Greater tuberosity bears a prominent pneumatic foramen ventrally. 4. Distal end bears two condyles and two epicondyles. 5. No supra-trochlear foramen present. Hence, it is humerus bone of fowl. b) Radius and ulna of fowl: - 1. Two long, unequal bones unite at both ends. 2. One is slender and nearly straight -known as radius while the other is slightly curved and stout–known as ulna. 3. Proximal end of ulna bears a cup-like semilunar notch and an olecranon process. 4. Distal end of ulna bears articular surfaces. Hence, it is radius and ulna bones. 1. The bones are light. 2. Proximal end of radius is slightly concave whie the distal end is convex. 3. Distal end of ulna bears three convex articular surfaces. 4. Presence of a nutrient foramen in ulna.

NSOU CC - ZO - 01 147 Hence, it is radius-ulna of fowl. c) Carpometacarpus of fowl : 1. Compound bony structure consisting of two bones. 2. Both the bones fused completely at both ends leaving a wide gap in the middle. 3. The bones are light in weight. 4. Thickness of the bones are unequal. pneumatic foramen head deltoid ridge olecranon fossa coronoid fossa condyles intercondylar groove (Anterior View) (Posterior View) HUMERUS great irochanter head nutrient foramen distal condyles inter conoylar fossa outer condyle (Anterior view) (Posterior view) FEMUR cups for distal condyles of humerus olecranon process sigmold notch nutrient foramen ulna radiate carpal RADIUS & ULNA curved axial surface of ulne radius fused distal carpal bones I metacarpal II metacarpal III metacarpal CARPOMETACARPUS head of fibula fibula tibiotarsus distal lateral tubercle condyles (Anterior view) TIBIOTARSUS FIBULA distal groove tibial crest (Posterior view) TARSOMETATARSUS of Female nodule of I metatarsal (Anterior view) TARSOMETATARSUS of Male II metatarsal III metatarsal IV metatarsal articular facels for tibiotarsus spur

148 NSOU CC - ZO - 01 5. One bone is straight and cylindrical while the other bone is curved and Thinly flattened. 6. Proximal end with a large convexity and a short rod-like process. 7. Distal end with three articular surfaces. Hence, it is carpometacarpus of fowl. d) Femur 1. A long, stout, cylindrical bone and both ends are broadened. 2. Proximal end bears a round head extending a way from the shaft called head of femur. 3. A trochanter present near the head. 4. The distal end bears pulley-like condyles. Hence, it is a femur bone. 1. It is light in weight. 2. Head of femur is situated approximately at right angle to the shaft. Trochanter pointed. 4. The distal and pulley-like condyles are seperated by intercondylar groove. oblique xiphoid processes poster lateral metasternal process lower xiphoid processes stemal line lateral surface of crest or keel metasternum sternal crest or keel cranial process crest or keel articular surface of groove for coracoid foramen or notch of manubrium manubrium anterior metasternal process costal racers of grooves

NSOU CC - ZO - 01 149 5. Shaft is made up of bone while the ends are made up of calcified cartilage. Hence, it is the femur of fowl. e) Tibio-tarsus and fibula of fowl 1. Two long bones are partially fused. 2. Bones are grossly unequal in thickness and slightly unequal in length. 3. The stout, long bone is tibia and the slender bone is fibula. 4. Crenial crest present in the proximal end of tibia. Hence, it is tibia and fibula bone. 1. The bones are light in weight. 2. Astrogalus and calcaneum, and the proximal tarsal bones fused with tibia forming tibio-tarsus bone. 3. Tibio-tarsus bears two articular concavities and two prominent crenial crests at the anterior end while the distal end is pulley-like. 4. Fibula is slightly expanded at the anterior end and gradually tapers at the posterior end. 5. Anterior end of fibula is fused with the lateral surface of tibio-tarsus while the tapening posterior end is free and extends close to the distal end of tibio-tarsus. Hence, it is the tibio-tarsus and fibula bone of fowl. f) Tarso–metatarsus of fowl 1. Compound bony structure formed by complete fusion of three elongated bones except at their distal ends. 2. Light in weight. 3. Proximal end with 2 articular concavities, 2 foramina and a prominent ventral crest. 4. The bones are seperate at distal end, each ending in a pulley–like structure. 5. The distal end also bears a single foramen. Hence, it is tarso-metatartus bone of fowl.

150 NSOU CC - ZO - 01 k) Thoracic rib of fowl 1. Elongated, thin and flattened bone 2. Light in weight, two articulating surfaces. 3. The proximal end is bifurcated into a dorsal tuberculum and a ventral capitulum. 4. Aprroximately at the middle region a backwardly directed thin process is present called uncinate process. Hence, it is a thoracic rib of fowl. 4.2 Disarticulated skeleton of white rat A) Skull of white rat 1. Compound structure, numerous bones united together enclossing a central cavity. 2. Foramen magnum, occipital condyle present. 3. Olfactory, optic, otic capsules are present. Hence, it is a skull. 1. Presence of double occipital condyle. 2. Thecodont and heterodont dentition. 3. Sutures distinct. 4. Secondary palate present. tuberculum capitulum unicinate process

NSOU CC - ZO - 01 151 Figure 8 : Skull of white rat (DORSAL VIEW) (VENTRAL VIEW) (LATERAL VIEW)

152 NSOU CC - ZO - 01 5. Well developed zygomatic arch. Hence, it is a skull of a mammal. 1. Tympanic bone fused with the skull. 2. Secondary palate without large psoterior vacuities. 3. Base of zygonatic arch is not perforated. Hence, it is a skull of eutherian mammal. 1. Orbit incomplete. 2. Slender zygomatic arch. 3. Incisor chisel shaped and one in each half. 4. Temporal and orbital fossa confluent. 5. Canine teeth absent, well-developed diastema. Hence, it is a skull of rodentia 1. Incisor slightly curved. 2. Premolar absent. 3. Dental formula : 1.0.0.3 1.0.0.3 Hence, it is the skull of rat/white rat (Rattus sp.) B) Vertebrae of white rat:- a) Atlas of white rat: - 1. Centrum present on bony structure. 2. Neural arch, neural canal, neural spine present. 3. Zygapophyses present. 4. Transverse process present. Hence, it is a vertebra. 1. Centrum acoelous. 2. Intervertebral foramen present. Hence, it is a vertebra of a mammal.

NSOU CC - ZO - 01 153 1. Ring like structure without centrum. 2. Neural canal large. 3. Two concave facets on the anterior side for articulation with double occipital condyles of the skull. 4. Transverse process wing like and bears vertebraterial foramen. 5. Neural spine reduced. 6. A small mid - ventral hypapophysis present. 7. Pre-zygapophysis absent but post-zygapophysis present. Hence, it is atlas vertebra of white rat. b) Axis of white rat: - Upto vertebra of a mammal same as atlas. 1. Centrum bears an anterior tooth -like odontoid process. 3. Transverse process short, rod-like, backwardly directed. 4. Both pre-and post-zygapophyses are well developed. 5. Vertebrarterial foramen present at the base of transverse process. Hence, it is 2nd/Axis vertebra of white rat. c) Anterior and posterior thoracic vertebra of white rat:- Upto vertebra of a mammal same as atlas. 1. Neural spine long, pointed and directed vertically upward. 2. Facets for articulation of ribs on transverse process and centrum present. 3. Transverse process short, stumpy and not perforated at the base. Hence, it is anterior thoracic vertebra of white rat. 1. Neural spine small and directed backwardly upward. 2. No facet for articulation of rib on transverse process. 3. Transverse process short, stumpy and not perforated at the base. Hence, it is posterior thoracic vertebra of white rat.

154 NSOU CC - ZO - 01 vertebrarterial canal 4. AXIS (Lateral view) neural canal neural spine neural arch neural spine neural spine neural canal neural arch vertebrarterial canal transverso process transverso process facet for arfticular surface on axis facet for odontoid process facets for occipital condyles facets for articular surfaces on axis 1. ATLAS (Drosal view) 2. ATLAS (Anterior view) 3. ATLAS (Posterior view) neural spine neural arch neural arch neural spine neural arch neural spine odontoid process post-zygp pre-zygp articular surface for atlas cervical rib centrum vertebrarterial canal cervical rib epiphysis on centrum neural cartal transverse process vertebraterial canal neural canal centrum facet for tuberculum of rib pre-zygp. post- zygp. inter- vertebral notch centrum demifacets for capitulum of ribs 5. TYPICAL CERVICAL (Lateral view) 6. ANTERIOR THORACIC (Anterior view) 7. ANTERIOR THORACIC (Lateral view) metapophyses pre. zygp. inter- vertebral notch neural spine neural spine metapophyses metapophyses neural spine post. zygp. post. zygp. centrum anapophyses anapophyses post. zygp. pre. zygp. neural canal neural arch hypapophysis transverse process transverse process centrum facet for rib transverse process centrum 9. ANTERIOR THORACIC (Anterior view) 8. POSTERIOR THORACIC (Anterior view) 10. POSTERIOR LUMBAR (Lateral view) pre. zyp. neural spine neural spine post. zygp. post. zygp. neural spine intervertebral foramina vertebrae 1st sacral vertebra post. zygp. pre. zyp. centrum pre. zyp. centrum 11. SACRUM (Lateral view) intervertebral foramine articular facel for ilium articular facet for illum 12. SACRUM (Dorsal view) 13. CAUDAL (Dorsal view)

NSOU CC - ZO - 01 155 d) Lumber vertebra of white rat: - Upto vertebra of a mammal same as atlas. 1. Stout and large bone. 2. Neural spine well developed and directed forward and upward but obliquely. 3. On the dorsal side of pre-zygapophysis a pair of metapophyses is present. 4. A pair of anapophyses is present below the post-zygapophyses. 5. Prominent epiphysis as a ventromedian ridge. Hence, it is a typical lumber vertebra of white rat. e) Sacrum of white rat: - Upto vertebra of a mammal same as atlas. 1. Compound structure formed by the fusion of 4 sacral vertebrae. 2. Approximately traingular in shape, broad anteriorly and gradually narrowing posteriorly. 3. Each vertebra of compound structure possesses centrum, neural canal, neural arch, transverse process etc. 4. Narrow neural canal. 5. Neural spines are flattened, ridge like. 6. Intervertebral foramina present in between two adjacent vertebrae. 7. Pre-zygapophis is well developed on the anteriormost vertebra. 8. Transverse process on the anterior most vertebra is stout, laterally expanded and with rough dorsal area; while the same of the posterior regions is not laterally expanded and gradually reducing in size. Hence, it is the sacrum of white rat.

156 NSOU CC - ZO - 01 f) Caudal vertebrae of white rat : Upto vertebra of a mammal same as atlas. 1. Neural spine short and directed upward. 2. Transverse processes absent. 3. Pre-and post -zygapophyses are very small. 4. Size of the vertebra is comparatively small. Hence, it is a caudal vertebra of white rat. N.B. –There are 16 candal vertebrae in white rat. Size of the vertebrae gradually decreases posterirly and the last two are rod -like. g) Pectoral girdle of white rat:- The pectoral girdle consists of two seperate equal halves. Each half consists of the followings: - 1. Compound structure made up of scapula, supra–scapula and coracoid bones. 2. Triangular in shape, anteriorly narrow and posteriorly wide. 3. Scapula is thin, flat, plate-like large structure. 4. Presence of a dorsal, anteriorly directed scapular spine which bears acromion and metacromion processes at its anterior. 5. Coracoid is a knob-like small bone fused at the narrow end of scapula. 6. Presence of a short, curved, hook-like caracoid process. 7. Supra-scapula is a thin rim of cartilase situated on the wide posterior border of scapula. 8. Glenoid cavity is present which is a concave facet at the narrow end of scapula. Hence, it is one-half of pectoral gridle of white rat.

NSOU CC - ZO - 01 157 Figure 10 : Pectoral girdle of white rat h) Pelvic girdle of white rat The pelvic girdle consists of two equal halves and each half is known as os- innominatum. Each half consists of the following: - 1. Compound structure made up of complete fusion of three bones–ilium, ishium and pubis. 2. Ilium is flat, elongated and stout bone with a broad distal end. 3. Ischium is short, stout and L-shaped with ischial spine. 4. Pubis is flat, thin and curved. 5. At the junction of 3 bones there is a cavity called acetabulum. 6. A large obturator foramen present which seperates ischium and pubis. Hence, it is one–half of pelvic Indte or os-innominatum of white rat. 7. Both the halves joined together mid-ventrally by pubic symphysis to form a stout and Strong Irdle. Hence, it is complete pelvic girdle of white rat. glenoid cavity acromion process coracoid process coracoid border spine scapula suprascapula glenoid border metacromion process

158 NSOU CC - ZO - 01 Figure 11 : Pelvic girdle of rabbit (A) Complete; (B) One half i) Limb bones of white rat Humerus of white rat: - 1. A rod-like single slightly curved bone with a narrow shoft and broadened at both ends. 2. A round head present at the proximal end called head of humerus. 3. Deltoid ridge present. Hence, it is a humerus bone. 1. Shaft stout and both ends are more or less equally broad. 3. A bicipital groove is present in between head of the humerus and greater tuberosity. 4. Distal end bears apulley-like trochlea with two lateral epicondyles. 5. A supra trochtear foramen is present at distal end. Hence, it is a humerus bone of white rat. pubic symphysis (A) ischial tuberosity ischiam obturator foramen acetabulum cotyloid bone articular surface for sacrum facel for sacrum cotyloid bone cotyloid bone cotyloid bone cotyloid bone cotyloid bone illum (B)

NSOU CC - ZO - 01 159 Fig. 12 : Limb bones of rabbit-(A-C) Forelimbs (D-F) Hindlimbs ( ) ( ) ( ) ( ) ( ) ( ) bicipital fossa lessor tuberosity bicipital fossa greater tuberosity coronoid fossa trochlea supra- trochlear foramen shaft deltoid ridge head olecranon fossa olecranon process greater tuberosity epiphyses sigmoid notch radius ulna epiphyses claws 2 3 4 5 centrale trapezoid 1 trapezium radiale radius ulna ulnare intermedium unciform magnum metacarpals phalanges trochlea HUMERUS (Posterior view) HUMERUS (Anterior view) RADIUS-ULNA (Side view) BONES OF HAND head lesser trochanter inter- condylar groove condyles shaft 3rd trochaner greater trochaner head lesser trochanter patellar groove condyles proximal epiphysis cnemial crest centrale tibula distal articular surface for tarsals claws 5 4+5 distal tarsals 3rd distal tarsal fibulare or calcaneum tibiale or astragalus 2nd distal tarsal fibula metatarsals phalanges 4 3 2 RIGHT FEMUR (Back view) BONES OF HANDFOOT RIGHT FEMUR (Front view) LEFT TIBIO-FIBULA (Front view)

160 NSOU CC - ZO - 01 Radius-ulna of white rat: - 1. Two long, unequal bones unite at both ends. 2. One is slender and nearly straight known as radius while the other is slightly curved and stout known as ulna. 3. Proximal end of ulna bears a cup-like sigmoid or semilunar notch and an olecranon process. 4. Distal end of ulna bears articular processes. Hence, it is radius-ulna bone. 1. Both the bones are of equal thickness but are of unequal in length. 2. Radius is shorter than ulna. 3. Both the bones are joined at both ends leaving a small gap in the middle. 4. Sigmoid notch is situated at the neck of ulna. 5. Distal end of both ulna and radius bears articular processes or styloid processes. Hence, it is the radius-ulna of white rat. Femur of white rat : 1. A long, stout, cylindrical bone and its both ends are broadened. 2. Proximal end bears a round head extending away from the shaft called head of femur. 3. A trochanter present near the head. 4. The distal end bears pulley-like condyles. Hence, it is a femur bone. 1. Shaft of the bone is stout, straight and some what flattened. 2. Head of the femur is borne on a distinct neck. 3. A large greater trochanter, a small lesser trochanter near the neck of femur is present. 4. Distal end bears two large lateral condyles seperated by intercondylar or patellar groove.

NSOU CC - ZO - 01 161 5. A prominent lateral crest extends down the shaft for some distance. Hence, it is a femur bone of white rat. Tibio-fibula of white rat: - 1. Two long bones are partially fused. 2. Bones are grossly unequal in thickness and slightly uneuqal in length. 3. The stout, long bone is tibia and the slender bone is fibula. 4. Crenial crest present in the proximal end of tibia. Hence, it is tibio–fibula bone. 1. Both the bones are lying close together but narrowly separated at the proximal end. 2. Proximal end of tibia bears two concave articular surfaces along with a crenial crest, while the distal end of it bears two irregular articular surfaces. 3. Ends of both these bones are covered by cartilagenous cap. Hence, it is tibio-fibula of white rat. Fig. 13 : A thoracic vertebra with its ribs in rabbit Sternum of white rat:- 1. The thorax is bounded mid-ventrally by the sternum which consists of five elongated bony pieces, known as sternebrae. thoracic vertabra tuberculum vertebral portion of rib centrum capitulum stemebra stemal portion of rib

162 NSOU CC - ZO - 01 2. The sternebrae constitute the main body of the sternum, called mesosternum. 3. The first anterior most sternebra is the longest and called manubrium or presternum. 4. The sternum is ventrally produced into a keel. 5. The first pair of sternal ribs articulate with keel in the middle. 6. Sixth sternebrae is the smallest of all and the last one is long and slender. 7. Except first rib, all the sternal ribs called xiphisternum terminating into an expanded xiphoid cartilage are attached at the inter-sternebral junctions. Fig. 14 : Sternum in rabbit 4.3 Carapace and plastron of turtle Both these structures form the shell of turtle. 4.3.1 Corapace of turtle 1. The dorsal half/portion of the shell of turtle is known as carapace and structurally it is convex in nature. manubrium capitulum tuberculum costal bone stemebrae stenal ribs xiphoid cartilage xiphisternum

NSOU CC - ZO - 01 163 2. It is made up of an inner plate of bones, covered by seperate outer plate of horny materials compared to the scales of other reptiles. 3. Inner plate is formed by the fusion of dermal bone with expanded ribs and vertebrae. 4. On the surface of carapace, keratinized shields/plates of epidermis cover the underlying inner plate. 5. The inner bony plate of carapace consists of the followings: - (a) A median row of 8 neural plates. (b) A single, large nuchal plate joining with the first neural plate. (c) 3 pygal plates lie behind the 8th neural plate. (d) 8 pairs of large, rectangular, transversely arranged costal plates, 8 on each side of neural plates. (e) First two pygal plates are united to form a suprapygal which joins with the 8th neural plate. (f) The costal plates are fused with the ribs which project beyond the outer margin of costal plates. (g) Each rib ends in one of the marginal plates which form the boundary of carapace. (h) There are usually two pairs and one unpaired posteromedian marginal plates. (i) First marginal plate is attached to the side of nuchal plate, while the last one joining with the last pygal plate. (j) The nuchal, pygal and marginal plates are of endodermal derivatives while the neural and costal plates are regarded to be the expanded portion of endoskeletal structures. 6. The dorsal surface of carapace is externally covered by the horney shields and are regularly arranged as follows: - (a) A median row of 5 vertebral shields. (b) Two lateral rows of costal shields consisting of four on each side and attached with the vertebral shields. (c) A marginal row of 24-25 marginal shields.

164 NSOU CC - ZO - 01 (d) Of the marginal shields, the anteromedian is known as nuchal shield while the posteromedian one is known as pygal or supracandal shield. Figure 15 : Carapace of turtle 4.3.2 Plastron of turtle 1. The ventral half/portion of the shell of turtle is known as plastron and structurally it is flat in nature. 2. It is made up of an inner plate of bones, covered by seperate outer plate of horney materials compared to the seales of other reptiles. 3. The inner plate forms the floor of the shell and it represents the fussed dermal bones along the belly. 4. On the surface of plastron, keratinized plates of epidermis cover the inner plate. 5. The dermal bones of inner plate of plastron consists of nine plates –one entoplastron, and a pair of each epiplastra, hyoplastra, hypoplastra and xiphiplastra. 6. The entoplastron is supposed to correspond to interclavicle while the epiplastra composed of clavicle. 7. All the pieces are in close contact by their margins to form a continuous plate. 8. The plastron is covered externally by 6 pairs of horney shields which are known Cervical Marginal Vertebral Costal Pleural Nuchal Peripheral Suprapygal Pygal

NSOU CC - ZO - 01 165 as gular, humoral, pectoral, abdominal, femoral and shields and all these are paired. 9. One or two intergular shields are present in front of gular shields. Figure 16 : Plastron of turtle 4.4 Mammalian skulls : one herbivorous (rat) and one carnivorous (dog) animal 4.4.1 One herbivorous skull (e.g. Rat) Same as skull of white rat. 4.4.2 Skull of dog (a carnivorous mammal) Upto skull of eutherian mammal same as white rat. 1. The skull is strongly built. 2. Temporal and orbital fossa confluent. 3. Incomplete posterior border of orbit. 4. Zygomatic arch is strong and outwardly curved. Intergular Gular Humeral Pectoral Abdominal Femoral Anal Epiplastron Entoplastron Hyoplastron Hypoplastron Xiphiplastron

166 NSOU CC - ZO - 01 5. Presence of well-developed sagittal and lambdoidal crest. 6. Canine is large, pointed and slightly curved. 7. Carnassial teeth present. 8. Incisors are 3 3 and comparatively small. Hence, it is the skull of order canivora. 1. Elongated facial part. 2. Paroccipital process small. 3. Dental formula: 3.1.4.2 3.1.4.3 Hence, it is the skull of Dog (Canis sp). Figure 17 : Skull of Dog

NSOU CC - ZO - 01 167 Unit - 5 ????? Examination of gametes Structure 5.1 Introduction 5.2 Ultrastructure of sperm 5.3 Sperm of frog 5.4 Sperm of rat 5.5 Ultrastructure of ovum 5.6 Ovum of frog 5.7 Ovum of rat 5.1 Introduction Gametes are the highly specialised sex cells developed within the primary sex organs- the testis in male and ovary in female. There are two types of gametes or reproductive cells, viz., spermatozoa and ova. These reproductive cells originate from the germ cells. Within the gonad the primordial germ cells are known as primary gametogonia which multiply rapidly by mitosis. In male the gametogonia produce sperm cells and are called spermatogonia, while in female gametogonia giving rise to ova or egg cells are known as oogonia. Sperm and ovum are responsible for bringing together of hereditary factors in the new individual from the parents and to provide material substance from which the new individual will arise. The gametogonia in both the sexes transform to fulfil these two purposes. The development of male gametogonium or spermatogonium to sperm is called spermatogenesis and change of female oogonium to ovum is known as oogenesis. The gametogonia then transform into the specific gametes and in both cases, the transformation involves reduction of diploid to haploid number of chromosomes and considerable preparation in different components of the cell. 5.2 Ultrastructure of sperm Sperm or spermatozoon may defined as the small highly differentiated male haploid sex cell which is nutrientless, genetic material packed active motile cell developed within the seminiferous tubules of the testis.

168 NSOU CC - ZO - 01 Sperm consists of three distinct parts—head, middle piece and tail. Head: Head contains nucleus and acrosome. Nucleus forms the major part of the head. It contains densely packed genetic material within the nuclear membrane. The nucleus contains DNA and histone protein. Acrosome is present at the tip of the nucleus. It is double-walled sac containing dense granules. Two important enzymes such as hyaluronidase and acrosin which functions during sperm entry into the ovum at the time of fertilization. Middle piece: The tubular extended part in the posterior region of the nuclus is known as middle piece. It is connected with the nucleus by a narrower neck. Middle piece consists of two centrioles, mitochondria and ring centriole. The two centrioles present in the middle piece are at right angle to one another. The anterior centriole is called proximal centriole which is present in the depression at the posterior part of the nucleus. The posterior centriole is known as distal centriole which is responsible for the formation of the microtubules of the sperm tail. The filamentous structure associated with the distal centriole is known as axoneme or axial filament. Around the axial filament of the middle piece spiral mitochondria are present. Due to the presence of mitochondria, it is thought that the middle piece is a 'power plant' which provides energy during the locomotion of sperm. At the posterior extremity of the middle piece lies another dark, dense ring called the ring centriole. Tail: The tail forms the longest part of the spermatozoon. It is divided into two regions– the principal piece and the end piece. The principal piece is structurally similar with the cilia or flagella. In the principal piece, the arrangement of axial filament (9+2) and 9 longitudinal fibres have been found but no mitochondrial sheath is noticed. The axial filament is surrounded by a thin layer of cytoplasm and plasma membrane. The end piece is a short portion of the sperm tail. It consists of only axial filament and is covered with cytoplasm and plasma membrane. 5.3 Sperm of frog Identifying characters: 1. Mature spermatozoon of a frog is made up of three parts, viz. head, middle piece and tail. 2. The head is long and cylindrical. It consists of nucleus and acrosome. The acrosome secretes enzyme like hyaluronidase which help penetration into the egg.

NSOU CC - ZO - 01 169 3. Middle piece region is very small as compare to that of the other sperms. 4. The middle piece of spermatozoon is composed of almost entirely of mitochondria and centrioles. 5. The mitochondrial apparatus supplies the required amount of energy in the form of ATP. 6. The tail of sperm is flagellar and very long. It helps in locomotion and thus is very essential for the mobility of the sperm. 5.4 Sperm of rat Identifying characters: 1. Mature spermatozoon is a microscopic, elongated and highly specialised cell. 2. It measures about 60-70 μm long with a head measuring about 8-10 μm. 3. Sperm is divided into head, middle piece and tail. 4. Head is hook-shaped and it contains nucleus and acrosome. 5. Middle piece is connected with the head by a narrower neck. 6. At the neck region of sperm two centrioles lying at right angle to one another. 7. Anterior centriole called the proximal centriole which is situated in the depression at the posterior part of the nucleus. 8. The posterior centriole called the distal centriole which is present next to the proximal centriole. 9. The distal centriole acts as the basal body for axoneme or axial filament. 10. Throughout the whole middle piece, the mitochondria are present spirally twisted around the axial filament and form one continuous body. 11. Ring centriole is present at the posterior extremity of the middle piece. 12. The tail has two regions, namely, principal piece and end piece. 13. The principal piece forms the longest part of the tail and it consists of peripheral fibrous sheath. 14. The end piece is a short part of the sperm tail and it consists of only the axial filament covered with cytoplasm and plasma membrane.

170 NSOU CC - ZO - 01 5.5 Ultrastructure of ovum Ovum is much larger in size than the body cells in general. Special cytoplasmic substances are accumulated in the cytoplasm which are used up during development either directly, or by becoming transformed into the various structures. The size of egg varies greatly in different animals. The size is chiefly attributable to the quantity of yolk present. The egg is surrounded by plasma membrane (oolemma) which encloses cytoplasmic part called vitellus. Within the vitellus, most prominent is nucleus which is 200-300 times larger than the ordinary cell nucleus. The nucleus contains single large nucleolus rich in RNA and enveloping chromatin materials. Immediately beneath the plasma membrane, there is a thin layer of cytoplasm called cortex. In many eggs, the cortex contains special granules, called cortical granules which play an important role during fertilization. The cytoplasm contains various organelles like mitochondria, Golgi complex and reserve food materials in the form of yolk. The egg or ovum contains one or more membranes are described as primary, secondary and tertiary membranes. The ovum has three basic functions: (i) to contribute a nucleus containing half of the chromosomal component of the future embryo. (ii) to supply almost all the cytoplasm to the zygote, (iii) to supply food reserves that will enable the embryo to develop upto a stage when it can begin to feed upon exogenous materials. Yolk plays a vital role in determining the egg types. Depending upon the amount of yolk in various quantities, eggs are microlecithal or oligolecithal, mesolecithal and megalecithal. According to the distribution of yolk in the cytoplasm of the egg, it may be Homolecithal or Isolecithal, Centrolecithal and Telolecithal. 5.6 Ovum of frog Identifying characters: 1. The ovum or egg of frog is spherical and it measures about 1.6 mm in diameter. 2. It is surrounded by three egg membranes, viz., outer jelly coat, middle vitelline membrane or oolemma.

NSOU CC - ZO - 01 171 3. The egg shows well marked polarity. 4. Because of uneven distribution of yolk, such an egg is said to have an animal pole where the concentration of yolk is small amount. 5. The opposite pole is termed as vegetal pole where the cof yolk is large amount. 6. The nucleus of the ovum is approximated to the animal pole. 7. The ovum contains moderate amount of yolk, hence it is moselecithal type of egg. 8. The egg shell is absent, hence it is non-cleidoic egg. 5.7 Ovum of rat Identifying characters: 1. The ovum or egg of rat is round or spherical and is about 270 μm in diameter. 2. The ovum contains three egg membranes, such as vitelline membrane, zona pellucida and corona radiata. 3. Thin vitelline membrane remains closely associated with the plasma membrane around the cytoplasm. 4. Zona pellucida is present outside the vitelline membrane. 5. Presence of corona radiata around the ovum and exterior to the zona pellucida. 6. Corona radiata is formed by a singly layer of columnar cells. 7. Perivitelline space is present in between plasma membrane and zona pellucida. 8. Nucleus is large in size and it is about 55 μm in diameter. It enlarges to form a germinal vesicle. 9. The ovum of rat contains very little amount of yolk, hence it is microlecithal egg.

172 NSOU CC - ZO - 01 Unit : 6 ????? Chick : developmental stages Structure 6.1 Chick embryo of 24 hours of incubation 6.2. Chick embryo of 48 hours of incubation 6.3 Chick embryo of 72 hours of incubation 6.1 Chick embryo of 24 hours of incubation Identifying characters: 1. Distinguishable into central area pellucida and a peripheral area vasculosa. 2. Neural folds are well developed at the cephalic end. 3. Sub-cephalic pocket present on each side of head fold. 4. Distinct anterior border of foregut and margin of anterior intestinal portal. 5. Presence of distinct median notochord. 6. Four pairs of somites are visible in the middle of the body. 7. Primitive streak in a reduced state. 8. Hensen's node located posteriorly. 9. Non-segmental mesoderm and lateral mesoderm present. 10. Blood islands are restricted to the posterior end of the embryo. Hence, it is the whole mount of chick embryo of 24 hours of incubation.

NSOU CC - ZO - 01 173 6.2. Chick embryo of 48 hours of incubation Identifying characters: 1. Embryo consists of a downwardly bent head, an elongated trunk and a short tail region. 2. Anterior half of the body is twisted and lies on the left side. 3. Cranial flexure and cervical flexure well developed. 4. Neural tube differentiated into brain and spinal cord. 5. Optic cup distinct. 6. Auditory vesicles prominent. 7. Amniotic head fold covers the anterior half of the body, a small tail fold of amnion present posteriorly. 8. Presence of well developed heart. 9. Three pairs of arterial arches arise from the ventral aorta. 10. Twenty six pairs of somites are present. 11. Vitelline blood vessels well developed. Figure 1 : 24 hours chick embryo

174 NSOU CC - ZO - 01 Hence, it is the whole mount of chick embryo of 48 hours of incubation. Figure 2 : 48 hours chick embryo 6.3 Chick embryo of 72 hours of incubation Identifying characters: 1. Embryo consists of a swollen, downwardly bent (flexed) head, an elngated trunk and a short upwardly bent (flexed) tail. 2. Both cranial and cervical flexures prominent, caudal flexure well developed.

NSOU CC - ZO - 01 175 3. Amnion completely encloses the body except posterior opening. 4. Large optic vesicle with distinct outer pigment layer and inner sensory layer. 5. Presence of well developed eyes, lens and auditory vesicles. 6. Telencephalon located below the level of heart, diencephalon with an epiphysis. 7. Presence of well differentiated heart with four aortic arches. 8. Presence of paired wing bud and hind limb bud. 9. Vitelline blood vessels present. 10. Pharynx and four pharyngeal pouches visible. 11. 36 pairs of mesodermal somites are present. 12. Appendages rudiments are present. Hence, it is the whole mount of chick embryo of 72 hours of incubation. Figure 3 : 72 hours chick embryo 176 NSOU CC - ZO - 01 Unit 7 ????? Demonstration of whole mount preparation of chick embryo Structure 7.1 Introduction 7.2 Materials required 7.3 Experimental methodology 7.1 Introduction The egg of hen is telolecithal type. It developes only on a limited range of temperature (about 37-39ºC) which is approximately the body temperature of the adult bird. The temperature of incubator must be carefully controlled. 7.2 Materials required (i) Fertilized hen's egg, (ii) Forceps, (iii) Fine scissors, (iv) Scalpel, (v) Petridishes, (vi) Saline, (vii) Distilled water, (viii) Alcohol grades, (ix) Eosin stain, (x) Incubator, (xi) Binocular microscope, (xii) Microscope. 7.3 Experimental methodology 1. Clean the egg surface with cotton wool soaked in 50% alcohol to kill the organisms. 2. Incubate the egg at 38ºC temperature. 3. Remove the egg from incubator after specific time of incubation and crack a small area of egg shell at the broad end with the help of handle of scalpel. 4. Remove the egg shell pieces gently till the opening is large enough to pore out the contents without damaging the vitelline membrane around the yolk. 5. Transfer the contents of egg in a clean sterilized petridish containing saline. Care must be taken to ensure that the whole mass of yolk and embryo must be completely immersed in saline. 6. Observe the embryo under binocular microscope. In the animal pole, the embryo appears as a small white body on the surface of the yolk at the centre.

NSOU CC - ZO - 01 177 7. Hold the vitelline membrane with a pair of fine forceps and cut it close to the embryo with a pair of fine sharp scissors. 8. Carefully separate the embryo from the underlying yolk and transfer it to a watch glass containing physiological solution, i.e. saline. 9. Wash out the yolk with a fine brush. 10. Pass the embryo by alcohol series of 30% ? 50% ?70%?90% alcohol (10- 15 minutes in each change) for dehydration. 11. Stained the embryo with eosin stain for 3 minutes. 12. Cleaning in 100% alcohol. 13. Wash and clear in xylene for 10 minutes. 14. Mount the embryo on a clean glass slide in canada balsam or DPX. 15. Observe the whole mount of the embryo under microscope. For unstained preparation of the whole mount of chick embryo: (a) Procedural steps upto point 10 -same as stated above. (b) Mount the embryo, which is free from yolk and other materials, on a glass slide with 1-2 drops of glycerine. (c) Observe the whole mount of the embryo under microscope.

178 NSOU CC - ZO - 01 Unit - 8 ??????????Animal album Structure 8.0 Objectives 8.1 Protozoa 8.2 Porifera 8.3 Cnidaria 8.4 Platyhelminthes 8.5 Nemathelminthes 8.6 Annelida 8.7 Arthropoda 8.8 Mollusca 8.9 Echinodermata 8.10 Hemichordata 8.11 Urochordata 8.12 Cepholochordata 8.13 Cyclostomata 8.14 Chondrichthyes 8.15 Osteichthyes 8.16 Amphibia 8.17 Reptilia 8.18 Aves 8.19 Mammalia 8.20

Selected reading

NSOU CC - ZO - 01 179 8.0 Objectives

By studying this unit learners would be able to

know about

habit, habitat and distribution of different invertebrate and vertebrate phyla. 8.1 Protozoa 1. Amoeba sp. Habit and habitat: 1. Fresh water, commonly found on the surface of mud and rotten vegetation at the bottom of ponds, lakes and slow running streams. 2. It occurs in abundance in the water which contains bacteria and organic substance such as leaves, twigs and other aquatic vegetation in abundance. 3. Nutrition holozoic-feeds on bacteria, algae, protozoans and small multicellular organisms like rotifers. 4. Food is captured by pseudopodia. Distribution: It is found all over the world. 2. Euglena sp. Habit and habitat: 1. Euglena is a solitary and free living freshwater flagellate. 2. Found in surface of fresh water ponds, abundant in stagnant ponds with greenish water. Also found in fresh water pools, ditches and slow running streams. 3. When euglenas are in abundance, they impart green colour to the water. 4. Nutrition holophytic but becomes saprophytic in absence of light. 5. Synthesize carbohydrate by the process of photosynthesis. Distribution: Cosmopolitan.

180 NSOU CC - ZO - 01 3. Plasmodium sp. Habit and habitat: 1. Plasmodium lives as an endosparasite, found in the RBC of man in the form of mature adult stage or trophozoite stage. 2. It causes malarial fever in man, trasmitted by female anopheles mosquito. 3. In the life cycle of Plasmodium having two hosts, man and female anopheles mosquito. Man is considered to be definitive host in which asexual phase of the life cycle of parasite is completed. Female anopheles is considered as an intermediate host in which sexual phase of the life cycle of parasite is completed. 4. In 1898, Sir Ronald Ross(Nobel Prize winner in Medicine, 1902) proved that malarial parasites are sucked by female anopheles mosquito and later injected into human blood. 5. Four species of Plasmodium causing four types of malarial fever: (i) P. vivax-benign tertian fever (ii) P. falciparum-malignant tertian fever (iii) P. malariae- quartan fever (iv) P. ovale - ovale tertian fever Distribution: Malarial parasites are found in all countries. The tropical zone is the endemic of all malarial parasites. P. vivax is the prevailing species of the temperate zone while P. malariae is a parasite of subtropical zone. The distribution of P. ovale has been reported from Africa and Philippines. 4. Paramoecium sp. Habit and habitat: 1. Paramoecium found in fresh water ponds, pools, lakes, ditches, streams etc. containing decaying vegetable matter. It is popularly known as slipper animalcule or 'Ladies slipper'. 2. Nutrition holozoic, feeds on bacteria, small protozoans, algae, diatoms etc.
NSOU CC - ZO - 01 181 3. Can be easily cultured in hay infusion. 4. Reproduces sexually by conjugation. Distribution: World wide distribution. 8.2 Porifera 1. Sycon sp. Habit and habitat: 1. Sycon is a small, solitary colonial, marine sponge found in shallow water upto a depth of 50 fathoms (1 fathom= 6 feet) and in well oxygenated water. 2. It is a branching colonial sponge, though solitary individuals are also found. 3. Attached by a sticky secretion with submerged solid objects like rocks, wooden structures, shells of molluscs, corals etc. 4. They thrive well where wave action is not too strong and at low tide mark. Distribution: Cosmopolitan in marine and freshwater, but is best known from North Atlantic shores. 2. Hyalonema sp. Habit and habitat: 1. Marine, found in 10-15 meters deep in sea. 2. Vase-shaped, generally measuring 30-45 cm.long. 3. Due to presence of hyalonemic root-tuft often spirally twisted like rope, hence they are called glass-rope sponge. Distribution: Found in USA and Coast of England at the depth of 10-15 meters. 3. Euplectella sp. Habit and habitat: 1. Euplectella is solitary animal found abundantly in deep sea water at the depths from 500 to 5000 meters in slow running water.
182 NSOU CC - ZO - 01 2. It is popularly known as 'venus flower basket' due to its beautiful elegant glossy shape. 3. Sponge is fastened in mud of sea bottom by a root-tuft, root-spicules are adapted to anchor sponge to unstable substratum. 4. Euplectulla exhibit an interesting commensal association with certain species of shrimps. Young shrimps enter into spongocoel and after growth they are unable escape through the minute sieve plates of osculum. Their entire life is passed in sponge prison. 5. Skeleton of Euplectella is in great demand in Japan for good wedding gift in marriage ceremony. Distribution: Deep sea near Philippines and West Indies. 8.3 Cnidaria 1. Obelia sp. Habit and habitat: 1. Obelia is a typical sedentary, exclusively marine and colonial form. It is commonly knowas 'Sea-fur'. 2. They are found attached on the surface of sea-weeds, molluscan shells, rocks and wooden piles in shallow water up to 80 meters in depth. 3. It exists in two principal forms, the polyp and the medusa. 4. The polyp or hydroid form represents the asexual phase of its life history and the medusoid form represents the sexual phase. 5. There is an alternation of these two phases or generations in its life cycle and thus shows typical instance of 'Metaganesis'. Distribution: Cosmopolitan distribution, abundant in both Atlantic and Pacific coastal waters.
NSOU CC - ZO - 01 183 2. Physalia sp. Habit and habitat : 1. Marine, colonial, free-floating pelagic animal of warm sea, commonly known as 'Portuguese man-of-war'. 2. Presence of bladder like brightly coloured float or pneumatophore which supports the colony on water surface. 3. A gas in the float chamber contains 90% nitrogen, 9% oxygen and 1% argon. 4. Mainly feeds on fishes. 5. Tentacles are useful in capturing prey, chiefly fish. 6. They can cause painful injuries to man. Distribution: Found in Tropical and sub-tropical oceans. 3. Jelly fish [Aurelia aurita] Habit and habitat: 1. Marine, solitary, free-swimming, pelagic animals in medusoid forms, popularly known as moon jelly. 2. It is carnivorous, feeding on small planktonic animals with the help of its long oral arms. 3. It responds to various stimuli and is most active in diffuse light. 4. It inhabits coastal water of all oceans. Distribution: Cosmopolitan in distribution, abundantly found in temperate, tropical and subtropical waters, very common along the entire Atlantic and Pacific coast. 4. Sea Anemone Habit and habitat: 1. Marine, brightly coloured solitary animal.

184 NSOU CC - ZO - 01 2. They are sessile, live in shallow water or littoral zone, remain attached with rocks, sea-weeds, molluscan shells, sandy and muddy bottom etc. 3. They are represented only by hydroid or polyp stage and the medusoid generation is absent. 4. Carnivorous, feeding on minute organisms, small crustaceans. 5. It is very sensitive and highly contractile, when touched the animal contracts its body immediately. Distribution: Cosmopolitan, more abundant in tropical and sub-tropical waters along the Atlantic and Pacific coast. 8.4 Platyhelminthes 1. Taenia sp. Habit and habitat: 1. Digenetic endoparasite, involves mainly two hosts-man and pig. 2. Adult lives in intestine of man, cysticercus stage lives in the muscles of pig, hence it is known as the pork tape worm. 3. Man
is the primary host and pig is the secondary host. 4.
Infection occurs by eating undercooked pork meat containing cysticercii. 5. Taenia causes loss of apetite, continuous indigestion, vomiting, abdominal pain, anaemia, insomnia etc. These effects are together known as 'Taeniasis' Distribution: Taenia is found endemic in the pork consuming areas. Its infection is abundant in China, India and European countries. 8.5 Nemathelminthes 1. Ascaris sp. Habit and habitat: 1. Monogenetic endoparasite, involves only one host, no secondary host.
NSOU CC - ZO - 01 185 2. It lives in the small intestine of man which is commonly known as 'round worm'. 3. Shows sexual dimorphism with separate male and female individuals. 4. Infection occurs by eating raw and uncooked vegetables. 5. Ascaris causes abdominal pain accompanied with peritonitis, diarrhoea, vomiting, intestinal obstruction. Migratory larvae in the lung produce cough, dyspnoea and a slight temperature which are altogether symptoms of pneumonia. This disease is generally referred to as ascariasis. Distribution: Cosmopolitan distribution but chiefly found in India, China, Korea, Philippines and Pacific Islands. 8.6 Annelida 1. Aphrodite sp. Habit and habitat: 1. Marine, inhabiting in shallow waters below the low-tide mark. 2. It lives buried in soft sea bottom with the posterior end projecting into water. 3. Capable of digging burrow from 5 to 50 meters deep or crawls on sea bottom. 4. Carnivorous. 5. Since the animal has distinct stiff and irridescent bristles, hence it is known as 'sea mouse'. Distribution: Cosmopolitan. 2. Nereis sp. Habit and habitat: 1. Marine polychaete, found in the inter-tidal zone, lives in the sea shore in shallow water, in mud or muddy sand, under stones, in the crevices of rocks or in the sea weeds, some live in the tubular burrows lined by mucous in sand or mud at the tidal level.
186 NSOU CC - ZO - 01 2. They are commonly known as Sandworm or clam worm. 3. Nocturnal in habit, very active during night and passive during the day. 4. During night they come out from burrow or from their hidden places, start crawling over the sand and swimming by lateral wriggling of the body. 5. Carnivorous, feeds on worms, soft body of small molluscs, small insects etc. Distribution: Cosmopolitan, found abundantly along the North Atlantic coast, Pacific coast and in Europe. 3. Earthworm Habit and habitat: 1. Terrestrial, burrower, lives in 12-18 inches below the surface of slightly damp soil much in decaying organic matters in gardens, irrigated farm land, near the banks of the ponds. 2. Nocturnal in habit, during night they come out of their burrows in search of food and reproduction. 3. Feeds on dead organic matter which is taken along with the soil. Soil and undigested food matters are voided as castings. 4. Earthworms are better known as the friend of farmers due to improve the fertility of soil. Their habit of burrowing and soil feeding make the soil porous which permit both aeration and manuring the soil. So these worms are also known as natural ploughman of the soil. 5. In Some cases, earthworms become harmful. Their burrows may cause loss of water by seepage from ditches in irrigated lands. They also damage the grass lands by making tunnels in the ground when present in huge numbers. Distribution : Cosmopolitan. 4. Hirudinaria Habit and habitat: 1. Found in ponds, lakes, swamps and slow-flowing streams.
NSOU CC - ZO - 01 187 2. Sanguinivorous (blood -sucking) and ectoparasitic in nature, sucking the blood of fishes, frogs and also cattle and man. It is commonly known as Indian cattle leech. 3. If full meal in ingested, it can live more than one year without taking further meal. 4. Saliva contains 'hirudin'—blood anticoagulant. 5. Feeds on worms, small snails and insect larvae. Distribution: Cosmopolitan and specially found in India, Bangladesh, Burma, Srilanka. 8.7 Arthropoda 1. Palaemon sp. Habit and habitat: 1. Inhabits fresh water ponds, lakes, streams and rivers. 2. Nocturnal, lies hidden at the bottom during the day and comes to the surface during night in search of food. 3. It is a good swimmer but also capable of crawling on the surface and at the time of danger can jump backwardly with the help of a pair of uropods. 4. Omnivorous, feeding on small organisms like algae, mosses, weeds, small insects, decaying leaves, detritus etc. 5. Migrate to brackish water for breeding. 6. During the breeding period (May to July) the female is seen carrying a large number of eggs between its abdominal appendages. 7. It has edible value and commonly known as prawn. Distribution: World -wide in distribution. 2. Squilla sp. Habit and habitat: 1. Marine, found in shallow water, lives in burrows in the sand or mud at the bottom of sea or in existing holes and crevices in the substratum.

188 NSOU CC - ZO - 01 2. Squilla is active and predatory, it catches hold of the prey with the powerful maxillipedes, hence called ''mantis shrimp''. 3. Raptorial carnivore, feeds on small invertebrates including crustaceans, molluscs and small fishes. Distribution: India, Gulf of Mexico and Southern Coast of Florida, USA. 3. Carcinoscorpius sp. Habit and haitat: 1. Marine and estuarine, found near the shore in sandy or muddy bottom in which remain partly buried. 2. It is commonly known as 'King Crab'. 3. It can dig by the help of cephalothorax and may remain buried. 4. Active at night. The full grown horse-shoe crabs usually crawl by using legs, while the youngs can swim invertedly with the help of abdominal appendages. 5. They feed on polychaete worms, small bivalves and bottom algae. 6. It comes sandy beaches in the early summer to breed, eggs are laid in holes in the intertidal zone. 7. During breeding season, both male and female come on land and dig holes at the upper limit of high tides to lay eggs. Special notes: It has been reported from paleozoic period when it was abundant and known since Triassic period, are living today, hence called a 'living fossil'. Distribution : It inhabits eastern coast of Asia and its Island, Eastern coast of North America from Nova Scotia to Florida. Carcinoscorpius rotundicauda is found in West Bengal. 4. Penaeus sp. Habit and habitat: 1. Inhabits freshwater ponds, lakes, streams and also brackish water.

NSOU CC - ZO - 01 189 2. They are bottom dwellers, mostly crawling over the muddy bottom, occasionally swimming with the help of swimmerets. 3. Feeds on polychaetes, crustaceans, insects, small mollluscs, fish remains, detritus etc. 4. It has edible value, commonly known as 'Tiger shrimp'. Distribution: Commonly in India. 5. Scolopendra sp. Habit and habitat: 1. Terrestrial, lives in crevices, protecting damp places such as under bark, stones, logs or thick vegetation. 2. It is commonly known as centepede. 3. Very active, fast moving. 4. Carnivorous, kill their prey with their poison claws, feeding on insects, spiders, worms etc. 5. Poison is an apalescent, acidic fluid, painful bite causing severe local pain and swelling in man, but not fatal. Distribution: Cosmopolitan. 6. Millipede sp. Habit and habitat: 1. Terrestrial, lives in dark, damp places under logs, stones, barks of dead trees, leaves etc. 2. They are commonly known as 'thousand beggers'. 3. Millipede are sluggish and timid. In spite of their numerous legs, they move very slowly, when touched or lifted they curl up in a flat spiral like a watch spring. Some may roll themseves into a ball.

190 NSOU CC - ZO - 01 4. Mostly herbivorous (vegetarian) or saprophytic (scavenger), food mainly consists of dead and decaying vegetable matters. 5. It burrows in the soil to feed on the roots of the living plants to which it causes great damage. Distribution: Cosmopolitan but specially in tropical countries. 7. Periplaneta sp. Habit and habitat: 1. Terrestrial, nocturnal, very active runner, found close to human habitation, avoiding the day light. 2. Lives in kitchen, grocery stores, bekeries, godowns, drains, latrines, sewage etc. 3. Omnivorous and scavengers, they devour any animal and vegetable substances and even paper, cloth, leather etc. causing great loss. 4. They produce a pungent secretion from the abdominal glands are regarded as the defensive mechanism of this insect. 5. Act as a transmitter of variety of pathogenic bacteria. Distribution: Cosmopolitan. 8. Apis sp. Haleit and habitat: 1. Social, colonial, lives in a hive containing a queen, some drones(male) and numerous workers (sterile female) exhibiting polymorphism and division of labour. 2. Queen and drones are concerned solely with reproduction, while workers perform all other duties. 3. Mouth parts suctorial, collects nectar, pollen and fruit juice to be used as food.

NSOU CC - ZO - 01 191 4. They produce honey and wax. 5. They are active throughout the year but in winter season they do little work and do not rear the brood. 6. In spring season i.e., at the time of flowering they prepare a colony with honey rich combs. 7. The bee hives with thousands of individuals are observed hanging down from the branches of trees and ceilings of houses. 8. The workers communicate informations for the location of the food sources through the 'round dance' and 'waggle dance', a phenomenon called as ''Bee language'' by the eminent biologist Karl Von Frisch. 9. In India three species of Apis are commonly found viz. Apis cerana indica, A. dorsata and A. florea of which A. cerana indica is the domesticated species. Distribution : Cosmopolitan. 8.8 Mollusca 1. Chiton sp. Habit and habitat: 1. Marine, sluggish polyplacophoran mollusc, well adapted for life in rocky shores attached to rocks and other hard uneven surface in the intertidal littoral zone. 2. It is mostly nocturnal (i.e. active at night) and remains concealed under rocks during day-time. 3. Feeds on algae and sea weeds. 4. Development includes a trochophore larva. 5. All members of the class are commonly called chitons. Distribution: Widely distributed in Tropical and subtropical waters.

192 NSOU CC - ZO - 01 2. Dentalium sp. Habit and habitat: 1. Marine, living in clean sand in various depths from shallow water to 2600 fathoms in the sub-littoral zone. 2. The shell is a slightly curved tube, opening at both ends resembling an elephant's tusk, hence it is called as 'Elephant's tusk shell' 3. Development includes veliger larva. Distribution: Found in all seas except the polar. 3. Pila sp. Habit and habitat: 1. Pila globosa is one of the largest fresh water gastropod abundantly found in ponds, lakes, tanks, pools, paddy fields and in water having sacculent vegetation. 2. Pila is a voracious eater, feeds on aquatic plants like Pistia, Vallisneria. 3. They are amphibious being adapted for life in water and on land. They respire in water by ctenidium and by pulmonary sac on land. 4. The animal creeps very slowly by its muscular foot, covering about five centimeter per minute. 5. To facilitate movement over a hard dry surface, the snail secretes slime which when dried, leaves a silvery trail behind. 6. Sensing any danger, it immediately retreats into the shell and shuts the aperture with the operculum attached to its foot. 7. During rainy season Pila comes out of ponds and makes long terrestrial tours. It can overcome long periods of drought in a dormant condition and buried in the mud, this period of inactivity is called 'aestivation or summer sleep''. Distribution: Confined to Oriental and Ethiopian regions, found all over India except Punjab and Sindh.

NSOU CC - ZO - 01 193 4. Lamellidens sp. Habit and habitat: 1. Freshwater mussels are found in freshwater ponds, lakes, streams and rivers, inhabiting the surface layers of the muddy beds of rivers and lakes. 2. Exhibiting sedentary life but ploughs slowly through the mud or sand by its wedge-shaped muscular foot at the bottom of the pond or river. 3. They do not go deep in the burrow, because the posterior extremities of the valves is to be kept exposed for the ingress and egress of respiratory water current. 4. They usually stay in shallow water during night, but migrate to deeper water during daytime. 5. Fiter-feeder, comprises microscopic organisms both plants and animals. Distribution : Found throughout Indian Subcontinent including Burma and Srilanka. 5. Loligo sp. Habit and habitat: 1. Marine, rapid swimmers, found in shallow coastal water. 2. Loligo is a very common cephalopod and is commonly called 'squid'. 3. Carnivorous, feed on small shrimps, prawns, crabes and fishes. 4. Short tentacles are called arms, shell internal, hectocotylised arms act as capturing the prey. 5. Ink sac secretes the ink and serves for defence. 6. Loligo is used as food by Chinese and Italians and also as bait for marine fishing. Distribution: World-wide, abundant in Tropical and Subtropical waters. 6. Sepia sp. Habit and habitat: 1. Sepia is exclusively marine, found in shallow coastal warters.

194 NSOU CC - ZO - 01 2. They are good swimmers and can swim either forward or backward by its fins, funnel and the arms. 3. They are found in groups, either swimming freely or resting on the sea bottom. 4. Carnivorous, feeds on small crabes, shrimps, prawns, fishes and other animals. 6. Ink sac secretes ink which serves for defence. 7. Sepia is popularly known as 'cuttle fish'. Distribution: Widely distributed specially in warmer seas like Mediterranian. 7. Octopus sp. Habit and habitat : 1. Marine, found in shallow coastal water, bottom dweller, lives in crevices and under rocks. 2. Slow swimmer, most of the time crawls over the substratum. 3. Shell is absent, secretes inky fluid used for defence from the enemies. 4. Carnivorous, feeds on crabes, prawns, fishes and other molluscs. 5. Octopus is popularly known as 'devil fish'. 6. Octopus has the properly of changing colour of the body when it is irritated. Distribution: Cosmopolitan in distribution and is specially found in Antlantic and Pacific Coasts. 8.9 Echinodermata 1. Starfish sp. Habit and habitat: 1. Marine, bottom dwelling or benthic animal, lives on sandy or muddy bottoms and crawls over rocks and shells. 2. They are abundant on various types of sea-bottoms, specially at places where bivalves are available as food.

NSOU CC - ZO - 01 195 3.

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They move slowly on hard substratum or adhere firmly to it with the help of their locomotary podia or tube feet. 4.

Carnivorous, feeds on crustaceans, tubicolous polychaetes, molluscs and other echinoderms. 5. Exhibit remarkable power of autotomy and regeneration. Distribution: World-wide in distribution. 2. Ophiura sp. Habit and habitat : 1. Marine, bottom dwelling or benthonic animal, found in shallow or deep water. 2. It is commonly called 'brittle star'. 3. Nocturnal, remain quiet in daytime and become active during night. 4. Detritus feeder. 5. Possesses a great power of regenrating its lost arm. Distribution: World-wide. 3. Cucumaria sp. Habit and habitat : 1. Marine, inhabits about 200 fathoms deep wholly or partially buried in mud. 2. Cucumaria is commonly known as Sea Cucumber. 3. It displays a creeping movement on the bottom surface. 4. It feeds on detritus and plankton. Distribution: Found in Tropical and Subtropical waters. 4. Echinus sp. Habit and habitat: 1. Marine, benthonic animal, occurring from intertidal zone to a depth of 5000m. 2. They habitually live in hard or rocky bottoms, found in gregarious forms.

196 NSOU CC - ZO - 01 3. Omnivorous, feeds on sea weeds and small animals. 4. Echinus is commonly known as 'Sea urchin.' Distribution: World-wide in distribution. 5. Antedon sp. Habit and habitat: 1. Marine, prefers shallow water rich in nutrients 2. Found at moderate depths of water attached to hard substratum like rocks and stones by aboral cirri, but with the attainment of adulthood it breaks off from its stalk and swims about actively by the arms. 3. Microphagous, feeds on minute planktonic organisms and detritus, 4. They are gregarious froms and commonly known as 'Feather star'or 'Sea -lily.' Distribution: Found in sea waters of the Atlantic, Western Africa, the Mediterranian and West of Tropical America. 8.10 Phylum—Hemichordata Balanoglossus sp. Habit and habitat : 1. Balanoglossus is a marine, tubicolous, living inside the U-shaped burrows excavated in the sandy bottom of shallow coastal waters of intertidal zone. 2. The walls of the tube are lined with mucous secreted by the mucous gland of the animal. The burrows are open at both ends and faecal matter is expelled to the outside in the form of castings, very similar to those of earthworms, may be seen at the posterior opening. 3. Ciliary feeder; food, comprises of microscopic organisms and minute organic particles, is taken in along with large amount of sand and mud.

NSOU CC - ZO - 01 197 4. Fragile body has considerable power of regeneration. 5. It is commonly known as Acorn worm or Tongue Worm. Distribution: World-wide in distribution. Note: Presence of hollow buccal diverticulum or stomochord extend into the probosics, earlier considered as 'Notochord' for a long time by many workers. Hence, Balanoglossus included a subphylum in Hemichordata under Phylum chordata in lower Chordates or Protochordates. Because they belived that 'buccal diverticulum' is homologous with notochord. But most recent workers denied such homology and thus Hemichordata has been removed from phylum Chordata. Now it is placed as a separate Phylum of non-chordata. 8.11 Sub-Phylum-Urochordata Herdmania sp. Habit and habitat: 1. Exclusively marine, found in shallow waters along the sea coast. 2. It is a solitary and sedentary ascidian, found attached to a rocky sea bottom by its base or foot. 3. Sometimes living as commensal in association with the gastropod shell. Herdmania conceals and protects the mollusc from enemies, being unpalatable due to its spicules. 4. The tunic of Herdmania provides shelter for many organisms. Green algae commonly grows on the tunic which sometimes hides the whole animal. 5. Microphagous, ciliary feeder, feeding on microscopic animals and plants like algae, diatoms etc. 6. Indirect development, free-swimming tadpole larva undergoes retrogressive metamorphosis to become the degenerated sessile adult. Distribution: Widely distributed, found in Pacific, Atlantic and Indian ocean.

198 NSOU CC - ZO - 01 8.12 Sub-Phylum-Cophalochordata Branchiostoma sp. Habit and habitat : 1. Marine, found in shallow waters, both in marine and estuarine habitats, commonly known as amphioxus or lancelet. 2. It leads a dual life. Mostly it is buried in sand in an upright position with only the anterior end protruding above the sand. However, at night it comes out of the sand and swim vertically in water. 3. Ciliary feeder, feeds on planktonic micro-organisms. Distribution: Cosmopalitan but abundant in temperate and tropical sea coasts. 8.13 Class-Cyclostomata Petromyzon sp. Habit and habitat : 1. Marine and freshwater in habit, highly active, lives near the water surface, commonly known as 'Lamprey' 2. Semiparasitic, remain attached on the ventral surface of fishes, turtles and many other aquatic animals with the help of suctorial buccal funnel which acts as a vacuum cup. 3. They attached to the fishes, rasp the flesh by the horny teeth on the buccal funnel and suck blood of fish, hence they are sanguinivorous. 4. Lampreys usually live in the sea and migrate to the river for the purpose of spawning. After spawning they usually die. 5. The larval stage is known as Ammocoetes larva which inhabits in feshwater. Distribution: World-wide distribution.

NSOU CC - ZO - 01 199 8.14 Class-Chondrichthyes 1. Sphyrna sp. Habit and habitat : 1. Marine, lives beyond the continental shelf, strong and active swimmer. 2. They are very ferocious in nature. 3. Voracious feeder, preys on small fishes. 4. Shark oil is extracted from the liver of this shark. 5. It is commonly known as 'Hammer-headed shark.' Distribution: Tropical and subtropical seas and the Pacific ocean. 2. Pristis sp. Habit and habitat : 1. Marine, few species inhabit in fresh water. 2. Carnivorous, feeds on small fishes, crustaceans and other benthic invertebrates by slashing them with its saw. 3. It is commonly known as 'saw fish' because the rostrum is in the form of elongated saw-like toothed structure. 4. The cartilaginous fish is economically beneficial as its liver oil is rich in vitamin value and its skin is used for scale boards. Distribution: Found in coastal areas of Tropical and subtropical seas. Common species of Indian Coasts are Pristis cuspidatus and P. microdon. 3. Torpedo sp. [Electric ray] Habit and habitat : 1. Torpedo is a marine fish, found on flat sandy or muddy bottom at a depth of 40- 50 fathoms.

200 NSOU CC - ZO - 01 2. Carnivorous, food consists of small fishes and benthic invertebrates which are stunned by electric discharge. 3. Torpedo contains a pair a large kidney-shaped electric organs, one on either side of the body between head and the pectoral fins. Each is composed of several rows of hexagonal cells called 'electroplaxes'. The dorsal surface of electric plate is positive and ventral negetive. The electric current of 50-60 volts passes from dorsal to ventral surface. By discharging electricity from the electric organs they paralyse the preys, enemies and which may be fatal to man even. Distribution: Found in Tropical and subtropical seas. 4. Scoliodon sp. Habit and habitat: 1. They are predaceous and voracious feeder, attacking their prey with powerful jaws and sharp teeth. 2. Food comprises of fishes, lobsters, crabes and other marine animals. 3. Sharks are used as human food in many countires. Shark's fins are dried and then boiled yield a gelatinous, substance favoured for soups. 4. The tanned skin shagreen is used for cleaning furniture during polishing. 5. Liver oil is extracted from the liver of sharks. 6. It is popularly known as 'dogfish'. Distribution: Widley distributed in the Indian, Pacific, West Indies and eastern coasts of South America and Atlantic oceans. 8.15 Class-Osteichthyes 1. Labeo sp. Habit and habitat: 1. Labeo rohita is commonly known as 'Rohu fish.' 2. Exclusively freshwater, lives in ponds, rivers and lakes, very active and strong swimmer.

NSOU CC - ZO - 01 201 3. They are column feeders and feed only algae, vegetable debris, microscopic aquatic plants, decaying higher plants etc. 4. They have great food value as they are consumed as food fish all over India. 5. They are very responsive to induced breeding. Distribution: Widely distributed in Tropical and temperate regions specially found in India and Burma. 2. Exocoetus sp. Habit and habitat: 1. Exocoetus is commonly knowns as 'flying fish'. 2. Exclusively marine, active swimmer, lives in large group near water surface. 3. They are famous for the ability to glide above the water surface for about 400 meters by the help of expanded pectoral fins. 4. Carnivorous, feeds on prawns, small fishes and their eggs. Distribution: Distributed in Tropical and warmer Atlantic, Pacific and Indian oceans. Only one species Exocoetus volitans occurs in India. 3. Anguilla sp. Habit and habitat: 1. Anguilla is a freshwater fish, commonly known as 'eel'. 2. The adult-eels live in ponds, rivers, estuaries and coastal areas, also live in damp grass or moss outside water. 3. They can livesare often found buried in mud. 4. They migrate from river to sea for laying eggs in the sea exhibiting catadromous migration. 5. They are voracious feeder, feed on shrimps, fishes, insect larvae etc. Distribution: Common in Tropical and temperate regions of the world; found in Europe, Africa, Australia, West Indies, Mexico and Temperate Asia. Anguilla bengalensis is common throughout India.

202 NSOU CC - ZO - 01 4. Tenualosa sp. Habit and habitat : 1. Marine and brackish water, lives in large group near coastal areas of the sea. 2. Tenualosa ilisha is popularly known as 'hilsa fish.' 3. Feeds on phytoplankton, algae and small quatic plants. 4. They are well known as migratory fish and exhibits anadromous migration to lay eggs in the river. 5. Used as high quality of food fish. Distribution: Found all over India including Bay of Bengal. 8.16 Class-Amphibia 1. Uraeotyphlus sp. Habit and habitat : 1. Limbless amphibians or caecilians, sometimes called blindworms as the eyes are rudimentary, concealed and functionless. 2. They burrow in moist ground at depths of 20-30 cm beneath the top soil with their strong head. 3. They can feel their way about by means of protrusible sensory tentacles. 4. Feeds mostly on earthworms, small arthropods and other small invertebrates. Distribution: Found in Tropical and subtropical regions of America, Africa and Asia; in India-in Malabar and Cochin. 2. Salamander sp. Habit and habitat : 1. The Indian Salamander Tylototriton found in Eastern Himalayas. 2. They are aquatic and live in freshwater small ponds of Darjeeling, Sikkim and Manipur.

NSOU CC - ZO - 01 203 3. They are carnivorous and feed on worms, insect larvae, tadpoles and small fishes. 4. During winter season they hide in the hole and hibernate. From April to August, Salamander wanders on swampy areas and are found in pools. Distribution: There are 6 species of Tylototriton of which only T. verrucossus is found in India (Darjeeling, Sikkim and Manipur) and declared as endangered species. 3. Bufo sp. Habit and habitat : 1. Bufo is terrestrial, nocturnal, hiding under logs and stones or in burrows in broad daylight. 2. Lives in moist and shady areas. 3. They become active at night when they feed on worms, earthworms and insects trapping them with their sticky tongue. 4. During winter they undergo through a phase of winter sleep or hibernation. 5. The parotid glands of the toad secrete two toxic substances bufotalus and bufogus. These toxins if swallowed cause nausea, respiratory and muscular distrubances. Distribution: Found all over the world. 4. Hyla sp. Habit and habitat: 1. Hyla is arboreal in habit and adapted for life in trees, hence the animal is commonly known as 'Tree frog'. 2. The terminal phalanges are claw-like and swollen at the base to form adhesive pads by which it can climb the trees and rocks. 3. Nocturnal and feeds on insect 4. They exhibit parental care, lay their eggs in a foam nest on vegetation above water. 5. They change their colour according to their environment and show camouflage or mimicry.

204 NSOU CC - ZO - 01 Distribution: Cosmopolitan in distribution, found in damp forests in India, China, America, Africa and Canada. 8.17 Class–Reptilia 1. Turtle (Trionyx gangeticus) Habit and habitat: 1. It is most wide spread turtle, popularly known as soft-shelled freshwater turtle. 2. They are aquatic, living in freshwater rivers of India. 3. Carnivorous, feed on fishes, frogs and molluscs. 4. The feamale lays twenty spherical eggs at a time and bury the eggs in same distance from water. Distribution: Found in River Ganges and its tributaries of India. 2. Chamaeleon sp. Habit and habitat: 1. Arboreal in habit, limbs are modified for grasping, additional security is provided by a prehensile tail. 2. The eyes are elevated in small cones and move independently. 3. They are insectivorous and capture grasshoppers, flies, locusts and other insects. 4. It preys upon the insect by throwing its sticky club-shaped tongue far away from mouth. 5. Possesses a great power of colour change rapidly to blend with their surroundings. This is controlled by an autonomic nervous system and thus it is commonly known as 'Bohurupee'. 6. Female lays about thirty eggs in holes. Distribution: Distributed in Africa, Madagascar, Europe and India. Only single Indian species chamaeleon(= chamaeleo) zeylanicus occurs in the plains of South India.

NSOU CC - ZO - 01 205 3. Calotes sp. Habit and habitat: 1. Calotes is adapted for arboreal life, very common in garden, open jungles, bushes and hedges. 2. It is often seen running swiftly on the ground. It can swim, if necessary. 3. It feeds on insects, insect larvae and spiders. 4. Calotes is famous for colour chages. The original colour is olive green but on excitement colour changes to yellow and head becomes red. The colour changes largely governed by temperature, environment and also by hormones of pituitary. 5. The colour pigments are present in the skin. 6. Female lays eggs in holes in the ground. Distribution: It is widely distributed in India, Malayasia and Southern China. Calotes versicolor is the only Indian specis. 4. Draco sp. Habit and habitat: 1. Draco shows extreme adaptation for flying life with the help of their expanded patagium. 2. They can glide from one tree to nearby tree but at rest patagium remains folded. 3. During gliding patagia are used parachutes adapted for passive flight. 4. It is commonly known as 'flying lizard' or 'flying dragon.' 5. Draco is indentified by yellow to orange, red patagia and bluish underside with black spots. 6. They are insectivorous, feeds on tree ants, insects and insect larvae. 7. It is brilliantly coloured and shows camouflage (mimicry). 8. Female lays 2-5 -eggs at a time. Distribution: Distributed in Philippines, Malayasia to Indonesia, Java, Borneo of South East Asia; India. 206 NSOU CC - ZO - 01 Draco dussumieri occurs in South India while D. maculatus occurs in Assam and Nagaland. 5. Vipera sp. Habit and habitat: 1. Russell's viper (Vipera russelli) is found in rocky and bushy areas, usually remains coiled with the head in the centre of coil. It is commonly known as 'Chandrabora'. 2. Carnivorous, feeds on rats, mice, birds and lizards. 3. With least provocation or disturbance bifid tongue is protruded, body rhymically swell and hissing sound is produced, most active during night. 4. It is deadly poisonous, maxilla bears only one pair of tooth modified into large hollow poison fang. The fagns are largest in length among Indian poisonous snakes and are about 16 mm. 5. Poison fangs remain folded back within the mouth cavity but become erect during strike. 6. The poison glands contain about 108 mg venom. 72 mg venom may be injected at per strike. 15mg dose of venom thought to be the fatal dose for man. 7. The venom is haemotoxic and acts on the blood vascular system causing circulatory failure, internal bleeding and tissue destruction (gangrene). 8. Viviparous, giving birth to about fifty youngs at one time. Distribution: It is common throughout the Indian subontinent, Thailand, Burma, Srilanka in the plains and in the hills. 6. Naja sp. [Cobra] Habit and habitat: 1. Cobra is terrestrial and nocturnal, living in holes, understones, mud walls, open fields, thick vegetation and even near human inhabitation where their foods are available. 2. They are carnivorous and feed on rats, mice, frogs, toads and even other small snakes.

NSOU CC - ZO - 01 207 3. Deadly poisonous, anteriormost maxillary tooth modified into a large, grooved poison fang which remains erect and cannot be folded back into the mouth cavity. 4. Venom is neurotoxic, acts on nervous system causing paralysis and respiratory failure. 5. The amount of venom injected per strike is about 211mg. 12mg dose of venom becomes lethal for a man. The poison glands contain about 317 mg venom. 6. Three varieties of Cobra are found in India having three types of marking pattern are seen on its hood: (a) Binocellate form having spectacle-like mark connected by 'U' (b) Monocellate form with single oval mark surrounded by ellipses. (c) Acellate form without mark. Distribution: It is found throughout India including parts of U.P. Bihar, Assam, Odisha, West Bengal etc. 7. Crocodylus sp. Habit and habitat: 1. Crocodiles are amphibious reptile, spending mainly in water and part on dry land. 2. They live in rivers, lakes, marshlands, swamps, brackish waters and estuaries. On land they inhabit forests, grasslands and savannas. 3. Crocodiles are efficient predators, mostly nocturnal hunters, diet of young crocodilians include small fishes, snails, crabes, shrimps, tadpoles and frogs. Food of subadult ansd adult crocodilians consists of a bulk of fishes, crabes, turtles, small and large mammals. 4. Crocodiles dig deep tunnels in the sand to deposit their eggs. Distribution: Found in Africa, Asia, Australia, South and Central America. In India two species occur: Crocodylus porosus and C. palustris.

208 NSOU CC - ZO - 01 8. Gavialis sp. Habit and habitat: 1. Amphibious reptiles, lives in the banks of rivers in which it swims and searches for food. 2. Food cosists of fishes. 3. In spite of its large size it is completely harmless. 4. It is commonly known as 'Gharial' Distribution: Found in India, Burma, Malayasia. In India their presence are recorded in the river Ganges, Mahanadi, Indus and its tributaries. Indian species is Gavialis gangeticus. 8.18 Class-Aves 1. Columba sp. Habit and habitat : 1. Columba livia is the most common and familiar bird nesting in forts, old unused buildings, grain warehouses, temples, railway stations but never nests on trees. 2. They fly in flocks during day and rest together at night. 3. Pigeons are grain and seed eater, feeding on grains, pulses, seeds of fruits, ground nuts etc. 4. Pigeons lead a monogamous and partnership last for entire life. 5. Breeding continues throughout the year. The youngs are fed on 'pigeon's milk' formed in the crop of adult. 6. Pigeons are considered living symbol of peace, harmony and happiness all over the world.

NSOU CC - ZO - 01 209 7. Pigeon has homing instinct. If pigeons are sent in a closed basket, they will return to their loft which they can recognise without any mistake. 8. Pigeons can sometimes become pests in the houses and in the fields by consuming large quantities of grains. Distribution: Found throughout the world specially in Tropical and Temperate regions. 2. Parrot (Psittacula krameri) Habit and habitat: 1. One of the common bird is known as Indian parakeet or 'Tia' in Bengal. 2. The bird is identified by grass green colour of the body with distinct rose-pink collar and black band in front of the neck. 3. Feet are adapted for grasping, holding and climbing. 4. Parrot lives in holes of the tree trunk or in those excavated by the bird itself. Nesting season varies from February to April. 5. Flocks of parrot are seen in the crop fields and orchard fruit, feeds on fruits grains and berries. 6. They destroy more crops or ripening fruits by gnawing rather than eating. 7. Intelligent bird famous for mimicking or copying and can learn to speak like man. Distribution: Distributed in Indian subcontinent (Pakistan, Srilanka, Bangladesh and Myanmmar).

210 NSOU CC - ZO - 01 3. Kingfisher (Alcedo atthis) Habit and habitat: 1. Kingfisher is a common little bird found near the lakes, streams, tanks and the sea shore. 2. On searching of fish they suddenly jump into the water and dive to catch the fish by their long bill. Hence, this bird is commonly known as 'machhranga'. 3. They prey upon small fish, tadpoles and aquatic insects. 4. They produce characteristic sound during flight. Distribulention: They are distributed throughout India. 4. Koel (Eudynamys scolopeceous) Habit and habit in associated with romantic Bengali poetry. Distribution: Found throughout India, Bangladesh, Burma, Srilanka, Pakistan. 5. House Sparrow (Passer domesticus) Habit and habitat: 1. House sparrow is the most familiar companion bird in the house. They are found to nest in the houses. 2. Nest is made by the collection of straw, rubbish and feathers in the hole of ventilator, inverted lamp shade or any suitable place of the building. They nest throughout the year. 3. They are recognised as 'Charui' in Bengal. A chirping call like 'Cheer-Cheer' utter during flight. 4. Feet are adapted for perching with three toes anterior and the first toe or halux posterior.

NSOU CC - ZO - 01 211 5. Omnivorous; eats grains, insects, flower nectar and kitchen scraps. Distribution: Cosmopolitan. 6. Indian Woodpecker (Dinopium benghalense) Habit and habitat: 1. This bird is commonly called 'kath-thokra' in Bengal, found in single or in pairs on trunk of coconut plantations, orchards, mango trees and also in scrub jungle. 2. A nest is a unlined hole on the tree stem, chiselled out by the bird in rotten wood. The nesting season ranges from March to August. 3. Woodpecker digs into rotten wood by the help of long and strong beak. 4. Mainly insectivorous, feeds on insects, beetls, grubs, ants, insect larvae hiding under the bark within rotten tree trunks. They also eat pulp of ripe fruits. Distribution: India, Bangladesh, Burma, Srilanka, Pakistan. 8.19 Class-Mammalia 1. Sorex (Sorex minutes) Habit and habitat: 1. Sorex is the smallest mammal commonly known as 'Shrew' which is superficially resemble of mice. 2. They are terrestrial and burrower. 3. Voracious eaters, feeds mainly on insects, spiders and other invertebrates. 4. Cats avoid eating them because of their bad odour secreted from scent glands. Distribution: All over the Oriental region.

212 NSOU CC - ZO - 01 2. Megachiroptera (Pteropus Sp.) Habit and habitat: 1. Large in size among the Chiropterans and nocturnal in habit. 2. They are adapted for arboreal and aerial mode of life. 3. In the daytime they live in caves, crevices, old abandoned building, thick bamboo forest, large trees etc. hanging upside down by the help of hind limb claws with wings folded. 4. They are called the 'flying fox' because of fox like head, long snout and large eyes. 5. They are capable of active and sustained flight, skeletal system light in weight, Sternum has a carina. 6. Frugivorous, feeds mainly on juicy and sweet fruits like guavas, figs, bananas and mangoes etc. Distribution: Found only in Ethiopian, Oriental and Australian regions. The Indian species is Pteropus giganteus. 3. Microchiroptera (Synotus/Scotophilus sp.) Habit and habitat: 1. Microchiropterans are also arboreals and nocturnal in habit, active at dark and night. 2. During daytime they live in caves, crevices, old abandoned buildings, large trees etc., hang head downwards. 3. They are capable of active and sustained flight, skeletal system light in weight, sternum has a carina. 4. Most are insectivorous but may be frugivorous, necterivorous (feeds on honey), carnivorous or sanguinivorous.

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NSOU CC - ZO - 01 213 5. They are capable of echolocation. Distribution: Found all over the world except cold arctic, antarctic and alpine climates. 4. Squirrel Habit and habitat : 1. Squirrels are diurnal and arboreal, climb the trees very fast. 2. They can jump by pushing off the body with powerful hind limbs and steering with the bushy tail. 3. Herbivorous, feeding on nuts, fruits, grains, seeds, pine cones etc., while feeding they hold the nut in the fore limbs and gnaw it. Distribution: World-wide distribution, common throughout the plains of India, particularly near human habitation. Funambulus pennanti is commonly found in Bengal. 8.20 Selected Readings 1. Balinsky, B.I. (1981) : An Introduction to Embryology. W.B. Sounders Co. USA. 2. Bloom, W. and Fawcett, D.W.(1975) : A Text Book of Histology W.B. Saunders Co. USA. 3. Brusca, R.C. and Brusca, G.J. (2002) : Invertebrates. 4th Edition, Sinauer Associates, Inc. Publishers, Sunderland, Massachusetts, USA. 4. Ghosh, K.C. and B. Manna (2015): Practial Zoology. New Central Book Agency, Kolkata. 5. Gilbert, S.F. (2006) : Developmental Biology, VIII Edition, Sinaver Associates, Inc. Publishers, sunderland, Massachusetts, USA. 214 NSOU CC - ZO - 01 6. Jordon, E.L. and P.S. Verma (2014) : Invertebrate and Vertebrate Zoology. S. chand & company Ltd. New Delhi. 7. Ruppert, E.E. and R.D. Barnes(1994): Invertebrate Zoology. 7th Ed. Saunders College Publishing, N.Y.USA. 8. Kotpal, R.L. (2014) : Modern Text Book & Zoology Invertebrates and Vertebrates, Rastogi Publication, Meerut, India. 9. Meglitsch, P.A. and F.R. Schram (1991): Invertebrate Zoology, Oxford University Press. 10. Sinha, A.K. S. Adhikari and B. Ganguly (2006) : Biology of Animals (Vol I & II), New Central Book Agency, Kolkata. 11. Young, J.Z. (2004): The life of vertebrates. III. Ed. Clarendon press, Oxford, N.Y.

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216 NSOU CC - ZO - 01 Notes

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Phylum : Chordata Subphylum : Vertebrata Superclass : Gnathostomata Class : Reptilia Subclass : Lepidosauria Order : Squamata

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5/7	SUBMITTED TEXT	13 WORDS	87%	MATCHING TEXT	13 WORDS

Phylum : Chordata Subphylum : Vertebrata Superclass : Gnathostomata Class : Reptilia Subclass : Lepidosauria Order : Squamata

SA Animal Fact sheets.pptx (D57738123)

6/7	SUBMITTED TEXT	14 WORDS	87%	MATCHING TEXT	14 WORDS

Phylum : Chordata Subphylum : Vertebrata Superclass : Gnathostomata Class : Reptilia Subclass : Lepidosauria Order : Squamata

SA Animal Fact sheets.pptx (D57738123)

7/7	SUBMITTED TEXT	21 WORDS	69%	MATCHING TEXT	21 WORDS

They move slowly on hard substratum or adhere firmly to it with the help of their locomotary podia or tube feet. 4.

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Under Graduate Degree Programme NETAJI SUBHAS OPEN UNIVERSITY ZOOLOGY HZO CC-ZO-03 SELF LEARNING MATERIAL

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NSOU CC - ZO - 03 1 PREFACE In a bid to standardize higher education in the country, the University Grants Commission (UGC) has introduced Choice Based Credit System (CBCS) based on five types of courses viz. core, discipline specefic, generic elective, ability and skill enhancement for graduate students of all programmes at Honours level. This brings in the semester pattern, which finds efficacy in sync with credit system, credit transfer, comprehensive continuous assessments and a graded pattern of evaluation. The objective is to offer learners ample flexibility to choose from a wide gamut of courses, as also to provide them lateral mobility between various educational institutions in the country where they can carry their acquired credits. I am happy to note that the university has been recently accredited by National Assessment and Accreditation Council of India (NAAC) with grade "A". UGC (Open and Distance Learning Programmes and Online Programmes) Regulations, 2020 have mandated compliance with CBCS for UG programmes for all the HEIs in this mode. Welcoming this paradigm shift in higher education, Netaji Subhas Open University (NSOU) has resolved to adopt CBCS from the academic session 2021-22 at the Under Graduate Degree Programme level. The present syllabus, framed in the spirit of syllabi recommended by UGC, lays due stress on all aspects envisaged in the curricular framework of the apex body on higher education. It will be imparted to learners over the six semesters of the Programme. Self Learning Materials (SLMs) are the mainstay of Student Support Services (SSS) of an Open University. From a logistic point of view, NSOU has embarked upon CBCS presently with SLMs in English / Bengali. Eventually, the English version SLMs will be translated into Bengali too, for the benefit of learners. As always, all of our teaching faculties contributed in this process. In addition to this we have also requisitioned the services of best academics in each domain in preparation of the new SLMs. I am sure they will be of commendable academic support. We look forward to proactive feedback from all stakeholders who will participate in the teaching-learning based on these study materials. It has been a very challenging task well executed, and I congratulate all concerned in the preparation of these SLMs. I wish the venture a grand success. Professor (Dr.) Subha Sankar Sarkar Vice-Chancellor
2 NSOU CC - ZO - 03 Printed in accordance with the regulations of the Distance Education Bureau of the University Grants Commission. Netaji Subhas Open University Under Graduate Degree Programme Choice Based Credit System ((CBCS) Subject : Honours in Zoology (HZO) Course : Basic Concept of Taxonomy and Diversity of Non Chordates Course Code : CC - ZO - 03 First Print : December, 2021
NSOU CC - ZO - 03 3 Netaji Subhas Open University Under Graduate Degree Programme Choice Based Credit System ((CBCS) Subject : Honours in Zoology (HZO) Course : Basic Concept of Taxonomy and Diversity of Non Chordates Code : CC - ZO - 03 : Board of Studies : Members Notification

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NSOU CC - ZO - 03 5 Netaji Subhas Open University UG : Zoology (HZO) Course : Basic Concept of Taxonomy and Diversity of Non Chordates Code : CC - ZO - 03 Unit - 1 ? Basic of animal classification 7-32 Unit - 2 ? Subkingdom, Protozoa 33-107 Unit - 3 ? Porifera, Cnidaria and Ctenophora 108-148 Unit - 4 ? Phylum Platyhelminthes 149-172 Unit - 5 ? Ascaris & Wuchereria 173-199 Unit - 6 ? Phylum : Annelida 200-222 Unit - 7 ? Phylum : Arthropoda 223-243 Unit - 8 ? Phylum : Echinodermata 244-256 Unit - 9 ?? Phylum : Mollusca 257-275
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NSOU CC - ZO - 03 7 Unit - 1 ? Basic of animal classification Structure 1.0 Objective 1.1 Introduction 1.2 Hierarchy (Linnaean Hierarchy) 1.3 Taxonomic Types 1.4 Codes of Zoological Nomeclature 1.5 Rules of Zoological Nomenclature 1.6 Principles of Priority 1.7 Laws of Priority 1.8 Synonym and Homonym 1.9 Species Concept—Biological & Evolutionary 1.10 Numerical Taxonomy 1.11 Molecular Taxonomy 1.12 Questions 1.0 Objective By studying this unit learners would be able to know about— Taxonomic Concept The basis for identification of animals Process of classification The diversity of animal world 1.1 Introduction

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The term taxonomy is derived from the Greek words taxis meaning arrangement, and nomos meaning law.

It was first coined by the pioneer plant taxonomist Augustin Pyramus de Candolle in 1813 for the plant classification. Taxonomy clearly means arranging of organisms on the basis of some laws. To understand those laws and procedure of arrangement one should know the theory and then apply them. Hence taxonomy has been defined by Ernst Mayr (1982) as "Theory and practice of classification, including its bases, principles, procedures and rules." Christoffersen (1995) has defined taxonomy as "the practice of recognising, naming, and ordering
8 NSOU CC - ZO - 03 taxa into a system of words consistent with any kind of relationsips among taxa that the investigator has discovered in nature." The process of taxonomy involves two district steps– (a) correct recognition and definition of the organisms and their relationships and (b) application of suitable designations for the organisms and to different group which include them. The former is called classification which includes study of characters and grouping of individuals while the latter is termed as nomenclature. The term systematics, on the other hand, originated from Latinized Greek word 'systema' meaning to put together. The systematics partly overlap with taxonomy and originally used to describe the system of classification prescribed by early biologists. Linnaeus applied the term 'Sytematics' for the systems of classification in his famous book, 'Systema Naturae (4th edition) in 1735. This was later defined by simspson (1961) as "

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the scientific study of the kinds and diversity of organims and of any and all relationships among them." The other simple defintion by Mayr (1969) is "systematics is the science of diversity of organisms".

Systematics is more broader term than taxonomy. Systemaics deal with the evolutionary relationships between organisms. Systematics try to determine which organisms share a recent ancestry with others. Study on systematics include quite a broader areas of research which include

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not only morphology and anatomy, but also genetics, behavioural aspects and

population study (including population genetics, ecology and evolutionary biology). The unique properties of each species, common characters of certain taxa and the variation within taxa are the products of systematics that ultimately help to construct a phylogeny. Systematics is sometimes incorrectly used as taxonomy. Taxonomy, as mentioned earlier, is actully the study of the principles and practices of classification and as such it is only a part of systematics which consists of both taxonomy and evolution. Taxonomy is thus one of the components of systematics.Taxonomy is concerned with describing and naming the many kinds of organisms that exist today, those that have been extinct for many, even millions of years and also those that are becoming extinct. The second part of systematics, i.e. evolution, is concerned with understanding just all of the organisms arose in the first place and what processes are at work to maintain or change them. Classification is a logical system that consists of several categories or ranks each of which contains some number of organisms such that by the name of a category one can immediately imagine about the structure and other aspects of those oragnims. That the organisms are to be placed under a specific category require the study of thier realationships. The term realationship is vital and means

NSOU CC - ZO - 03 9 phylogentic and all biological realationships. Realationships will show how they are related to each other and how they differ from others. This again will show the path of origin and evolution of the group. Hence Zoological

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Classification can be defined as "the ordering of animals into groups or sets on the basis of their relationships" (

Simpson,1961). Here ordering means arranging the animals into groups. According to Mayr and Ashlock(1991), "a biological classifition is the ordered grouping of organisms according to their similarities and consistencies with their inferred descent." Thus biological classification is the scientific procedure of arrangement of living organisms into groups. It is done on the basis of their similarities and dissimilarities and placing the groups in a hierarchy of categories. Classification is the result of taxonomic studies because the taxonomists "classify" organisms based on certain principles and the end result is the classification.The purpose of classification is indentification and arrangement of diffrent types of organisms into groups on the basis of realationships and to express the degree of genetic relationships or affinity beteween different types of organims. The first pioneer work on biological classification was done by Carolus Linnaeus in the mid 18th century, and it is accepted by all with some modification till date. 1.2 Hierarchy (Linnaean Hierarchy) Simpson (1961) has defined hierarchy as "a systematic framework for animal classification with a sequence of classes (or sets) at different levels in which each class except the lowest includes one or more subordinate classes." In nature the number of animal and plant species is very large and it is necessary to arrange them into categories and taxa of different grades, and then arranging those categories and taxa in an ascending order, so that a higher taxa includes one or more lower taxa.This arrangement is called hierarchy of classification or Linnaean Hierarchy. Linnaeus recognised only five hierarchic levels within the animal kingdom.These were classis (class),ordo (order), genus, species and varietas (variety). Later, two additional categories- family (by Butschli in 1770) between genus and order, and phylum (by Haekel in 1886) between class and kingdom were added. The term varietas used by Linnaeus was subsequenty either discarded or replaced by the subspecies. The above discussed categories from the basic taxonomic hierarchy of animal, and any given species belong to these seven obligatory categories:
10 NSOU CC - ZO - 03 Kingdom Phylum Class Order Family Genus Species Howerver, as the number of known species increased, our knowledge of the degree of relationship of these species also increased, there was a need for a more precise indication of the taxonomic position of a given species. This was achieved by splitting the original seven basic categories and inserting additional ones. These additional categories are fromed by adding prefixes, designate as super above various of the basic levels and as sub and infra successively below them. Thus there are superclass, subclass, infraclass, superorder, suborder etc.More recently two other additional categories have become in use. These are tribe,between genus and family, used in entomology, and cohort, between order and class, in case of vetebrate classification. Some authors use terms for additional subdivisions,such as cladus, legio and sectio.There are as many as 33 categories presently in use in the hierarchic classification, of which only18 (marked with asterisk below) are generally followed. The standardised endings are shown in parentheses. Kingdom* Subkingodm* Infrakingdom Superphylum Phylum* Subphylum* Infraphylum Superclass* Class* Subclass* Infraclass Supercohort Cohort* Subcohort Infracohort NSOU CC - ZO - 03 11 Super order* Order* Suborder* Infraorder Superfamily (oidea) Family* (-idea) Subfamily* (-inae) Infrafamily Supertribe Tribe* (-ini) Subtribe (-ina) Infratribe Supergenus Genus* Subgenus* Super speices Species* Subspicies* 1.3 Taxonomic Types In zoological nomenclature, a 'type' is a zoological object on which the original publised description of a name is based. It is the objective basis to which a given zoological name is permanently linked. In other words, it is the nucleus of a taxon and foundation of its name. Once designated the type cannot be changed, not even by the original author who first described it, except by exercise of the plenary powers of the commission (Article 79) through the designation of a Neotype (Article 75). Types may be considered as secured standard of reference tied to the taxomic names. The method of typing names to taxa is called type method or typification. A type is purely a nomenclature concept and has no significance for classification. In case of zoological code a type is always a zoological object, never a name. The type of a family group taxon is a genus, the type of a genus group taxon is a species and the type of species group is a specimen. The primary purpose of designating a type is to enable scientists in the future to definitely identify a described species.When attempting to describe a new species, rather than depending solely on the published description, it is improtant to physically

12 NSOU CC - ZO - 03 examine previously described species to definitely conclude that a specimen we have on hand is in fact new to science. Thus, it is critically improtant for type species to be placed in a well maintained, universally accessible repository. KINDS OF TYPES : Several kinds of types are recognised by the code. Some of which are briefly discussed. (i) Holotype : A single specimen of any sex selected as the "type" by the original author at the time of publication for the original description of the species.This is the true type and most important of all types.The holotype is the key in the nomenclature of the species and settles many resolved questions in the name of the species. Zoological codes recognise the holotype. A holotype is usually a preserved specimen or fossil,but in rare case it may consist of an illustration, a live specimen or a tissue sample. As per recommendations 73c of the code, the following data are required for the holotype— (a) Specimen's size (b) Locality with date and other relevant data (c) Sex (d) Stage of development or form (e) Name of the host species in case of a parasite. (f) Name of the collector (g) Height in meters for terrestrial species. (h) Depth in meters for marine species. (i) In case of fossil species, the geological age and stratigraphic position, if possible in meters. (j) Register number assigned to the collection. (ii) Allotype : A single specimen of the same species as the holotype,being the opposite sex of the holotype. For example, if in holotype, the sex of the species is male,the female species is considered as allotype.It is often used to illustrate morphological characters not seen in the holotype.The zoological code does not favour the use of allotype which is viewed as a mere paratype. (iii) Paratype : A specimen other than the hologype used by the original author in his description. While describing a new species the author selects a number of specimens for study of characters of the species. He or she marks or selects one of the specimens as holotype and marks rest of the specimens as paratypes (i.e. specimens of paratype status). (iv) Syntype : When a species description is based on two or more specimens and where no holotype is designated, all the specimens are considered as syntypes. Recently the zoological codes do not approve the designation of syntype.
NSOU CC - ZO - 03 13 (v) Lactotype : A lactotype is a specimen later selected to serve as the single type speciemen for species originally described from a set of syntypes. In other words a lactotype is an element selected subsquently from amongst syntypes to serve as the nomenclature type. (vi) Neotype : It is a substitute specimen that is selected subsequent to the description of a species to replace a preexisting type that has been lost or destroyed or damaged beyond recognition. Neotype stands for the species in asbence of its holotypic, lectotypic or syntypic specimens. (vii) Plastotype : A plaster cast of a type of a species forms the plastotype of that species. It is extensively used in paleozoology. (viii) Paratype : While describing a species on the basis of a good number of specimens, its author selects several specimens for basing the description of the species. The author marks one of these as the holotype and a sexual opposite of the holotype as the allotype and then labels the remaining specimens as paratypes. (ix) Topotype : It is a specimen of a species which is earmarked as “collected from type-locality” (the place where from the type speciemen was collected) of the species by a reviser or a subsequent worker who may collect and identify the sample himself. It is quite a valuable type specially when original type get lost or become inaccessible. (x) Homotype : A specimen compared with the type by a person other than the describer and determined by the said person as conspecific with the type. A homotype is important as a holotype and selected when original type is damaged or lost. (xi) Monotype : A holotype based on a single specimen. However, when holotype is correctly designated, it is synonymous with it. 1.4 Codes of Zoological Nomenclature The International Code of Zoological Nomenclature is a widely accepted convention in zoology that rules the formal scientific naming of organisms treated as animals. Names are given to all animals. The name of a particular animal differs in different languages. Even within the same country one animal is known in different names in different regions. To avoid this intricacy of names, it was proposed to give them a scientific name. Such scientific names are Latinised words given as per the International Code of Zoological Nomenclature (I.C.Z.N.)

14 NSOU CC - ZO - 03 Nomenclature (Latin words– 'nomen' meaning name; 'clature' meaning to call) means a system of name and, thus, is the language of zoology and the rules of nomenclature are its grammer. Since all zoologists deal with animals and use their names for communication, it is, thus essential that the general principles of zoological nomenclature be familiar to all zoologists, irrespective of whether they are systematist or not. Brief history of International Code of Zoological Nomenclature The need for a code to give a scientific name to every species was first realized by British Association for the Advancement of Science in 1842, when a set of rules were framed by it. This was also felt by American Association for the Advancement of Science in 1877. Then similar learned bodies in different countries like France, Germany and Soviet Union developed codes for their respective countries. In 1889, at the International Congress of Zoology in Paris, discussions were made to find out some common code of nomenclature. First version of code was adopted in the V th International Congress of Zoology in Berlin in 1901. In the XV th session held in London in 1958, the codes were rewritten and published on 6 th November, 1961 and the updated version of the code (1961) was made available in 1964 (2nd edition). This code is concerned only, upto naming of super family and did not satisfy the zoologists. The latest edition (4 th edition) of the code was published in 1999 and its effective use has started from 2000. The International Zoological Congress elects a judicial body, called International Commission of Zoological Nomenclature which interprets or recomends the provisions of the code for classification or nomenclatural problems of the animals. Again the International Code of Zoological Nomenclature (ICZN) formed by the International Commission of Zoological Nomenclature to see the rules and principles of nomenclature and the application of these rules for both living and fossil animals. Zoological nomenclature is independent of other systems of nomenclature, for example, botanical nomenclature. This implies that animals can have the same generic names as plants. The rules and recommendations have one fundamental aim-to provide the maximum universality and continuity in the naming of all animals, except where taxonomic judgement dictates otherwise. The code is meant to guide only the nomenclature of animals, while leaving zoologists freedom in classifying new taxa. Parts of Code of Zoological Nomenclature The International Code of Zoological Nomenclature contains three main parts–
NSOU CC - ZO - 03 15 (i) the code proper, (ii) The Appendices and, (iii) the official glossary. The code proper includes a preamble followed by 90 articles which cover mandatary rules without any explanation. There are three Appendices, of

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which the first two cover the status of recommendations and the third part of the Appendices is the constitution of the commission. The glossary contains the terms used in the codes

with detailed definition. Binomial and Trinomial Nomenclature. The sceintific method of naming plants and animals by applying two components is called binomial nomenclature. It was evolved by Carolus Linnaeus (Karl Von Linnae), the great Swedish naturalist, and adopted by the International Code of Zoological Nomenclature. According to binomial nomenclature, the scientific name of an organism is composed of two Latin or Latinized words, the first word is called Genus (generic name or generic epithet) followed by the second word called species (specfic name or specific epithet). For example, the scientific name of tiger is Panthera tigris, where Panthera is genus and tigris is species. Very rarely the generic and specific names are same. They are called tautonymes, e.g. Gorilla gorilla, Catla catla, Naja naja, Rattus rattus, etc. Sometimes it becomes the trinomial nomenclature. 1.5 Rules of Zoological Nomenclature At present the naming of the animals is governed by the International Code of Zoological Nomenclature. There are many rules (Articles) concering the Zoological Nomenclature. Of these rules, some important ones are citied below : 1. Zoological Nomenclature is independent of other system of nomenclature. The scientific name of animals and plants must be different, and the generic name of a plant and an animal may be same, but this should be avoided. For example, the generic name of banyan or fig tree is Ficus and the fig shell (a kind of gastropod shell) is Ficus.

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The scientific name of fig tree is Ficus carica or F. indica but the scientific name of the fig shell is Ficus ficus or Ficus gracilis. 2. The scientific names of a species is to be binomial (Article/Art. 5.1) and a subspecies to be trinomial (Art. 5.2). For example, the scientific name of Indian bull frog is Rana tigrina (

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it is binomial), while the scientific name of Indian lion is Panthera leo persica (

it

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is trinomial). 3. The first part of a scientific name is generic (L. Genus = race) and is

a
16 NSOU CC - ZO - 03 single word and the first alphabet or letter must be written in capital letter. The genus must be a noun in the nominative singular. The generic part assigns

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a Latin noun, A latinized Greek or a Latinized vernacular word. 4. The second part of a name is species (L. species = particular kind) name and

may

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be a single word or group of words. The first alphabet or letter

of the species name must be written in small letter. The species name must be adjective form in nominative singular agreeing in gender with genus name which is in noun form; e.g.: Ending in spccies name Ending in Full name of the genus name species genus name Masculine ending (–i) (-i/-us/-es) Common mongoose (Herpestes edwardsi) River lapwing (Vanellus duvaucelli) Feminine ending (-a/-e) (-a/-e) Golden cuttle fish (Sepia esculenta) Humpnosed viper (Hypnale hypnale) Neuter ending (-um/-us, etc.) (-um/-us, etc.) Tusk shell (Dentalium elephantinum) Common crane (Grus grus) Lesser black-backed gull (Larus fuscus) The specific name (species part) indicates distinctness while generic part shows relationship. 5. If the species names are framed after any person's name, the endigns of the species are i, ii and ae, or if the species name are framed after geographical place, the endings of the species are 'ensis', 'iensis', e.g. : Species name after Hooded cuttle fish – Sepia prashadi (Prasad + i) person's name Tree frog – Rhacophorus jerdonii (Jerdon + ii) Antarctic flying squid – Todarodes filippovae (Filippove + ae) Species name Common Indian monitor – Varanus bengalensis (Bengal + ensis) after place Cookiecutter shark – Isistius brasiliensis (Brasil + iensis) Butterfly fish – Chaetodon madagascariensis (Madagascar + iensis) 6. First part of a compound species-group name is a Latin letter and denotes a character of the taxon, connected to the remaining part of the name by a hyphen (–), e.g., NSOU CC - ZO - 03 17 Sole (a kind of flat fish)– Aseraggodes sinus–arabici. *L. Sinus = recess China-rose (a kind of coloured rose)– Hibiscus rosa–sinensis. *L. rosa = rose 7. If a subgenus taxon is used, it is included within parenthesis in between genus and species part and is not included in binomial and trinominal nomenclature, e.g. : Name Genus Subgenus Species Subspecies Fan shell (Bivalvia) Atrina (Servatrina) pectinata pectinata Dussumieri's half Hemirhampus (Reporhampus) dussumieri beak (Osteichthyes) 8. The person who first publishes the scientific name of an animal, is the original auther of a name, may be written after the species name along with the year of publication. The author's name may be in its abbreviated form. Lion– Felis leo Linnaues, 1758 [Lion– Felis Leo Linn., 1758 or Felis leo L., 1758] 9. Comma is only used between author's name and the year of publication (Art. 22. A. 2.1), e.g., the scientific name of Common octopus is Octopus vulgaris Cuvier, 1797. No punctuation marks are considered one to other ends of the name e.g., "Octoups vulgaris Cuvier, 1797" (Not considered). No diacritic mark, apostrophe (i') and hypen (–) are used in names. In German word the umlaut sign is removed from a vowel and the letter 'e' is inserted after the vowel, e.g., mulleri becomes muelleri. 10. If the original generic name given by the first author who also reported the species name, transfers the species part from one genus to the other, the name of the orignal author is put within parenthesis, e.g., Tiger-Felis tigris Linnaeus, 1758. At first almost all the members of the cat family were placed under the genus-Felis. Later the genus Felis was divided into two genera, the genus of the larger cats (tiger, lion, leopard, etc.) is Panthera and smaller cats such as jungle cat, fishing cat, golden cat, etc. are placed under the genus Felis, e.g. : Lion– Felis leo Linnaeus, 1758 Lion– Panthera leo (Linnaeus, 1758) Jungle cat– Felis chaus 11. The names are not acceptable before the publication of Linnaean treatise,

18 NSOU CC - ZO - 03 Systema Naturae (10 th edition) which was published on 1st January, 1758 except the Nomenclature of spiders which starts in 1757. The book Aranei suecici was published by C. Clerck in 1757. 12. The scientific names must be either in Latin or Latinised or so constructed that they can be treated as a Latin word. 13. The scientific names must be italicised in printed form, or under lined in hand wirtten or in typed forms, e.g. : Indian leopart– Panthera pardus fusca (Meyer) [in printed form] Indian leopard–Panthera pardus fusca [in handwritten or typed forms] 14. All taxa from subgenera level and above must be uninominal (Art. 4.1, 4.2) and are plural nouns for names above genus, and singular nouns for genus and subgenus. Taxon 'species' may be used as singular or plural. 15. In case of animals some rules and practices are applied on the basis of zoological codes (Art. 29.2) for the formation of suprageneric taxa from superfamily to tribe, e.g.: Taxon level Endings of the name Examples Superfamily –oidea (for vertebrates) or Hominoidea –acea (for invertebrates) Genus Homo (Latin) = man Genitive Hominis Root Homin–of Homo Family –idae Hominidae [Homin + idae] Subfamily –inae Homininae [Homin + inae] Tribe –ini Subtribe –ina 16. A family name should be based on the basis of type-genus, e.g., Chitonidae– Chiton (type genus) + idae = Chitonidae. 17. Two species under a same genus should not have the same name. 18. Nomenclature of a hybrid/bybrids cannot be considered because the hybrids are normally individuals but not population. Thus such names have no status in nomenclature. Hybrids are typically sterile and becomes synaptic failure during meiosis. They are prevented from back crossing with either parental species. 19. A name published without satisfying the conditions of a availability (nomen nudum = naked name) has no standing in zoological nomenclature and is best never recorded, even in synonymy.

NSOU CC - ZO - 03 19 20. A scientific valid name which is not used about 50 years in literature, then as per zoological code's provision the unused senior valid scientific name is treated as obliterated name and junior name which is

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used continuously in literature (atleast by 10 authors in 25 publications) becomes the accepted official name. Remark: The disadvantage of

the binominal system is its instability and the name of species changes every time and is transferred to a different genus (Mayr and Ashlock, 1991). 21. As per the zoological code's provision (Art. 18), the species and subspecies parts of a name may be same spelling and even the second or the third component of the name repeats the generic name (tautonomy), e.g.: Scandinavian red fox– Vulpes vulpes vulpes. 1.6 Priniciple of Priority Of all the rules of zoological nomenclature, the most difficult to formulate was the one determining which of the two or more connecting names should be chosen. Owing to the French Revolution (1789) and the Napoleonic wars (1801-1815), there was a period of disturbed communication and taxonomists of one country were often unaware of the new species and genera described by taxonomists in other countries. Each author used his/her own judgement as to which name to adopt. The nomenclature chaos prevalent during that period is not appreciated by those contemporary authors, who blamed the rules of nomenclature for all the evils of name changing. The fathers of modern nomenclature believed that the continuous changing of names could be prevented if priority were adopted as a basic principle of nomenclature. Under this principle it would not be possible to change or replace an earlier name merely because it was incorrectly formed or misleading or for other personal aesthetic or even scientific reasons. It is evident from much of the earliest writings on the subject that the "priority" these authors had in mind was a priority of usage rather than priority of publication. However, admirable though, the principle of priority of usage is it is subjective and so an attempt was made to restore objectivity by replacing priority of usage with priority of publication. This priority of publication means that when a name is given, it should be a living entity and accompanied by a description.
20 NSOU CC - ZO - 03 Reasons for the Changes of Name: 1. Changes dictated by scientific progress: (i) Change of the generic part of binomial (binominal). (ii) Change of specfic name. (iii) Synonymising of currently accepted species names. (iv) Analysis of species complex. 2. Changes dictated by rules of nomenclature: (i) Discovery of an earlier (senior) synonym. (ii) Discovery of an earlier (senior) homonym. (iii) Discovery of an earlier genotype fixation. (iv) Discovery of inapplicable type-specimen. 1.7 The Law of Priority The Law of priority covers the period from 1st January 1758 to the present. Article 23 of the Code deals specifically with the rules and as amended at Paris in 1948. Its essential provisions are that the valid names of genus or species can only be that name under which it was first designated on the conditions : 1. That (Prior to January 1931) this name was published and accompanied by an indication or a definition or a description. 2. That the author has applied the principles of Binomial Nomenclature. 3. That no generic name nor specific trivial name published after December 31st, 1930, shall have any status of availability (hence also of validity) under the rules, unless and until it is published either– (i) With a statement in words indicating the characters of the genus, species or subspecies concerned. (ii) In the case of a name proposed as a substitute for a name which is invalid by reason of being a homonym with a reference to the name which is thereby replaced. (iii) In the case of a generic name or sub-generic name, with a type species designated or indicated in accordance with the one or other of the rules prescribed for determining the types species of a genus or subgenus, upon the basis of the original publication.
NSOU CC - ZO - 03 21 4. That even if a name satisfies all the requirements specified of, that name is not a valid name if it is rejected under the law of homonymy (one name for two or more individuals). The Law of Priority in zoological nomenclature is a basic law of International Code and promotes stability. A zoological name and name of a taxon become valid if they belong to the category of senior synonym and senior homonym. The Law of Priority in zoological nomenclatrure applies only from subspecies to family category but not to the higher categories. Priority of the zoological name and taxon are considered from the date of publication. Priority means the oldest date, month and year of the publication. Examples : (i) In 1855, John Edward Gray published the name Antilocapara anteflexa for a new species of pronghorn, based on a pair of horns. However, it is now thought that his specieman belonged to an unusual individual of an existing species, Antilocapra americana, with a name published by George Ord in 1815. The older name, by Ord, takes priority; with Antilocapra anteflexa becoming a junior synonym. (ii) In 1856, Johann Jakob Kaup published the name Leptocephalus brevirostris for a new species of eel. However, it was realized in 1893 that the organism described by Kaup was in fact the juvenile form of the European eel. The European eel was named Muraena anguilla by Carl Linnaeus in 1758. So Muraena anguilla is the name to be used for the species, and Leptocephalus brevirostris must be considered as a junior synonym and not be used. Today the European eel is classified in the genus Anguilla (Garsault, 1764), so it's currently used name in Anguilla anguilla (Linnaeus, 1758). (iii) Nunneley 1837 established Limax maculatus (Gastropoda) and Wiktor 2001 classified it as a junior synonym of Limax maximus Linnaeus 1758 from S. and W. Europe. Limax maximus was established fitst, so if Wiktor's 2001 classification is accepted, Limax maximus takes precedence over Limax maculatus and must be used for the species. There are approximately 2-3 million cases of this kind for which this principle is applied in zoology.

22 NSOU CC - ZO - 03 1.8 Synonym and Homonym Homonyms : Homonyms are names spelt in an identical manner for two or more different taxa but based on different types. If such names come into widespread use, then they create confusion. The earliest of such names are referred to as senior-homonym, while the later names are junior-homonyms. Articles 52 through 60 deal with the validity of homonyms and with replacement names for junior homonyms. They are one of the most difficult areas of zoological monenclature. According to the Code, out of the two or more homonyms, all except the oldest (senior homonym), are excluded from use. The junior homonyms can, therefore, never be names those that have never been used for taxa in the animal kingdom. The Zoological Code explicitly states that two identical species-group names placed in different genera that have homonymous names are not to be considered as homonymy. For example Noctua variegata of Insecta and Noctua variegata of Aves are not to be considered as homonyms. Homonyms are of different types : (i) Senior homonyms : The available name on the basis of priority. (ii) Junior homonyms : A preoccupied name (not in use) on the basis of priority or by a ruling by a nomenclatorial body. (iii) Primary homonyms : In a species-group (species, subspecies, etc.) these are names that are the same and were proposed in the same genus-group taxon. The junior homonym must always be replaced either by a new name or a junior synonym (if one exists) (iv) Secondary Homonyms : These are species that are placed in the same genus subsequent to their publication and they have the same specific epithets. The senior secondary homonym is the older of the two names. An alternative name will have to be provided either through description or junior synonyms for the junior homonym. Synonyms : Two or more names given to the same taxon are known as synonyms. The correct establishment of synonymies is one of the most important tasks, as elaboration of a classification and the preparation of keys depend on the correctness and completeness of the synonymies. The oldest of such names is considered to be Senior Synonym while the later ones as Junior Synonyms. According to the principle of priority, only one name can be accepted by which the taxon may be properly known, and it is, in general, the oldest (senior synonym) one. The later or junior synonyms form what is called the synonymy of the accepted

NSOU CC - ZO - 03 23 name of the taxon. For the consultation of taxonomic works, it is thus important to disginguish clearly the name accepted as valid from those cited in the synonymy. Modern taxonomic research has to cope with frequent excess of names over taxa. This has come about in two main ways– (i) Lack of awareness of previously published names. (ii) Insufficient appreciation of the amount of variation that can exist within a species. This is the result due to lack of sufficient specimens. Presently with more material available and greater opportunities for field and experimental studies, there is no dearth of species. Moreover, with modern communications, international taxonomic associations have reduced the likelihood of the same taxon being described more than once under different names. However, keeping abreast of the current literature, synonymy is still a problem in spite of the advent of computerised abstracting and data-handling services. Taxonomic and nomenclatre synonyms : Two kinds of synonyms are generally present. 1. Nomenclature synonyms : Nomenclature synonyms are synonyms based upon the same type. Their synonymy is said to be absolute and not a matter of taxonomic opinon. They are also known as obligate, objective or homotypic synonyms. 2. Taxonomic synonyms : Taxonomic synonyms are synonyms based upon differnt types. They remain as synonyms only as long as their respective types are considered to belong to the same taxon. The are also known as subjective or heterotypic synonyms. Nomenclatural synonymy are indicated by the mathematical sign of congruence '≡', while the taxonomic synonymy by the sign of equality '='. Synonyms are of different types : (i) Senior synonyms : The oldest of two or more names that are considered valid by nomenclatorial codes. This is usually based on priority but may also be done on the basis of choice of names by the first revisor or by a nomenclatorial governing body. (ii) Junior synonyms : The junior names are those that are considered invalid on the basis of priority or because of a choice of the first revisor, or by

24 NSOU CC - ZO - 03 a governing body of nomenclature. These names, however, can be elevated to senior synonyms if new taxa are identified later and the type(s) of the new taxa are the name bearers of these names. (iii) Objective synonyms : Different names that by examination of nomenclatorial literature alone are judged to refer to the same taxon. For example, any two family-group names with the same type genus or any two genera with the same type species are objective synonyms. These synonyms are generally created only by a drug or alcohol-induced stupor that lasts for days or weeks for the author or by an inadvertent error. (iv) Subjective synonyms : These are different names that have been applied taxon as determined by a taxonomist or systematist. An example would include two species originally described as distinct but were later determined by a professional in the field that they are the same species. This is the most common types of synonymy and these can be the sources of confusion and great debate. Significance of synonyms : Irrespective of the fact that the names placed by an author in synonymy are not valid, it, however, does not imply that they are of no significance. A considerable amount of information may be recorded in the literature under these invalid names. Therefore, the synonymy of a taxon is a key to information about the taxon, and it is for this reason that taxonomic research is concerned for the establishemnt of the correct synonym. 1.9 Species Concept- Biological and Evolutionary The foremost task of a taxonomist is to know the different 'kinds' of organisms occuring in nature. These 'kin . ds' are actually the species. History tells us that the existence of species has been recognised by man since the dawn of civilization. The species, like the cell and the organism, is one of the most fundamental units in biology. It is fundamental in two very important ways. On the one hand it is a basic populational and evolutionary unit. Species become transformed through time. They undergo speciation, giving rise to separate and distincit lineages that diversify through time. On the other hand, it is also a basic unit in classification.

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Each species is given a name, that serves as a unique

identifier and has a place in a hierarchial arrangement that at once reflects its evolutionary relationships and provides a basis for biologists' language. Small, almost imperceptible changes in an existing species lead to the shifts that at length are manifested in the appearance of a new species. The species
NSOU CC - ZO - 03 25 provides a common ground where micro- and macro evolution meet. In this role, the species is the critical unit in evolution. New species must come from old if there is to be evolution. Biological Species Concept : Linnaeus established species as a practical unit of classification but the notion that species are biological units, is forwarded by Buffon (1707-1788). He was the first to introduce the idea that breeding between individuals characterizes a species. By that time various concepts on species like Typological Species concept, Nomina listic Species concept, etc. had been put forwarded by various workers. But no one was universally accepted. Mayr (1940) reviewed the works of others on species problem and introduced the Biological Species Concept (BSC). It is completely different from the earlier species concepts. According to this concept, "species are groups of acutally or potentially interbreeding natural population which are reproductively isolated from other such groups (Mayr, 1940). The advantage of biological definition is that, it can be tested objectively. If two populations in the same locality do not fertilize each other and if cross fertilization occur but hybrids are not viable and fertile, then the two populations tested can be considered as two separate species. According to Biological Species Concept the members of a species shows the following there properties. These are–– (a) A reproductive community : The individuals or members of an animal species recognize each other as potential mates and seek each other for the purpose of reproduction. The species-specific genetic programme of every individual ensures intraspecific reproduction. Biological species is, therefore, a reproductive unit in which, theoretically all individuals of the community may contribute to the procreation of descendants. (b) An ecological unit : The members of a species form an ecological unit which regardless of the individuals that constitute it, interacts as a unit with other species with which it shares its environment. (c) A genetic unit : The species finally is a genetic unit consisting of a large inter communicating gene pool, whereas the individual organism is merely a temporary vessel holding a small portion of the contents of the gene pool for a short period of time. These three properties show that species do not conform to the typological or

26 NSOU CC - ZO - 03 morphological definition of a class of objects. Instead, species are biological populations. The ability of one or more populations to interbreed denotes that the members of the population or populations belong to a single species, whereas a failure of interbreeding denotes populations beloning to different species.The individual members of a population possess some cytological, genetical or ecological isolating mechanism (reproductive isolation) which maintains the gene pool of the species. According to Dobzansky (1950 "species is the largest and most inclusive reproductive community of sexual and cross-fertilizing individuals which share a same gene pool." He worte, "species are formed when a once actually or potentially interbreeding array of Mendelian population becomes segregated in two or more reproductively isolated arrays", or more briefly, "A species is the most inclusive Mendelian population." Both Mayr's and Dobzansky's definitions treat the species as a dynamic unit, a stage in the process of evolution, and not as a fixed static entity. The emphasis lies on the achievement of reproductive isolation. Most modern taxonomists consider the biological species concept as the widely accepted species concept, because maximum workers apply this concept during their work. This concept has no fixity, and always changable and has the potentiality for modifications required by the evolution. Although biological species concept has wide acceptance, this concept, when applied universally, has some drawbacks or difficulties as mentioned below : 1. Although it is easy to observe the reproductive barriers (isolation) between populations found in the same locality (sympatric population) but not so in case of populations that are naturally separated or geographically isolated (allopatric population). Thus the definition does not tell whether populations isolated from each other in space or in time could actually interbreed or not. 2. To the museum taxonomists working with dead specimens, and especially to the paleontologists, who have no choice but to work with non-living materials (fossils), this concept is of no value. One can not test fossil populations as to whether they can or can not exchange genes either among themselevs or with present populations. 3. One final difficulty with the biological species definition is that it is limited to sexually reproducing species and not applicable in apomictic species (i.e. asexually reproducing groups) that do not fulfil interbreeding criterion which is the most important characteristic feature in biological species concept. Apomictic groups
NSOU CC - ZO - 03 27 show uniparental reproduction by parthenogenesis, hermaphroditism apomixis, budding, etc. Uniparental reproduction is seen in lower invertebrates and lower vertebrates. The descendents of apomictic groups are termed agamospecies or binoms (Grant, 1957), paraspecies (Mayr 1987 b) but Ghiselin (1987), Mayr (1988 a) stated that these are not considered as "species". In spite of the difficulties inherent in the biological species definition, the biological species generally agree and the exceptional cases are most instructive. Evolutionary Species Concept : Not all taxonomists specially palaeontologists are not satisfied with the biological species concept. They preferred a definition of species which is related to the evolution. This concept was proposed by Simpson (1961) and had undergone many modifications. According to Simpson, "an evolutionary species is a lineage (an ancestral-descendant sequence of populations) evolving separately from others and with its own unitary evolutionary role and tendencies." Simpson has stated that the above defintion not only is consistent with biological or genetical concept of species but it helps to clarify and remove some limitations of the biological species concept. Simpson attempted to solve the species definition by adding to it the time dimension, which was deficient in biological species concept. According to Mayr (1982) the above definition is related to the phyletic lineage, not indicates a species concept. Reif (1984) and Mayr (1987) had stated that there are many demerits in evolutionary species concept. The main weakness of evolutionary species concept are–– (a) The definition is of a phyletic lineage and not of a species. There is no view as to why phyletic lines do not interbreed with each other. (b) The concept ignores the core of the species problem as to causation and maintenance of discontinuities between contemporary species. (c) This concept has failed to solve the problem of how to deal with the relationship of descendant populations in a single lineage. Ideally evolutionary species concept utilizes morphological, genetic, behavioral and ecological variables. But the problem of an evolutionary definition is that it may be difficult to apply in practice. Thus the growing agreement on the concept of the biological species has resulted in a uniformity of standard and precision that has been beneficial for practical as well as theoretical reasons.

28 NSOU CC - ZO - 03 1.10 Numerical Taxonomy Numerical taxonomy or taximetrics, nowadays frequently and perhaps more appropriately referred to as phenetics, refers to the application of various mathematical procedures to numerically encoded character state data for organisms under study. Thus, it is the analysis of various types of taxonomic data by mathematical or computerized methods and numerical evaluation of similarities or affinities between taxonomic units, which are then arranged into taxa on the basis of their similarities. Contemporary to Linnaeus, Michel Adanson, a French botanist introduced a new system of classification in which he put forwarded a plan for assigning numerical values to the similary between organisms and proposed that equal weightage should be given to all the characters while classifying plants. He used as many characters as possible for the classification and such classifications came to be knwon as Adansonian classifications. Numerical taxonomy was, however, largely developed and popularized by Robert R. Sokal and P.H.A. Sneath (1963). Principles of Numerical Taxonomy Numerical taxonomy involves two aspects : (a) Construction of taxonomic groups : (i) In numerical taxonomy, first individuals are selected and their characters spotted out. There is no limitation to the number of characters to be considered. However, the larger the number of characters, better is the approach for generalization of the taxa. (ii) The resemblances among the individuals are then established on the basis of character analysis, which can often be worked out with the help of computers, the accuracy of which depends on the appropriateness in character. The best way to delimitate taxa is, to utilize maximum number of characters, with similar weightage given to all of them. (b) Discrimination of the taxonomic groups : When the taxonomic groups chosen for the study show overlapping of characters, discrimination should be used to select them. Discrimination analysis can be done by various techniques, specially devised for such purposes. Numerical taxonomy is based on certain principles and following seven principles have been enumerated by Sokal and Sneath. (i) The greater the content of information in texa, and more the characters taken into consideration, the better a given classification system will be.

NSOU CC - ZO - 03 29 (ii) Every character should be given equal weightage in creating new taxa. (iii) The overall similarity between any two entities is a function of the individual similarities in each of the many characters, which are considered for comparison. (iv) Correlation of characters differ in the groups of organisms under study. Thus distinct taxa can be recognized. (v) Phylogenetic conclusions can be drawn from the taxonomic structure of a group and from character correlations, assuming some evolutionary mechanisms and pathways. (vi) The science of taxonomy is viewed and practiced as an empirical science. (vii)Phenetic similarity is the base of classifications. Merits of Numerical Taxonomy : According to Sokal and Sneath, numerical taxonomy has the following advantages over conventional taxonomy : (a) The data of conventional taxonomy is improved by numerical taxonomy as it utilizes better and more of described characters. The data are collected from a veriety of sources, such as morphology, chemistry, physiology, etc. (b) As numerical methods are more sensitive in delimiting taxa, the data obtained can be efficiently used in the construction of better keys and classification systems, creation of maps, descriptions, catalogues, etc. with the help of electronic data processing systems. Numerical taxonomy has, in fact, suggested several fundamental changes in the conventional classification systems. (c) The number of existing biological concepts have been reinterpreted in the light of numerical taxonomy. (d) Numerical taxonomy allows more taxonomic work to be done by less highly skilled workers. Demerits of Numerical Taxonomy : Numerical taxonomy has, however, proved to be disadvantageous from the following points of view : (a) The numerical methods are useful in phenetic classifications and not phylogenetic classifications.

30 NSOU CC - ZO - 03 (b) The proponents of "biological" species concept, may not accept the specific limits bound by these methods. (c) Character selection is the greatest disadvantage in this approach. If characters chosen for comparison are inadequate, the statistical methods may give less satisfactory solution. (d) Different taxonometric procedure may yield different results. A major difficulty is to choose a procedure for the purpose and the number of characters needed in order to obtain satisfactory results by these mechanical aids. It is necessary to ascertain whether a large number of characters would really give satisfactory results than those using a smaller number. In spite of the above demerits this method of classification is still being used by the plant taxonomists, molecular biologistis and others. Computers and numerical taxonomic programmes are now standard resources in every museum and systematics laboratory. One of the very useful software is NTSYS. 1.11 Molecular Taxonomy Molecular taxonomy is the classification of organisms on the basis of the distribution and composition of chemical substance in them. The species can be differentiated on the basis of amino acid sequences in the proteins of an organism and on differences between these as found in different species. Crick (1958) called it 'Protein Taxonomy'. It is also believed that the changes in the enzyme structure can also help in the discovery of new species. Lahni (1964) coined the term 'Molecular Taxonomy' which was primarily based on the nucleotide sequnces of polynucleotides. To measure the degrees of genetic relationship it is important to look for the genetic material they are composed of and here the molecular taxonomy comes into play. Turner (1966) preferred to divide molecular taxonomy into two–– Micromolecular and Macromolecular Taxonomy. The former gives emphasis upon the distribution and biosynthetic interrelationships of small molecular weight compounds such as free amino acids, alkacids, terpenes, flavonoides, etc. These are commonly referred to as secondary compounds. This type of approach is especially useful in resolving some systematic problems where hybridization has been a factor. The latter (macromolecular taxonomy), is concerned with the polymeric molecules. It is more or less close to the core of heridiatry information, i.e. the DNA sequence, RNA, polysaccharides and proteins. This approach is useful for resolving some of the more intractable systematic problems, espeically those involving relationship among higher categories.
NSOU CC - ZO - 03 31 There are many examples where biochemical characters have been found extremely useful in solving taxonomic problems. Basu Chaudhary and Chatterjee (1969) demonstrated phylogenetic relationship among various orders of birds on the basis of the quantitative analysis of ascorbic acid. In some birds (Anseriformes, Columbiformes, etc.) it is produced in the kidney, in some (Piciformes) it is produced in the liver, while in some in both liver and kidney, and in others, in neither. Accordingly they clarified that the ancestral enzyme systems involved occured first in kidney, were somehow transferred to the liver, and in some of the more evolved passerine birds, completely lost. Similarly Brand et al. (1972) established the phylogeny of a group of fire ants using biochemical characters of the highly unique fire ant venoms. Walbank and Waterhouse (1970) corrected the phylogenetic affinities (based earlier on morphological data) of certain genera of Australian cockroaches after analysing their defence secretions. Thus, the present biological approach is definitely helpful in solving many taxonomical problems. But this, too, is not useful in many cases. Such studies are possible only in the existing. organisms and therefore, it is difficult to trace the course of evolutionary history. It cannot lead to definite judgements with regard to the phylogeny of any organism whose fossil records are inadequate or lacking. Most of the molecular or biochemical taxonomic works are based on qualitative and quantitative differences in single chemical constituent of whole organisms or one of their tissues. Like morphological characters, chemical characters are also variable. A proper understanding of the taxonomic relationships of organisms requiers comparison of a number of biochemical characters in combination with one another to reveal the diversity on biochemical patterns rather than on a single biochemical character. Since proteins and nucleic acids provide a much reliable estimate of the degree of genetic homology among animals (Wilson and Kaplan, 1964), comparison of various characteristics of these molecules as such, are more suitable than other constituents for understanding their taxonomic relationships. The distribution of free amino acids in different organs of insects is of greater taxonomic value than their mere presence or absence or concentration in whole animals or in one of their tissues (Seshachar et al.). In mammals, the classification of species, based on amino acid sequences of the peptides, agrees in general with the accepted one based on morphological data (Blomback and Blomback, 1968). In molecular taxonomy, studies are conducted in five ways– immunological, chromatographic, electrophoresis, infra-red spectrophotometry and histochemical

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32 NSOU CC - ZO - 03 studies. More recently the molecular techniques like DNA and protein sequencing, DNA-DNA or DNA-RNA hybridization methods, immunological methods are being used to establish genetic relationship between the members of different taxonomic categories. The data obtained from such studies are used to construct phylogeneic tree Fitch and Margoliash (1967) made first phylogenetic tree based on molecular data. The tree was so close to the already established phylogenetic trees of the vertebrate that the taxonomists realized the significance of molecular data and that made them understand that other traditional methods are although important but molecular evidences could be final or confirmatory evidences. The advent of DNA cloning and sequencing methods have contributed immensely to the development of molecular taxonomy and population genetics over the last two decades. These modern methods have revolutionalised

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the field of molecular taxonomy and population genetics with improved analytical power and precision. [

For further reading one can consult the following Review Article on molecular taxonomy–"Molecular Taxonomy : Use of Modern Methods in the Identification of a Species", by A. K. Singh, Indian J. L. Sci. 2(1) : 143-147, 2012] 1.12 Questions a) Who coined the term taxonomy? b) How many levels of taxonomy are present? c) Distinguish between taxonomy & systematics d) What is the proposed hypothesis of Henig? e) What do you mean by polytypic & Monotypic species? f) What do you mean by type? g) How different types are determined? h) What do you mean by sibling species? i) Define classification j) What do you mean by Laws of Priority? k) In which language naming of animals are made? l) What is the contribution of Linneus in classification? m) Mention the rules of nomenclature
NSOU CC - ZO - 03 33 Unit – 2 ????Subkingdom : Protozoa Structure 2.0 Objective 2.1 Introduction 2.2 General characteristics of protozoa 2.3 Classification 2.4 Euglena 2.5 Amoèba 2.5 1 Nutrition in Amoèba 2.6 Paramoècium & Plasmodium 2.6 1 Reproduction in Paramoècium 2.7 Life cycle of Plasmodium vivax 2.8 Types of human malaria 2.9 Life cycle of Entamoèba histolytica 2.10 Evolution of Symmetry 2.10.1 Segmentation of metazoa 2.11 Questions 2.1 Introduction Protozoa (Gr. protos = first; primitive; zoon = animal) are microscopic, eukaryotic, unicelluler organisms, in which all life activities occur within the limits of a single plasma membrane. The term protozoa was coined by Goldfuss (1818) and unicellular nature of protoza was established by von Siebold (1845). Unicellular eukaryotes are found wherever life exists. They are highly adaptable and easily distributed from place to place. They require moisture, whether they live in marine or freshwater habitats, soil, decaying organic matter, or plants and animals. They may be sessile or free swiming. There are about 8000 species of protozoa certainly belong to Portista. 2.0 Objective By studying this unit learners would be able to know about— To learn the details about protozoan animals & its diversity of protozoa.

34 NSOU CC - ZO - 03 2.2 General Characteristics 1. Protozoa are small, generally microscopic, primitive unicellular animals with eukaryotic organization. 2. Most of them are solitary individuals but a number of them are colonial. 3. They exhibit all types of symmetry. 4. The body is bounded by cell membrane (plasma membrane). Body may be naked or is covered by a pellicle (cytosekleton) or test (exoskeleton). 5. Body shape variable, may be spherical, oval, elongated, flattened or irregular. Size varies from 1.0 μm to 0.25 m (some giant benthic marine amoeba), most being in between 5 and 250μm in diameter. 6. Most protozoa have a single vesicular nucleus (containing considerable nucleoplasm) while a few are multinucleate. 7. Locomotor organelles include cilia (e.g. Paramecuin), flagella (e.g. Euglena) and flowing extensions of the body called pseudopodia (e.g. Amoeba). Some protozoans are sessile (attached or fixed) 8. Nutrition may be holozoic, holophytic saprophytic, mixotrophic or parasitic. 9. Digestion occurs intracellularly within the food vacuole. 10. Respiration generally through body sufrace by diffusion. Some are obligatory or facultative anaerobes. 11. Excretion either through the general body surface or through contractile vacuoles, the later also serves for osmoregulation. 12. Reproduction is asexual or sexual. A sexual reproduction by binary fission, multiple fission and budding or plasmotomy. Sexual reproduction occurs either by conjugation or fusion of gametes (syngamy). 13. Protozoans exploit all types of habitat and may be free-living, commensal, mutualistic or parasitic. Free living protozoans are aquatic. 2.3 Classification Protozoans had been classified differently by various authors like Hyman (1940), Parkar and Haswell (1949), Honiberg et al. (1964) depending upon their size, shape locomotory organs, habit and habitat, etc. But the classification of protozoa, proposed by Levin et al. (1980) is the recent one which was published in the Journal or Protozoology, 27(1) : 37-58. This scheme of classification is widely accepted by modern zoologists. In this scheme they have uplifted the phylum protozoa of previous classification scheme to the rank of subkingdom. Under subkingdom protozoa there are seven phyla.

NSOU CC - ZO - 03 35 Phylum : Sarcomastigophora Phylum : Labyrinthomorpha Phylum : Apicomplexa Phylum : Microspora Phylum : Ascetospora Phylum : Myxozoa Phylum : Ciliophora Classification in outline (up to classes) Subkingdom : Protozoa Phylum 1. Sarcomastigophora Subphylum 1 Mastigophora Class 1 Phytomastigophora Class 2 Zoomastigophora Subphylum 2 Opalinata Class 1 Opalina Subphylum 3 Sarcodina Superclass 1 Rhizopoda Class 1 Lobosea Class 2 Acarpomyxea Class 3 Acrasea Class 4 Eumycetozoea Class 5 Plasmodiophore Class 6 Filosea Class 7 Granuloreticulosea Class 8 Xenophyophorea Superclass 2 Actinopoda Class 1. Acantharea

36 NSOU CC - ZO - 03 Class 2. Polycystinea Class 3. Phaedarea Class 4. Heliozoea Phylum 2. Labyrinthomorpha Class Labyrinthulea Phylum 3. Apicomplexa Class 1. Perkinsea Class 2. Sporozoea Phylum 4. Microspora Class 1. Rudimicrosporea Class 2. Microsporea Phylum 5. Ascetospora Class 1. Stellatosporea Class 2. Paramyxea Phylum 6. Myxozoa Class 1. Myxosporea Class 2. Actinosporea Phylum 7. Ciliophora Class 1. Kinetofragminophorea Class 2. Oligohymenophorea Class 3. Polymenophorea Classification with characters (upto classes) Phylum 1. Sarcomastigophora 1. Locomotory organelles are either flagella or pseudopodia or both. 2. Nucleus is of one type, except in Foraminiferida. 3. No spore formation. 4. Reproduction asexually but when sexually it is by synagamy.

NSOU CC - ZO - 03 37 The phylum includes three subphyla––(i) Mastigophora; (ii) Opalinata; (iii) Sarcodina Subphylum 1. Mastigophora 1. Presence of one on more long slender flagella (sing flagellum) at some or all stages in the life cycle is characteristic of the Mastigophora (Gr. mastix, whip + phoros, bearing). The flagella serve for locomotion and food capture and may be sense receptors. Some posses undulating membrane. 2. The body is usually of definite form—oval, long and spherical–covered by a firm pellicle. 3. Nucleus single. 4. Nutrition autotrophic or heterotrophic or both. 5. Reproduction usually by binary fission sexual reproduction is uncommon. 6. They may be free living, parasitic, solitary or colonial. The subphylum includes two classes–(i) Phytomastigophorea; (ii) Zoomastigophorea Class Phytomastigophorea 1. Presence of chromatophores with typical chloroplasts. 2. Nutrition mostly autotrophic (holophytic) 3. Presence of one or two flagella. 4. Reserve food strach or paramylon 5. Sexual reproduction in some forms. 6. Mostly free living. Examples : Euglena, Volvox, Cryptomonas, Chilomonas, Ochromonas, etc. Class Zoomastigophorea 1. Chromatophores or chlorophil absent. 2. Nutrition heterotrophic (holozoic or saprozoic), Reserve food is glycogen. 3. Presence of one to many flagella. Some possess undulating membrane.

38 NSOU CC - ZO - 03 4. Parasitic, commensal or symbiotic. Examples : Trypanosoma, Giardia, Trichomonas, Trichonympha, Leishmania. Subphylum 2. Opalinata 1. Entire body surface is covered by oblique rows of cilia like organelles. 2. Cytostome or cell mouth absent. Nutrition saprozoic. 3. Two or many monomorphic nuclei. 4. Asexual reproduction by longitudine binary fission. 5. Sexual reproduction involves syngamy. 6. All are parasites or commensals. The subphylum includes a single class-Opalinatea. Class 1. Opalinatea Characters are same as subphylum Opalinata. Examples : Opalina, Zelleriella, Protoopalina Subphylum 3. Sarcodina 1. Locomotory organs are pseudopodia. Flagella when present usually restricted to developmental stages of life cycle. 2. Body mostly amoeboid, naked or with external or internal skeleton or test. 3. Asexual reproduction by fission. 4. Sexual reproduction when present involves syngamy with flagellated (rarely amoeboid) gametes. 5. Most are solitary and free living, a few parasitic. Superclass Rhizopoda Locomotion by pseudopodia (as lobopodia, filopodia or reticulopodia) or by protoplasmic flow without production of discrete pseudodia. The superclass includes 12 classes. Class 1. Lobosea 1. Pseudopodia lobose type (lobopodia).
NSOU CC - ZO - 03 39 2. Usually uninucleate. Examples : Entamoeba, Amoeba, Chaos. Class 2. Acarpomyxea 1. Pseudopodia branched or sometimes reticulate. 2. Uninucleate. 3. No test 4. No spores or fruiting bodies Examples : Leptomyxa, Rhizamoeba, Corallomyxa. Class 3. Acrasea 1. Uninucleate amoeba with eruptive, lobose pseudopodia. 2. Fruiting bodies without stalk tube. 3. Sexuality unknown. Examples : Acrasis. Class 4. Eumycetozoea 1. Pseudopodia filiform type. 2. Flagella when present non mastigonemate. 3. Apical fruiting bodies with stalk tubes. Exampla : Protostelium, Dictyostelium. Class 5. Plasmodiophorea 1. Obligate intracellular parasites with minute plasmodia. 2. Zoospores with nonmastigonemate flagella. 3. Sexuality in some species. Exampla : Plasmodiophora, Sorosphaera. Class 6. Filosea 1. Hyaline, filiform pseudopodia, often branching sometimes anastomosing.
40 NSOU CC - ZO - 03 2. No spores or flagellate stages known. Exampla : Gromia, Nuclearia, Euglypha. Class 7. Granuloreticulosea 1. Delicate, finely granular or hyaline reticulopodia or, rarely, finely pointed, granular but nonanastomosing pseudopodia. 2. Test with single or many chambers. Exampla : Elphidium, Fusulina. Class 8. Xenophyophorea 1. Multinucleate plasmodium enclosed in branched-tube system of organic substance. 2. Fecal pellets retained outside organic tube system as conspicuons dark masses. 3. Marine. Exampla : Psammetta, Stannophyllum. Superclass 2. Actinopoda 1. Usually planktonic (floating) with spherical body and delicate psuedopodia. 2. Skeleton when present composed of organic matter and/or silica or of strontium sulphate. 3. Reproduction asexual and/or sexual. The superclass includes 4 Classes–– Class 1. Acantharea 1. Skeleton is of strontium sulphate and usually composed of 20 radial or 10 diametral spines; sometimes many more spines randomly oriented. 2. Extracellular outer and inner envelopes usually present. 3. All marine. Examples : Acanthocolla, Psuedolithium. Class 2. Polycystinea 1. Skeleton mostly siliceons, made up usually of solid elements.
NSOU CC - ZO - 03 41 2. Capsular membrane composed usually of polygonal plates. 3. Marine planktonic. Examples : Plagonium, Eucoronis, Octodendron Class 3. Phaeodarea 1. Skeleton (sometimes absent) of mixed silica and organic matter, consisting usually of hollow spines and/or shells. 2. Very thick capsular membrane. 3. Marine and planktonic. Examples : Astracantha, Sagospheera. Class 4. Heliozoea 1. Without central capsule. 2. Skeleton (when present) is siliceous or organic. 3. Axopodia radiating on all sides. 4. Most are freshwater, some marine. Examples : Clathrulina, Actinophrys, Gymnosphaera. Phylum 2. Labyrinthomorpha 1. Generally trophic stage with ectoplasmic network and spindle shaped or spheridal nonamoeboid cells. 2. In some genera amoeboid cells move within network by gliding. 3. Unique cell-surface organelle, associated with ectoplasmic network. 4. Most species form zoospores. This phylum includes only one class––Class 1. Labyrinthulea Characters are same as phylum. Examples : Labyrinthula, Thraustochytrium. Phylum 3. Apicomplexa 1. Presence of apical complex which can be seen under electron microscope. 2. Anterior apical complex consisting of polar ring(s), rhoptries, micronemes, conoid and subpellicular microtubles at some stage. 3. Micropore(s) generally present at some stage.

42 NSOU CC - ZO - 03 4. Cilia absent 5. Reproduction generally by syngamy, some reproduce asexually. 6. All are parasitic. This phylum includes two classes–(i) Perkinsea and (ii) Sporozoa Class 1. Perkinsea 1. Conoid forming incomplete cone. 2. "Zoospores" flagellated with anterior vacuole. 3. No sexual reproduction. Example : Perkinsus. Class 2. Sporozoa 1. Conoid, when present, forms complete cone. 2. Locomotion of mature organisms by body flexion, gliding or undulation of longitudinal ridges. Pseudopodia ordinarily absent, if present used for feeding, not locomotion. 3. Flagella present only in microgametes of some groups. 4. Reproduction generally both sexual and asexual. 5. Oocysts generally containing infective sporozoites which result from sporogony. Examples : Monocystis, Gregarina, Plasmodium, Eimeria, Babesia. Phylum 4. Microspora 1. Unicellular spores, each with imperforate wall. 2. Sporoplasm with one or two nuclei. 3. Simple or complex extrusion apparatus always with polar tube and polar cap. 4. Mitochondria absent. 5. Diamorphic in sporulation sequence (often but not usually). 6. Obligatory intracellular parasites in nearly all major animal groups.

NSOU CC - ZO - 03 43 This Phylum includes two classes––(i) Rudimicrosporea and (ii) Microsporea Class 1. Rudimicrosporea 1. Spores with simple (rudimentary) extrusion apparatus consisting of polar cap and thick polar tube. 2. Spore spherical or subspherical. 3. Polaroplast and postorior vacuole absent. 4. Sporulation sequnce with dimorphism. 5. Hyperparasites of gregarines in annelids. Examples : Amphiacantha, Metchnikovella. Class 2. Microsporea 1. Spore with complex extrusion apparatus of Golgi origin, often includes polaroplast and posterior vaculoe in addition to polar tube and polar cap. 2. Polar tube typically filamentous. 3. Spore shape various, spore wall with three layers. 4. Often dimorphic in sporulation sequence. Examples : Nosema, Amblyospora, Encephalitozoon. Phylum Ascetospora 1. Spores are generally multicellar, may be single celled. 2. Sporoplasm may be one or more. 3. Polar capsules and polar filaments are absent. 4. All parasitic. This phylum includes two classes––(i) Stellatosporea, (ii) Paramyxea Class 1. Stellatosporea 1. Spore with one or more sporoplasms. 2. Haplosporosomes present. Examples : Marteilia, Haplosporidium, Urosporidium. Class 2. Paramyxea 1. Spore bicellular, consisting of parietal cell and one sporoplasm. 2. Spore imperforate (without orifice).

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NSOU CC - ZO - 03 45 Example : Paramyxa. Phylum 6. Myxozoa 1. Spores are of multicellar origin, with one or more polar capsules and sporoplasms. 2. Spore membrane with one, two, three or rarely more valves. 3. All are parasitic. This phylum includes two classes––(i) Myxosporea and (ii) Actinosporea. Class 1. Myxosporea 1. Spore with one or two sporoplasms and 1-6 (typically 2) polar capsules. 2. Each capsule with coiled polar filament which function probably anchoring. 3. Spore membrane generally with two valves (occasionally upto six valves). 4. Trophozoite stage well developed. Exampla : Myxidium, Myxobolus. Class 2. Actinosporea 1. Spores with three polar capsules, each enclosing coiled polar filament. 2. Spore membrane with three valves. 3. Several to many sporoplams. 4. Trophozoite stage not well developed. Example : Triactinomyxon. Phylum 7. Ciliophora 1. Simple cilia or compound ciliary organelles are seen at least one stage of life cycle. 2. Subpellicular infraciliature present even when cilia absent. 3. Presence of two types of nuclei with rare exception. 4. Contractile vacuole typically present. 5. Nutrition heterotrophic. 6. Asexual reproduction by transverse binary fission. Budding and multiple fission also occur. 7. Sexual reproduction involves conjugation, autogamy and cytogamy.

46 NSOU CC - ZO - 03 8. Most species are free living, but many are commensal, some truely parasitic and large number found as symphorionts on variety of hosts. This phylum includes three classes––(i) Kinetofragminophorea, (ii) Oligohymenophorea and (iii) Polymenophorea. Class 1. Kinetofragminophorea 1. Cytopharyngeal apparatus commonly prominent. 2. Compound ciliature typically absent. 3. Oral infraciliature only slightly distinct from somatic infraciliature. 4. Cytostome often apical (or subapical) or mid-ventral, on surface of body or at bottom of atrium or vestibulum. Examples : Balantidium, Rasbena, Didinium. Fig. 3 Representatives of Phylum Protozoa Note the variety of forms in the Phylum Protozoa (after Hyman). A. Euglypha. B. Chilomonas. C. Ceratium. D. Zoothamnium. E. Pandonna. F. Saccorhiza. G. Plagiopyla. H.Greganna. I. ivoctiluca. J. Myxidium. K. Sarcocystis. L. Nyctotherus (nor drawn up to scale).

NSOU CC - ZO - 03 47 Class 2. Oligohymenophorea 1. Oral apparatus, at least partially in buccal cavity, generally well defined, although absent in one group. 2. Oral ciliature, clearly distinct from somatic ciliature. 3. Cytostome usually ventral and/or near anterior end. 4. Cysts not uncommon. 5. Colony formation common in some groups. Examples : Paramoecium, Trichodina, Tetrahymena, Vorticella. Class 3. Polymenophorea : Fig. 4 : A few examples of Phylum Protozoa (after various sources). A. Tritrichomonas augusta. B. Macrotnchomonas lighti. C. Arcella vulgans. D. Belphansma latentium. E. Saccinobaculus doroaxostylus. F. Hexamastix termopsidis. G. Monocercomonas verrens. H. Holomastigoloides hemigymnum. I. Didinium sp. J. Chlamydomonas sp. K. Vol- vox colony.

48 NSOU CC - ZO - 03 1. Well developed, conspicuous adoral zone of numerous buccal or peristomial organelles. 2. Somatic ciliature complete or reduced or appearing as cirri. 3. Cytostome at bottom of buccal cavity or infundibulam. 4. Cytoproct or cytopyge often absent. 5. Cysts common in some groups. 6. Often large and commonly free living. Exampla : Nyctotherus, Strombidium, Metopus, Ascobius. 2.4 Englena Systematic Position : Kingdom : Protista/Protoctista Sub-kingdom : Protozoa Phylum : Sarcomastigophora Sub-phylum : Mastigophora Class : Phytomastigophora Genus : Euglena Euglena is a solitary free living (free swimming) freshwater protozoa. It is a phytoflagellate as it possess both chloroplasts as well as flagella. Euglena commonly found in ponds, pools, ditches and slowly-running streams, where there is considerable amount of vegetation. Under favorable environemtal conditions it multiplies rapidly and form green scum on water surface. The most common species of Euglena is Euglena viridis. Structure : Euglena viridis is a small microscopic organism. The body is elongated and spindle-shaped with blunt anterior end and pointed posterior end. It is about 40-60 microns in length and 14-20 microns in breadth at the thickest middle part of the body. From the anterior end arises a whip-like flagellum which is seen moving when the animal is progressing forward. The body shape is maintained by a thin flexible and strong covering membrane or pellicle that is marked spirally by parallel straitions or thicknings. The pellicle is closely followed by a plasma membrane on the inner-side. Within this there lies a thin layer of clear ectoplasm around the main mass of granular non-flowing endoplasm. At the blant anterior end of the body there is a narrow depression–the the gullet or cytopharynx which leads to a permanent flask shaped and non-contractile cavity, the reservior. Its external opeing is called the cell mouth or cytostome.

NSOU CC - ZO - 03 49 The cytostome and cytopharynx are not used for ingestion of food but as a canal for escape of fluid from the, reservoir. A large osmoregulatory body, the contractile vacuole lies closely associated with the reservoir. It is surrounded by several minute accessory vacuoles which probably fuse together to form the larger one. The contractile vacuole discharges the excess water along with some waste products of metabolism into the reservoir from where it goes out through the cytostome. Near the reservoir is a large pigment spot or stigma (Fig. 6). The stigma is red in colour and is composed of small granules of carotenoid pigments embedded in colourless stroma. The stigma is sensitive to light. Fig. 5 : Euglena viridis, note the radiating disposition of its chloroplasts Fig. 6 : Euglena viridis (after various sources). A. Enlarged view of the anterior and, B. Magnified view of flagellum and C. Arrangement of chloroplasts.

50 NSOU CC - ZO - 03 Fig. 7 : Details of the Structures of Flagellum under E.M.

NSOU CC - ZO - 03 51 A long whiplike flagellum emerges out of the cytostome through the cytopharynx. The length of the flagellum differs in different species of Euglena but in Euglena viridis it is almost equal in length of the body. It arises by two roots from the base of the reservoir. Each root arises from a blepharoplast or basal granule which lies embedded in the anterior part of the cytoplasm, just beneath the base of the reservoir. According to some there are two flagella–one short and one long. Each originates separately from two blepharoplasts and the shorter one soon after its origin units with the longer one. The long flagellum is thick and consists of two parts–an inner elastic axial filament, the axoneme, made up of several fibrils and a contractile cytoplasmic sheath surrounding the axoneme (Fig. 7) Euglena has a single, large, spherical and almost centrally placed nucleus. Radiating from the centre of the body there are a number of slender band like chloroplasts containing the green pigment Chlorophyl a, chlorophyl b and β–Carotene. Euglena derives its green colour from these chloroplasts which are arranged in a stellar fashion, like the rays of a star. A special type of animal strach, called paramylum remains scattered in the cytoplasm in the form of grains. Paramylum bodies serve as reserve food for Euglena. Euglena like green plants can synthesise carbohydrate food by photosynthesis. Locomotion : Euglena exhibits following two types of locomotion– (a) Flagellar movement, (b) Euglenoid movement. Flagellar movement : Euglena swims freely in water with the help of a single long flagellum. The actual mechanism involved in flagellar movement is not Fig 8 : Euglena. Path of flagellar movement.

52 NSOU CC - ZO - 03 satisfactorily known and there are varieties of flagellar movements. It has been observed that the flagellum makes a seris of lateral movements and as a result, a pressure is exerted on water at right angles to its surface. This pressure is resolved into two forces, one acting parallel and the other at right angles to the body axis. The parallel force causes the body to rotate while the force acting at right angles drives the animal forward. According to another observation Euglena moves forward by the undulating motion of flagellum. A series of undulating waves pass along the flagellum from base to its tip at the rate of twelve per second that push the animal forward. The flagellar action exerts forces on the surrounding water which is driven away from the stationary animal. The waves proceed along the flagellum in a spiral manner and cause the body of the animal to rotate about its axis, at about one complete body turn per second, as well as make a corkscrew pathway through water (Fig.). The rate of movement is 0.5mm per second, and it is about four times its body length. Euglena is able to change its direction by the action of contractile myonemes. Euglenoid movement : Euglena sometimes shows a very peculiar slow and limited movement, called metaboly or euglenoid movement. Upon a solid substratum, Euglena slowly wriggles like a worm by means of peristalsis. Waves of contraction and expansion sweeping over the body from anterior to posterior end and the animal creeps forward. The contractions are brought about by the localized fibrils called myonemes which are located in the cytoplasm, just beneath the pellicle. Nutrition : The modes of nutrition in Euglena are holophytic and saprozoic. Such a dual mode of nutrition is referred to as mixotrophic. There is no evidence of Fig. 9 : Euglena viridis. Types of locomotion. A. Euglenoid movement (after Buchsbaum). B. Rowing by flagellum.

NSOU CC - ZO - 03 53 animal-like nutrition or holozoic nutrition in Euglena. Like a true plant it assimilates carbon and synthesizes carbolydreates from carbon dioxide and water in presence of sunlight by the process of photosynthesis with the aid of chlorophyll present in the chloroplasts. Nitrogen and other minerals which remain dissolved in water are absorbed by the cell surface. Excess of carbohydrates manufactured is stored as a polysaccharide known as paramylum. In absence of sunlight and at times when the water body becomes polluted with dead or decaying organic matter, Euglena gives up the holophytic mode of nutrition and switches over to saprozoic mode. Dead and decaying matters dissolved in water are digested extracellularly and then they are absorbed through the general body surface of the animal. Some workers have reported that small organisms are forced to enter the reservoir by the movement of flagellum and they are engulfed. Such occurence of hotzoic mode of nutrition is doubtful. Reproduction : Euglena reproduces asexually by longitudinal binary fission and multiple fission. Eucystment also takes place. 1. Longitudinal binary fission : Usual mode of reproduction in Euglena is longitudinal binary fission. During Fig. 10 : Events during longitudinal fission in Euglena (from various sources). A—C. Events at the anterior end. D—G. Formation of two daughter individuals. Note that the individual splits from the anterior end. A. Nucleus comes to the anterior end within which intranuclear body divides into two, each of which splits to form a new blepharoplast and an intranuclear body. From the new blepharoplast develops a new flagellum. Two original blepharoplasts of the flagellum move one on each side of the reservoir. Contractile vacuole divides into two. B. The new flagellum unites with the old. Nucleus descends down and connections between intranuclear bodies and newly formed blepharoplasts persist. C. Nucleus, reservoir and gullet divide longitudinally.

54 NSOU CC - ZO - 03 active periods, under favourable ecological conditions such as food availability, optimum light, temperature and water, Euglena reproduces by this process. The fission is always symmetrogenic, i.e. the resulting daughter cells are exactly identical to one another (mirror image). Before fission locomotory activities are suspended and the flagellum is withdrawn in some cases. The blepharoplast is the first to divide and the two halves remain attached by a spindle-like structure or by a strand. This is followed by eumitotic division of the nucleus. Other anterior organelles flagellum, cytopharynx, reservoir and stigma–are duplicated. The body begins to divide lengthwise, from anterior end downwards to the posterior end resulting in the formmation of two daughter individuals. Regeneration of lost parts occurs immediately after division. Normally each one develops a new flagellum. In some cases the flagellum of the mother is retained by one of the daughters and a new one develops in the other. 2. Multiple fission and palmella stage : Under unfavourable environmental conditions such as lack of food and oxygen, excessive heat or cold, draught, etc. Euglena becomes inactive and throws off its long flagellum and forms a protective thick mucilaginous cyst around it. A number of such encysted euglenae come close together and embeded in a common gelatinous mass on the water surface. Within the cyst,each Euglena divides by repeated longitudinal binary fission giving rise to several daugther individuals (16 or 32). The latter form their own muciligenous coats within the original cyst. Such a gelatinous mass containing many cysts is called palmella stage which resembles the palmella stage of many algae such a chlamydomonas. These are often seen as green scum on ponds.Individual members of the palmella carry on their Fig. 10.1 : Euglena Multiple fission and encystation. A—Encysted individual. B—Fission in encysted condition. C—Palmella stage.

NSOU CC - ZO - 03 55 metabolic activities. When the environmental conditions become favourable these daughter euglenae, acquire normal flagella and escape out from the cyst to grow into normal euglenae and start normal and active life. Encystment : Euglena undergoes encystment during the periods of draught and extreme cold. The animal becomes inactive, withdraws its flagellum and assumes a round shape (Fig.). Gradually profective walls are secreted. The cysts are red in colour due to the presence of a pigment called haematochrome. 2.5 Amoeba Systematic Position : Kingdom : Protista / Protoctista Sub-kingdom : Protozoa Phylum : Sarcomastigophora Sub phylum : Sarcodina Super class : Rhizopoda Class : Lobosea Genus : Amoeba The genera Amoeba was first discovered by Russel von Rosenhoff in 1755. He called it the "little proteus" after the mythological Greek Sea God Proteus who is believed to be capable of changing his shape or form variously. Later in 1962, H.I. Hirschfield has given a full and comprehensive account of the biology of Amoeba. Fig. 10.2 : A. Palmella stage of Euglena. B. Encysted Euglena undergoing division.

56 NSOU CC - ZO - 03 Amoeba proteus is a minute free living protozoa occuring abundantly in the bottom of freswater ponds and other water bodies. They are always found in association with aquatic vegetations. Structure. External structure : The body resemble a tiny mass of irregular jelly and measures about 250 to 600μ (microns) in maximum diameter. To the naked eye, the larger A. proteus is just visible as a whitish blob. Under microscope it appears as an irregular, colourless and translucent mass of protoplasm, continuously changing its shape by sending out and withdrawing finger like processes, called pseudopodea. The outer boundary of the body is a very thin elastic and selectively permeable plasma membrame or plasmalemma. The thickness of plasma membrane may be between 0.5 μm to 2 μm. Recently the existence of a very thin and flexible pellicle covering the plasmalemma has been reported. Plasma membrane retains the inner contents and is permeable to respiratory gases and water. It plays important role in pseudopodia formation and food capture. Internal structure : Inside the plasmamembrane are placed the nucleus and Fig. 11: Amoeba proteus. Note various structures like nucleus, food vacuoles, contractile vacuole and pseudopodia.

NSOU CC - ZO - 03 57 cytoplasm. The nucleus is disc like and slightly biconcave and occupies no fixed position in the endoplams. Cytoplasm is differentiated into ectoplasm and endoplam. The ectoplasm is less extensive, gel in nature and non-granular, though under electron microscope it shows threads and particles. It is most clearly visible at the tip of the pseudopodia where it forms a hyaline cap. Ectoplasm is responsible for maintaining the shape and also protects the inner parts. Endoplasm is the matrix within which different organelles including nucleus remain suspended. The endoplasm exists in two colloidal states. The peripheral viscid part or gel state beneath the ectoplasm is termed plasmagel and the inner fluid part or sol state is termed plasmasol. The plasmagel forms a tube through which flows the plasmasol. Conversion of plasmasol to gel and back is important in the process of pseudopodia formation. Embedded in the endoplam are the following structures : 1. Contractile Vacuole : A single large and transparent contractile vacuole exist in the outer part of the endoplasm near the posterior end of the body. Many tiny vacuoles of water, called accessory vacuoles, appear in the vicinity of main vacuole. The main vacuole is also surrounded by many mitochondria. The main vacuole gradually increases in size, travel to the surface and ultimately bursts to release its contents in the surrounding water and disappears. A new contractile vacuole is formed again. Contractile vacuole is involved in osmoregulation, respiration and excretion. 2. Food Vacuole : One or more spherical non-contractile food vacuoles containing food particles and water are present at different phases of digestion. 3. Water Vacuole or globule : These are several small, spherical, non-contractile vacuoles filled with colourless fluid. They control the water balance of the body. 4. Stored Food : Numerous granules of stored food (fats and carbohydrates) are present. 5. Mitochondria : These are present in the form of rods or more or less oval shape with tubular cristae. 6. Crystals : Crystals of different sizes and shapes are seen within the body. These are probably metabolic wastes. Locomotion : Amoeba exhibits characteristic amoeboid movement by the formation of temporary finger-like projections of the body, the pseudopodia or false feet (G. pseudo = false; podium = food). Since pseudopodia of Amoeba are broad with
58 NSOU CC - ZO - 03 Fig. 12 : Figures illustrating the idea of Mast about the cytoplasmic flow during the formation of a pseudopodium in Amoeba proteus (after Kudo). Note that during the formation of a pseudopodium a hyaline cap appears. A. The plasmagel beneath the cap dissolves and plasmasol rushes through the gap. B. The plasmagel may persist as a thin layer. C. Break only at certain points. D. Dissolve completely. Fig. 13: Amoeboid movement on the basis of Allen's fountain zone contraction theory. Fig. 14 : Conversion of sol and gel in Amoeba. Large solid arrow indicates the direction of movement.
NSOU CC - ZO - 03 59 rounded or blunt tips like fingers (G. lobo = a lobe), they are called lobopodia which bear a distinctly clear ectoplasmic area, called the hyaline cap near each tip. Amoeba use their pseudopodia to move and to feed. During locomotion in Amoeba proteus one or more pseudopodia are formed at a time but only one grows, becomes larger and points in the direction of movement and others are gradually withdrawn. In contrast to flagellar or ciliary movements of protozoa, amoeboid movement has additional complexities invilving streaming movement of protoplasm which result in change in the shape and position of the amoeba along with an non-linear and irregular movement (the amoeboid movement). Starting from the latter half of the nineteenth century to the middle of part of the twentieth century, several theories or hypotheses, have been proposed to explain the mechanism of amoeboid movement. Most of the theories have been discarded today due to lack of proper evidences. However Change of Viscocity Theory or Sol-Gel Theory, first put forwarded by Hyman (1917) and later supported by Pantin (1923-1926) and Mast (1925), is the most accepted theory of psuedopodia formation. Most observed the reversible changes of protoplasm in amoeba from Sol (abridged form of solution) and more precisely plasmasol to gel (abridged form of gelation) and more precisely plasmagel. Mast then proposed that amoeboid movement is brought about by four processes occuring simultaneously : (i) The outermost thin elastic cell membrane or plasmalemma becomes attached to the substratum. (ii) A local and partial liquefaction of the plasmagel occurs at a point. This causes the central plasmasol, under tension, to flow forward and force the plasmagel against this weakened area to produce a bulge, the beginning of the psuedopodium. The pressure comes from osmotic and other forces. As plasmasol enters the newly formed pseudopodium, it rapidly changes into plasmagel around the periphery, thus forming a gelatinzed tube within which the plasmagel continues to flow forward. (iii) At the posterior side gel or plasmagel is converted to plasmasol, so that a constant flow of plasmasol is maintained from behid forwards, in the direction of movement. (iv) The outer tube of elastic plasmagel contracts at the posterior end to drive the plasmasol forward. As the plasmasol changes into plasmagel at the anterior end the plasmagel tube extends forward. The plasmagel thus exerts a squeezing motion from the sides and rear of amoeba, forcing the plasmalsol ahead. A thin plasmagel

60 NSOU CC - ZO - 03 sheet persists in between the plasmalemma and plasmasol to prevent the plasmalsol reaching the plasmalemma through the hyaline cap. Sometimes this sheet breaks so that plasmasol streams through filling the hyaline cap, but soon the plasmasol gelates to form a new plasmagel sheet. Pseudopodia are formed because the plasmagel is elastic and under tension, it is pushed out where the elastic strength is lowest. During locomotion of amoeba the elastic strength of plasmagel is the highest at the sides, intermediate at the posterior end, and lowest at the anterior end. This results in the forward extension of the anterior end of the animal to bring about locomotion by psuedopodia. Molecular basis of pseudopodia formation : Though sol-gel theory proposed by Mast (1925) was accepted by many as a probable mechanism of a amoeboid movement but Mast himself could not explain the molecular basis of sol-gel reversion. He could not because molucular biology was little known at that time. Molecular folding and unfolding theory propsed by Goldacre and Lorch (1950) provided a strong support to sol-gel theory and they have

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explained the molecular basis of solation and gelation. They propsed that the forces generated by the folding and unfolding of protein molecules

are responsible for formation of psuedopodia and amoeboid movement. According to them all proteins gelate when their molecules unfold and solate when their molecules fold again.

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In otherwords, the sol state of protoplams is due to the folding of protein molecules and gel state is due to their unfolding.

In the fluid endoplasm the protein molecules lie folded compactly i.e. remained at solution or sol state. At the tip of the advancing psuedopodium the protein molecules unfold i.e. they gelate to form a straightened and attached molcules. In the posterior part the protein molecules begin to fold again. This folding of protein molecules impart a contraction force. This contraction of force is confined towards the posterior end and forces the contracted protein molecules towards the anterior side. As amoeba moves, the plasmagel contracts at the posterior end, it changes into plasmasol (due to protein folding) which is forced through the central endoplasm to flow forward, and by gelation (due to protein unfolding) it forms the psuedopodium anteriorly. By analogy the psuedopodia formation can be compared with the squeezing of a tube of tooth paste to push out the paste. This squeezing can be compared with folding of the protein molecules to generate force which drives the paste (here plasmasol) to the front end where it forces out as a column of paste (here pseudopodium). For folding and unfolding of proteins a considerable amount of energy is requiered and it comes from ATP (adenosine triphosphate).
NSOU CC - ZO - 03 61 Fig. 15 : Diagrams showing the mechanism of pseudopod formation on the basis of Osmotic theory of amoeboid flow. A-A 1 . Chemical signals attach to the receptors and initiate the depolymerization of the actin molecules. B-C. Osmotic concentration in the ectoplasm increases and water nows toward the periphery. Formation of pseudopodium due to the inflow of water (alter Ruppert and Bames). Fig. 16 : Hypothesized mechanism of pseudopod formation during amoeboid locomotion. (a) Localized breakdown of the actin network increases osmotic concentration in that part of the cytoplasm. (b) Fluid from the interior of the cell moves toward the periphery. along the osmotic gradient, forming a pseudopod 9c),. (d) Actin repolymerized, reforming a stablizing network of filaments. From T. P. Stossel, "how Cells Crowl" American Scientist, 78:408-23, 1990. © American Scientist, Reprinted by permission.

62 NSOU CC - ZO - 03 This theory appears to be satisfactory. In higher animals ATP supplies energy for muscle contraction. In this respect mechanism of pseudopodia formation and muscle contractions are to some extent similar. Quite recently, role of polymerization of action subunits (G-action) into action microfilaments (F-action) and vice-verse have been established for folding-unfolding or sol-gel theory (Karp, 1996). View of Ruppert and Barnes (1994) on amoeboid movement : "The theories of amoeboid movement accepted by most zoologists at present assume that cytoplasmic flow is related to the changes between the sol and gel states of the peripheral cytoplasm. The pseudopodial tip controls the change. As a result of some initial stimulus, the outer gelled ectoplasm become fluid at the, site where the pseudopod will form, and internal pressure causes the inner fluid endoplasm to flow out at this point, forming a pseudopodium. In the interior of the pseudopodium, the endoplasm flows forward along the line of progression. Around the periphery, endoplasm is converted to ectoplasm, thus building up and extending the sides of the pseudopodium like a well-starched sleeve. In the conversion of endoplasm to ectoplasm actin subunits polymerize (become longer) and bond to each other at more or less right angles, creating a mesh of filaments. It is this mesh that accounts for the rigid gelatinous state of ectoplasm. The small mesh size excludes organelles and thus accounts for the hyaline appearance. At the posterior end of the body, ectoplasm is converted to endoplasm by depolymerization. Cell membrane is also removed here, and new cell membrane is added at the psuedopodial tip. The force for flow could be generated in one of the two ways. Bonding of myosin with the actin mesh could convert the mesh into a contractile jacket, Fig. 17 : Molecular folding-unfolding during solation and gelation of cytoplasm for amoeboid movement.
NSOU CC - ZO - 03 63 forcing the fluid interior endoplasm forward. However, myosin has been different to demonstrate in ectoplasm. Alternatively, the initial depolymerization of the actin mesh at the pseudopodial tip would increase the number of particles (actin subunits), (Fig.). Particle increase would raise the osmotic concentration and would flow from the endoplasm out into the tip." [Invertebrate Zoology, E.E.Ruppert and R.D. Barnes (1994) Sixth Edition, pages. 42-44.] View of J. A. Pechenixk (2000) on amoeboid movement : "Amoebozoans use their psuedopodia to move and to feed. Typically, they flow into the advancing pseudopodium, a process called cytoplasmic streaming. The amoebozoan body is thus truely formless, lacking permanent anterior, posterior or lateral surfaces; pseudopodia can generally form at particularly any point on the body surface.The mechanism by which pseudopodia form and change shape is not certain, although it seems clear that movement involves a controlled transition of cytoplasm between the gelatinous, ectoplasmic form (gel) and the more fluid endoplasmic form (sol). The factors co-ordinating this transformation in different parts of the body are not fully understood, although the hypotheses have become Fig. 18a: Changes in the nuclear apparatus during the binary fission of Amoeba. Fig. 18b: Morphological changes in Amoeba proteus during binary fission. A. In prophase. B. & C. In metaphase, D. In late anaphase, E. In telophase.
64 NSOU CC - ZO - 03 wonderfully complex during the past decade. The transformation may involve the interaction of actin and myosin molecules, both abundant in amoeba cytoplasm. A model of sliding actin filaments has been proposed, in which actin and myosin interact in a way that resembles their interaction in the muscle tissue of multicellular animals. Other hypotheses minimise the role of myosin in the gel-sol-gel transitions and instead emphasize the potential role of selective actin polymerization and depolymerization. In one model (Fig. 16), localized actin disassembly creates and area of increased osmotic pressure, which draws water from the more central region of the body to the periphery, forming a psuedopod. The actin is then repolymerized to form a bracing network, fixing the pseudopod's shape until the next bout of depolymerization. Whatever the mechanism, psuedopodial locomation is extremely slow, usually less than 300μm per minute." [Biology of the Invertebrates, Jan A. Pechenik (2000) Fourth Edition, pages. 53-54.] Reproduction : Amoeba proteus reproduces by asexual reproduction which takes place only by binary fission (Green et al. 1990). Other species of Amoeba, however, reproduce asexually by multiple fission, sporulation and cyst formation in addition to the common binary fission. Amoeba does not reproduce sexually by mating i.e. by the fusion of gametes. 1. Binary fission : Binary fission is the most common mode of reproduction. Amoeba undergoes binary fission during favourable conditions of food and temperature. It results in the division of parent amoeba into two daughter amoebae. Binary fission is triggered either by the surface area to volume ratio, and/or the ratio between cytoplasmic volume and nuclear volume. Thus, when amoeba attains a maximum size i.e. 0.25 mm, it starts to reproduce. Just prior to binary fission amoeba becomes sluggish and spherical with its surface covered with small radially arranged pseudopodia. Contractile vacuole ceases to function and disappears. The division involves the nuclear division is eumitotic type, i.e. there is distinct chromosome formation but the presence of 500 to 600 chromosomes make the mitotic picture obscure.

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It has been shown that there is a definite correlation between the stages of nuclear division and external morphological changes (Fig. 18). During prophase the animal become round, studded with fine pseudopodia and in reflected light a well-defined hyaline area

is seen at the cente. The hyaline area disappears in metaphase. The metaphase is marked by the arrangement of the chromosomes at the equator. During anaphase the psuedopodia become larger and irregilar in shape. The daughter chromosomes

NSOU CC - ZO - 03 65 separate and move towards opposite poles. The nucleus first becomes dumbel shaped by a middle constriction and finally divides into two daughter nuclei. In telophase the body elongates, cleave furrow appears in the middle and finally divides into two daughter amoebae, each having a daughter nucleus. Gradually the pseudopodia return to normal structure. Under ideal conditions the whole process of binary fission can be completed within 30 minutes. Each daughter amoeba then proceeds to feed and grwo to maximum size. 2. Eucystment : Encystment in Amoeba proteus has not yet been reported, though it is a very common feature in other amoeba. In Amoeba encystment occurs for survival under unfavourable conditions, i.e. to tide over draught and extreme temperatures (extreme hot or cold). During encystment pseudopodia are withdrawn and the body becomes round. The food vacuoles are absorbed and the contractile vacuole disappears. The cytoplasm secretes a double- walled resist envelope arount the body. The cyst is a resting stage with exteremely slow metabolism. On return to favourable conditions, excystment occurs. Cyst breaks and the amoeba emerges out to lead an active life. Fig. 19 : Encystment in Amoeba (after winchester). Although very common in other Amoebae. It rarely occurs in Amoeba proteus.

66 NSOU CC - ZO - 03 Now it is clear that the cyst in amoeba is protective in nature and not reproductive. Evidence in favour of amoeba undergoing nuclear division in encysted condition are rare. It is to be noted that one amoeba comes out of one cyst. 2.5.1 Nutrition in Amoeba Amoeba is entirely heterotropic (the nutrition is holozoic). The food of Amoeba consists of algal cells and filaments, bacteria, other protozoans (smaller flagellates and ciliates), even smaller animals like rotifers and nematodes. The nutrition of Amoeba involves the following activities– 1. Ingestion : Amoeba lacks a mouth and food is ingested at any point of the body surface, but it is usually at the advancing anterior end. Food is captured by pseudopodia usually by the formation of a food cup. Ingested food along with some water occupies a vesicle, called food vacuole. According to the nature of food Amoeba empolys the following five methods of ingestion (Rhumbler 1930). (i) Circumvallation : When an amoeba comes near an actively moving prey like a flagellate or ciliate, the bdoy part immediately in line with it stops moving and pseudopodia are formed above, below and on the sides of the food to form a food cup. The food cup does not touch the food but soon the edges of food cup fuse around the food to form a non-contractile food vacuole with some water within (Fig. 22). (ii) Circumfluence : When amoeba comes in contract with a less active or motionless organism like bacteria, the whole cytoplasm of amoeba flows around the food, encircling it into a food cup. Here the enveloping pseudopodia always maintain intimate contact with the surface of the prey. (iii) Import : In Amoeba verucosa the food like algal filament when comes in contact of the animal passively sinks into the body just as a solid body sinks in a swamp (Fig. 20). (iv) Invagination : In this method the prey is adhered by the toxic and sticky secretion of psuedopodia of amoeba (Amoeba verrucosa) and the plasma membrane invaginates at the point of contact forms an endoplasmic tube and the food is finally enclosed into a food vacuole. (v) Pinocytosis : Pinocytosis (cell drinking) is the process of ingestion of liquid food material in bulk by the plasmamembrane. The process of pinocytosis was first observed by Mast and Doyle (1934) in Amoeba proteus. It is understood that plasmalemma along with colloidal food mateirla forms pinocytosis channels which run from surface deep into the endoplasm.

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68 NSOU CC - ZO - 03 The internal ends of the channels then form pinocytosis vesicle or pinosomes containing engulfed liquid food. The pinosomes then pinch off from the internal ends of pinocytic channels and sink into the endoplasm. It is yet to be confirmed whether pinocytosis is a normal means of ingestion in Amoeba. 2. Digestion : Digestion takes place in the food vacuole by the help of lysosomal enzymes. The food vacuoles are analogous to the alimentary canal of higher animals except that digestion in food vacuoles is intracellular and that in alimentary canal is extracellular. Lysosomes containing digestive enzymes fuse with the food vacuoles and digestion of ingested food starts slowly. The presence of some enzymes such as proteases, amylases and lipases have been demostrated in Amoeba. 3. Absorption and assimilation : As digestion goes on, the food vacuoles gradually shrink in size. The food vacuoles keep on moving in the cytoplasm due to its streaming movement, called cyclosis. The digested simple food, water and minerals are absorbed by the surrounding endoplasm by simple process of diffusion and immediately get assimilated to build new protoplasm. Excess of digested food is stored as glycogen and lipid. Each food vacuole exists in cytoplasm for about 15 to 30 hours to complete digestion and assimilation. 24 25 :

NSOU CC - ZO - 03 69 4. Egestion : Egestion of undigested residue takes place at any point on the surface of the body. After its food contents are completely digested, a vacuole falls out of cyclosis and becomes stationary. It is simply left behind as the advancing body flows forwards (Fig. 27). As the plasma membrane of the temporary posterior end touches such a vacuole containing undigested food residue, it suddenly ruptures. Vacuolar membrane also simustaeously ruptures to allow exit of the vacuolar contents. There after, the plasmamembrane immediatly heals up to prevent any loss of cytoplasm. 2.6 Paramoecium & Plasmodium Paramecium Systematic Position : Kingdom : Protista/Protoctista Sub-kingdom : Protozoa Phylum : Ciliophora Class : Oligohymenophorea Genus : Paramecium Paramecium is a typical and well know ciliate protozoa. Ciliates are characterzed by the presence of cilia as locomotor organelle, nuclear dimorphism and a unique type of sexual reproduction called conjugation. The two type of nuclei are morphologically and physiologically distinct from one another. Paramecium is found in stagnant water of ponds, ditches, pools, reservoirs, rivers, streams rich in organic matter. They are free living and omnivorous in habitat. They can be cultured in laboratory in hay infusions. Common species of Paramecium are P.caudatum and P.aurelia. The species described here is Paramecium caudatum. Structure : Size and shape : Paramecium caudatum is a microscopic organism and is visible to the naked Fig. 26: Amoeba chasing food. Note constant formation of pseudopodia towards the direction of the food.

70 NSOU CC - ZO - 03 eye as a minute elongated body. It appears light grey or white measuring between 170 to 290 nm in length. Its body is somewhat elongated, slipperlike in shape, hence the animal is called slipper animalcule. One end of the body is slender but rounded or blunt representing the heel of the slipper. It is anterior end as it remains foremost during locomotion. The other end is broad and pointed, representing the top of the slipper. It is posterior end. The body is asymmetrical exhibiting a well defined oral or ventral surface and aboral or dorsal surface. The flattened ventral surface is with a oral grove that always faces the substratum. The opposite aboral or dorsal surface is somewhat convex. Cellular body of Paramoecium has the following structures : 1. Pellicle : The whole body is covered by a thin, firm and flexible membrane, the pellicle. It gives the definite shape to the organism. The pellicle is sculptured into a large number of polygonal or hexagonal depressions with their raised margins (Fig. 28). The depressions are provided with holes at the centre through which the cilia project. The anterior and posterior margins of the hexagonal depressions bear the openings of trichocysts which are small spindle shaped bodies. The electron microscopic study of pellicle by Ehret and Powers (1957) and Pitelka (1965) have revealed that the hexagonal depressions correspond to regular series of cavities, the alveoli. All alveoli collectively form a continuous aloveolar layer, which is delimited by an outer and an inner alveolar membranes. The outer alveolar layer is covered by

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plasma membrane which is continuous with the membrane surrounding the cilia.

Thus pellicle includes outer cell membrane, outer alveolar membrane and inner alveolar membrane. Å Cilia. Entire body surface of Paramecium is covered with numerous (10- 14 thousands) tiny (10-12 μm in length and 0.27μm in diameter), hair like projections of cytoplasm, called cilia (singular cilium). This condition of covering whole body by cilia is called holotrichous. Cilia are arranged in longitudinal rows and all are Fig. 27. Amoeba showing stages of egestion of undigested food.

NSOU CC - ZO - 03 71 Fig. 26: Paramecium caudatum. (Structure).

72 NSOU CC - ZO - 03 equal size except a few at the posterior extremity which are larger and constitute the caudal tuft. In Paramecium

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the ciliature may also be diveded into body ciliature which occures over the general body surface and the oral ciliature, which is associated with the

oral grove. The latter includes the larger cilia (Fig. 29). Each cilium consists of two parts–(i) a basal body or kinetosome which lies embedded in the ectoplasm and (ii) a shaft, short thread like structure lies above the pellicle. The basal body is a compact spherical body and homologous with the centriole. The electron micrograph (Fig. 29) of cross section of a cilium exhibits three majorparts : a central axoneme, the surrounding plasma membrane and the interposed cytoplasmic matrix. The entire ciliary projection is covered by a membrane that is contimuous with the outer plasma membrane. The core or shaft of the cilium, called axoneme, consists of an array of microtubules (sometimes called fibrils) that run longitudinally through the entire organelle. Axoneme has nine peripheral doublet microtubules Fig. 29: A. Ultrastructure of a cilium (flagellum). B. Cross-sectional view of a shaft. C. cross-sectional view of the basal body. B. Note that the peripheral fibrils (tubules or microtubules) are doublets and each A tubule is complete and smaller and B tobule is incomplete and larger, A tubule has dynein arm. C. Note that the central tubules (microtubules) and dynein arms are absent. Peripheral tubules of a basal body are triplets.
NSOU CC - ZO - 03 73 or doublets, surrounding a central pair of single microtubules or singlets (i.e. typical 9 + 2 arrangement of microtubeles). The microtubules extend continuously throughout the length of the axoneme. The diameter of the axoneme is 0.02μm. The nine peripheral microtubles or fibrils are radially arranged at a distance of 200? from each other. All the microtubules of the axonemes are composed of a globular protein, called tubulin. The inner micro tubule of each doublet is called A tubule and the outer micro tubule is called B tubule of which A is small and complete and B is comparatively larger and incomplete. A tubule contains 13 protofilaments or subunits while B tubule has 10-11. The protofilaments are called tubulin subunits. Nine radially arranged spokes originate from each A tubule of the peripheral doublets and extend towards the central sheath. Extending from each A tubule are two dynein arms– an outer arm and an inner arm that are oriented in the same direction in all peripheral doublets, i.e. clockwise direction (when the axoneme is viewed from base to tip) towards the B tubule of the neighbouring doublet. Since dynein protein is capable of hydrolysing ATP, it acts as an ATP ase enzyme. The peripheral doublets are connected by an inter doublet bridge, called nexin links, composed of an eleastic protein, nexin. The central two singlet microtubules are called C 1 and C 2 in which dynein arms and radial spokes are absent (Fig. 29). Cytoplasm Beneath the pellicle the protoplasm is differentiated into cortex and medulla. The cortex or ectoplasm is clear, non-granular, less extensive and contains many spindle shaped bodies called trichocysts. The medulla or endoplasm is granular, semi-fluid and bears nuclear apparatus, contractile vacuoles, food vacuoles, various organelles (Golgi bodies, mitochondria, ribosomes, etc.) Following organelles or systems are found in Paramoecium: 1. Infraciliary System : The infraciliary system consists of basal bodies. (Kinetosomes) of cilia and Kinetodesmata, all located just beneath the alveoli of pellicle. (i) Basal bodies or Kinetosomes : The base of each cilium is connected with a spherical basal body or kinetosome lying embedded in the ectoplasm and from which each cilium originates. Structure of the basal body is comparable to the centriole. (ii) Kinetodesmata (Kinetodesma) : A single fine fibril, called Kinetodesmos or Kinetodesmal fibril, arises from each kinetosome and extendes for a distance anteriorly to its right side (Fig. 30). It joins other fibrils from

74 NSOU CC - ZO - 03 adjacent Kinetosomes to form a longitudinal bundle of striated fibrils, called a Kinetodesmata. The individual fibrils do not run anteriorly farther than the five basal bodies or Kinetosomes. Thus the number of fibrils in each Kinetodesmata remains five. A longitudinal row of kinestosomes with their kinetodesma forms a collective longitudinal unit called a Kinety. All the kineties or kinetia together form infraciliary system of a ciliate. It was supposed that the infraciliary system co-ordinates the beat of cilia but the role of this system has not yet been conclusively demonstrated (Naitoh and Eckert, 1969). Infraciliature is also a tool by which the taxonomists used to distinguish the different ciliate species and the degree of differences on which the relationship is established. 2. Neuromotor system : Lund (1933) reported that some other types of fibrils remain connected to the Kinetosomes or basal bodies called neuronemes or myonemes. These are highly contractile and play the role in the movement of cilia. He also reported another dense bilobed mass of fibrils situated on the wall of the cytopharynx, called the motorium or neuromotorium. The Kinetosomes, neuronemes and motorium constitute the neuromotor system. The motorium has branches which interconnect with the fibrils of the ectoplasm and the whole fibrillar system is believed to act as controlling centre for feeding movement of oral cilia. 3. Trichocysts : Trichocysts are minute spindle shaped or bottle shaped bodies embedded in the toplasm. They alternate with basal bodies and are perpendicular to the surface of body. They open to the outside through the permanent pores existing in the ridges of hexagonal depressions of pellicle. The length of trichocyst Fig. 30: Paramecium. Electron microscopic structure of pellicle, infraciliary system and associated structure.
NSOU CC - ZO - 03 75 is about 8μm and the breadth is 2μm. It consists of a spindle or an oval shaped shaft and a terminal conical barb or spike covered with a cap. The shaft is not found at the undischarged state and probably polymerised in the process of discharge. The trichocysts are filled with homogeneous, refractive and semi-fluid substances with a fibrous protein, called trichinin and calmodulin. Upon stimulation, the ectoplasm suddenly contracts. This separates the cap of the trichocyst to let the water enter the sac and the protein of the shaft unfolds, the trichocysts themselves are expelled out of the body as a fine 40μm long striated thread like shaft having pointed sticky spike (Fig. 31). Once discharged trichocysts can not be withdrawn, they are replaced by new ones. The function of trichocysts is not clearly known. It is be lieved that these are organelles of defence. They also serve as a means of anchorage during feeding. The secreted substance may act as adhesive and helps to anchor the animal to the substratum (Cloyd and Jones, 1951). 4. Oral apparatus : Near the anterior end of the animal and on its ventral surface is a permanent ciliated broad and shallow longitudinal groove called the oral groove or peristome. The oral grove runs obliquely backward into a funnel- like depression, called the vestibule. The vestibule leads into a tubular passage, Fig. 31a: Various structures of paramoecium (modified from various sources). A. A highly magnified view of pellicle. B. A discharged trichocyst. C. The fibrillar system around cytopharynx. D. Transverse section through the cytopharynx.
76 NSOU CC - ZO - 03 the buccal cavity. The buccal cavity extends backwards and ends in a small oval aperture, the cytostome or mouth. The cytostome opens into a wide funnel shaped depression called gullet or cytopharynx, that forms a food vacuole at its proximal end. There exists a minute pore at a fixed point on the right side of the body between the posterior end of oral grove and posterior end of the body. It is called cytopyge or cytoproct. Undigested food is egested through it by active vacuolar activity (called exocytosis). In the oral groove the cilia show a variation in size and form. The cilia in the buccal cavity are fused to form a crescentic undulating membrane or endoral

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membrane which runs transversely along the right wall and marks the junction of the vestibule and buccal cavity.

There are three membranelles in the left wall of the buccal cavity (Fig. 33). Each membranelle is formed by adheraing four rows of cilia. These membranelles are of three types : a dorsal peniculus, a ventral peniculus and quadrulus. Ventral peniculus is short and ends at the cytosome. The dorsal wall (roof) of the buccal cavity, crosses over to the right wall near the cytostome. 5. Nuclear apparatus : The endoplasm bears at the centre the nuclear apparatus consisting of a large kidney-shaped mega or macronuclues and a small rounded micronucleus. Both the nuclei differ from each other not only in size and shape but also in function. The macronucleus, also called somatic or vegetative nucleus is polyploid and controls the metabolic Fig. 32b : Paramecium. A—An undischaged trichocyst. A—Apical portion of a discharged trichocyst 33:

NSOU CC - ZO - 03 77 activities of the cell. It is also concerned with the synthesis of RNA and DNA. The micronucleus, also called reproductive nucleus is diploid and controls the reproductive activities of the animal and gives rise to new micronuclei. It possesses a definite nuclear membrane and definite number of chromosomes. Contractile vacuole : There are two star-shaped fixed contractile vacuoles in between ectoplasm and endoplasm close to dorsal surface, one

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at the anterior end and the other at the posterior end of the body (

Fig. 33). Each vacuole consists of a large central vacuole which opens to the outside through a discharge canal in the pellicle on the dorsal side. Each vacuole is surrounded by 6 to 10 long and narrow radial or feeder canals. Each radial canal consists of three parts, a proximal injector canal which opens into the contractile vacuole, a middle ampula which is an inflated part and a terminal part of the radial canal. It is extended into the endoplasm and a network of minute tubules, called nephridial tubules or spongiome tubules (Rupprt and Barnes, 1994), are associated with the terminal part (Fig. 34). These tubules collect water from the surrounding cytoplasm and Fig. 33 : Paramecium. Contractile Fig. 34: Paramecium. Radial canal. A—Empty (systole); B—Full (diastole).
78 NSOU CC - ZO - 03 transfer it to the terminal part or collecting tubule. Endoplsmic reticulum and mitochondria are also found around the spongiome tubules. The function of contractile vacuole is osmoregulation and excretion. Food vacuole. Within the endoplasm a number of food vacuoles, with food particles at different stages of digestion, are seen. Food vacuoles move or circulate within the endoplasm by streaming movement of the endoplasm. Locomotion : Movement of animals from one place to another is locomotion. The locomotory organelles of Paramecium are cilia. Paramecium exhibits two types of movement––(i) Swimming or ciliary movement and (ii) Creeping movement or Metaboly. Swimming or ciliary movement : Paramecium can swim forwards and backwards by rhythmic beating of cilia. The cilia may be compared with the oars of a rowing boat. The cilia of a progressing Paramecium bend throughout its length and strike the water. Backward bending and beating of cilia in a synchronised way drive the animal forward. The backward movement of cilia is called effective stroke. The beating of cilia may be compared with the oscillation of a pendulum. Each oscillation consists of two strokes–(i) the effective stroke in which the shaft of the cilia become stiffened or rigid and slightly curved to strike the surrounding water like an oar. As a result of the effective stroke the animal drives forward, and (ii) recovery stroke in which there is no movement of the animal. In its recovery stroke the cilium becomes Fig. 35: Co-ordinated beating of cilla in a part of the body of Paramoecium. B. Course of progress of Paramoecium during locomotion. Note that the body rotates on its own axis during the forward movement.
NSOU CC - ZO - 03 79 flexible, offering relatively little resistance to the medium and returns to its original position. It now becomes ready for its next effective stroke. Paramecium swims at a rate of about 1mm per second. The direction of the effective stroke is oblique to the ling axis of the body of the animal. This causes the animal to swim in a spiral course and at the same time to rotate on its lingitudinal axis (Fig. 35). In Paramecium, cilia do not beat simultaneously, rather group of cilia bend in a coordinated unidirectional waves. The movement of adjacent cilia occur as a result of interference effect of the surrouding water layers. Thus, the hydrodynamic forces impose a co-ordination on the cilia. This coordinated sequential activation of cilia over the surface of the animal body is seen as a wave, called metachronal waves or metachronal rhythm (Fig. 36 & 37). The ciliary beat can be reversed and the animal can move backward. There is evidence that infraciliature and cytoplasm play a major role in the organised movement of cilia. The direction and intensity of beating of cilia are controlled by changing level of Ca ++ and K + ions. The synchronised movement of cilia is also controlled by the neuronema or neuromotor system in the body. Fig. 36 : Paramecium. Two stages of cciliary movement. A —Effective or power stroke; B—Recovery stroke 37:

80 NSOU CC - ZO - 03 Creeping movement : During creeping movement, the animal uses its cilia of the oral surface as minature legs and simply glides over the obstacles. As the pellicle is thin and elastic, the animal can easily bend and squeeze through gaps narrower than its own body diameter. After this its body assumes normal shape. Such a temporary change in body shape is called metaboly. It is brought about by the myonemes. Nutrition : Paramecium is typically a holozoic animal because it engulf's or ingests the solid food materials. It is an omnivorous or microbivorous animal and it feeds on a variety of microscopic biological materials such as bactria, algae, diatoms yeasts, small protozaoans and tiny fragments of large-sized animals and plants. Feeding mechanism : Food is ingested through cytostome. The cilia lining the oral groove perform a great role in capturing food particles. A current of water in the form of a vortex is produced by the constant and co-ordinated beating or lashing movement of the cilia of oral groove. Due to this the food particles are swept towards the cyclostome and are carried down into the cytopharynx. These food particles are aggregated into a rounded mass (ball) by the movement of penniculi and quadrulus at the bottom of the gullet. These food balls or bolus, along with some water, pass through cytostome to form food vacuoles in the endoplasm. 38 : 39 :

NSOU CC - ZO - 03 81 The formation of food vacuole is a continuous process. As soon as one food vacuole detaches from the gullet another starts forming. The food vacuoles circulate in a definite pathway. They first travel to the posterior end and then take a turn and travel anteriourly. They reach the anterior border of endoplasm and travel back and come to the middle of the body to complete the circulation. This type of movement of food vacuoles in a definite course is called cyclosis. During cyclosis the food materials are killed, digested and absorbed. Digestion is done by a variety of lysosomal enzymes. The food vacuole is first acidic but becomes basic later on. Digested food is absorbed and assimilated by the endoplasm during cyclosis. The undigested food is discharged or thrown out through a definite anal spot or cytopyge (also called cytoproct or cell anus) situated on the ventroposterior surface. Elimination of undigested food is done by active vacuolar activity called exocytosis. The cytopyge is only visible during exocytosis. 2.6.1 Reproduction : Paramecium reproduces both asexually and sexually. It multiplies asexually by transverse binary fission and sexually by conjugation. 1. Transverse binary fission : It is the most common mode of reproduction in Paramecium. In this process, a full grown individual divides into two daughter individuals. Before the beginning of fission Paramecium stops feeding and the body elongates to become spindle like. The oral groove disappears. The micronuclues divides eumitotically i.e. by passing through all the stages of mitosis and the 40 :

82 NSOU CC - ZO - 03 macronucleus during this period first elongates, then divides trnsversely by amitotic process, in which the number of chromosomes may differ. The products of these divisions are two micronuclei and two macronuclei. One micronuclues and one macronucleus go to the anterior part while the other pair to the posterior part of the animal. Finally a transverse constriction appears in the middle of the body. The constriction deepens gradually, and ultimately two equal sized daughter paramecia are formed. The anterior one is called anterior daughter or proter and the posterior one is called posterior daughter or opisthe. The oral groove is usually inherited by the daughter at the anterior end. However, in both of them the division is always followed by regeneration and reorganization of lost parts. The whole process of binary division normally takes 30-120 minutes depending on the availability of food and ambient temperature. Two to three divisions are not uncommon in 24 hours time. Sexual reproduction : After practising binary fission for a considerable number of generations, paramecia need a nuclear reorganization by conjugation or mating in which the nuclear material of two individuals is interchanged. Conjugation may be defined as a temporary union of two individuals of same species but two different mating types for the purpose of mutual exchange of nuclear material through the formation of a temporary cytoplasmic channel. The individuals participating in conjugation are called conjugants. Individuals which belong to a same species but can be differentiated on the mating behavior, are called varieties or syngens. Sonneborn reported a number of varieties wihin each species of Paramecium. The individuals which are morphologically alike but physiologically and genetically apart are called mating types. Members of same mating type never participate in conjugation, thus conjugation occures between different mating types. During conjugation two individuals come close together and pair by their ventral surfaces. The interlocking between them is made stronger by the gullets which degenerate to form a protoplasmic bridge between them. A substance produced by the cilia of both conjugants probably helps in adhesion of the two. The paired conjugants are however capable of movement. Soon a series of changes occur in the nuclei of both the conjugants and that are to some extent comparable to gametogenesis of higher animals. These nuclear changes are : (i) The macronucleus undergoes gradual disintegration and ultimately disappears.

NSOU CC - ZO - 03 83 (ii) The micronucleus which is diploid, undergoes two successive divisions forming four haploid micronuclei (sometimes called pronuclei) in each of the conjugants. One of the divisions is probably meiotic in nature. (iii) Three of these four micronuclei in each conjugant degenerate and the remaining one undergoes mitotic division to form two gametic nuclei. One of the gametic nucleus is large and is called stationary or female pronucleus while the small one is called migratory or male pronucleus. (iv) The migratory or male pronuclei of two conjugants are exchanged so that the male pronuclus of one conjugant passes through the cytoplasmic bridge into the other and fuses with the stationary female pronucleus forming the zygote nucleus or synkaryon which restores the diploid condition and initiates genetic variability in both the zygotic nuclei. Fig. 41: Stages of conjugation in paramoecium caudatum. Note that two individuals (shown in different shades) come together, exchange their nuclear material and then separate. Each individual ultimately produces four daughter paramoecia.
84 NSOU CC - ZO - 03 (v) The conjugants with the zygote nucleus now separate (after about 12-48 hours) and are called exconjugants. (vi) In each exconjugant the zygote nuclues undergoes three successive mitotic divisions to form eight daughter nuclei. (vii)Four of the eight nuclei grow in size to become macronuclei. Remaining four smaller nuclei are called micronuclei. Later on three of the four micronuclei degenerate leaving behind one active micronucleus. (viii) The micronucleus then divides mitotically forming two and at the same time the exconjugant divides by cytoplasmic division (binary fission) into two cells, each with two macronuclie and one micronucleus. (ix) The micronuclues divides again, followed by cytoplasmic division, resulting four paramecia from each exconjugant, each with one micro and one macronuclues (Fig. 41). (x) Thus after conjugation total eight small sized daughter paramecia are formed, each of which grow and reform lacking organelles. Significance of Conjugation : Conjugation resembles the sexual reproduction of higher animals in many respects. It is an important process of nuclear reorganization and nuclear exchange which recur in between the binary fission (asexual reproduction). After a number repeated binary fission, the daughter paramccia become weak. To gain vitality and physiological efficiency the role of conjugation is very important. It is the process of rejuvination by which the vigour of the species is maintained. Due to exchange of nuclear material, the macronuclus and micronuclus are totally reorganized and become a new one. Due to the reorganization the macronuclues controls the metabolic activities of the animal and the vitality and vigour of the individual are enhanced. Conjugation produces new type of genetic resuffling. Genetic or hereditary variations result in the formation of new combination of genes in the descendants and different mating types appear among population.
NSOU CC - ZO - 03 85 2.7 Life Cycle of Plasmodium vivax Members of the genus Plasmodium are collectively known as malarial parasites because they cause a febrile disease, by the bite of the malarial parasite infected female anopheles mosquitoes, called malaria. The life cycle of human malarial parasites (Plasmodium spp.) is completed by two hosts (digenetic). The asexual cycle of the parasite is completed within the reticulo-endothelial system of human being and the sexual cycle is completed within the digestive system of female anopheles mosquito. Mosquito is considered as primary host or definitive host (because sexual reproduction occurs there) and human being is considered as secondary or intermediate host (because asexual reproduction takes place here). Life Cycle of a Plasmodium vivax: The life cycle of Plasmodium vivax, is divided into following two stages–– (1) Asexual cycle in human and (2) Sexual cycle in mosquito. Asexual cycle in human. Classically the asexual life cycle of P. vivax is divided into 3 stages– (i) Pre-erythrocytic cycle, (ii) Erythrocytic cycle and (iii) Exo-erythrocytic cycle. But Cheng (1986) has divided it into two stages––(i) Exo-erythrocytic schizogony including pre-erythrocytic and exo-erythrocytic cycles and (ii) Erythrocytic schizogony. For the convenience of discussion the classical divisions are discussed here. 1. Pre-erythrocytic cycle : It begins with the inoculation of the parasite as sporozoites by the bite of the infected female Anopheles mosquito in the blood stream of a healthy person. The sporozoites are slender and spindle shaped, measuring 15 μm in length and 1μm in breadth. At the anterior end of the sporozoite there is a cup like depression with three concentric rings which forms a complex structure called apical complex. Within half an hour of their entry into the blood streams of human, the sporozoites take refuge in the liver parenchyma cells (Shortt, 1948). They remain within the parenchymal cells for about seven days and during this period each of them develops into an oval shaped biologically organised structure, called Schizont. It is about 42μm long and the nucleus is peripherally situated. The schizont carries on multiple fission (asexual reproduction) or Schizogony. This phase of multiplication within liver parenchyma cells is

86 NSOU CC - ZO - 03 called pre-erythrocytic cycle. Each schizont produces about 1200 genetically identical merozoites or cryptozoites within 8-9 dyas. Each merozoite measures about 1.5 to 1.75 μm in length and 0.5μm in breadth. It is oval in shape and the nucleus is distinct and centrally placed. These pre- erythrocytic merozoites are set free by the rupture of the schizont. The newly produced merozoites travel to liver sinusoids from where they invade fresh parenchyma cells or red blood corpuscles to inititate the erythrocytic cycle of development. 2. Exo-erythorcytic cycle : The pre-erythrocytic merozoites or cryptozoites enter the fresh hepatic cells (hepatocytes) and multiply by a second phase of asexual multiplication known as exoerythrocytic schizogony. This produces about 1000 exo-erythrocytic merozoites. The merozoites of the second generation produced in the liver cells are also called metacryptozoites Fig. 42: Life cycle of a malaria parasite (Plasmodium vivax). A—C. Pre-erythrocytic cycle in liver cells. D—J. Erythrocytic cycle. K—S. Sexual cycle (begins in man and completes only within mosquito). T. Fertilisation. U. Zygote. V. Ookinete (piercing the stomach wall of mosquito). W—Z. Development of sporozoites.

NSOU CC - ZO - 03 87 or phanerozoites. These merozoites invade fresh RBC. The exo-erythrocytic schizogony may be repeated several times and each time new liver cells are infected. Pre and exo-erythrocytic phases of parasite remain immune to the resistance of the host and the parasites are not susceptible to the action of any anti- malarial drug. Also little damage to the host is done during this phases. It is supposed that the merozoites of second generation i.e. metacrytozoites are of two types. Smaller and more numerous are micro-metacryptozoites while larger and less in number are macro-metacrytozoites. In fact, the micrometacrytozoites invade the red blood corpuscles and start erythrocytic schizogony, while the macro-metacryptozoites enter fresh liver cells to continue exo-erythrocytic schizogony. 3. Erythrocytic cycle (Erythrocytic Schizogony or Gametogony) : Micro metacryptozoites, after escaping into blood stream, invade the erythrocytes. They can penetrate the RBCs with mediated receptor sites. Inside the RBCs they assume the shape of a rounded disc-like structure with a single large nucleus, called the trophozoites. The trophozoite measures about 1/ Fig. 43 : Scanning electron micrograph of trophozoite of Plasmodium in RBC

88 NSOU CC - ZO - 03 3rd of the RBC and is approximately 2.5-3.00μm in diameter. The young trophozoite possesses pseudopodia and show amoeba like movement. The young trophozoite grows at the expense of haemoglobin of the RBC. It absorbs haemoglobin both by general body surface and pseudopodia. Within the trophozoite a non-contractile vacuole develops and the nucleus is pushed to one side. The shape of the trophozoite at this stage resembles a ring and it is called signet-ring stage. It takes about 36 to 40 hours for the trophozoite to be fully grown and it occupies the whole of the RBC. During the signet ring stage the parsites ingest the haemoglobin of the RBC and haemoglobin is decomposed into amino acids and haematin. The amino acids are used by the trophozoites and the unusual yellow-brown or black coloured haematin part, a kind of toxic malarial pigment is stored in the cytoplasm as haemozoin pigments. Another kind of closely packed fine granules are seen on the surface of RBCs. These granules, as seen under light microscope after Romanovsky's staining, are called Schuffner's dots (named after the discoverer). As the trophozoite grows in size the RBC also enlarges considerably. In about 48 hrs. a trophozoite becomes full grown, almost completely fills the enlarged corpuscle.The full grown trophozoit is now called Schizont which is round in shape. The schizont multiplies asexually by schizogony or merogony. This is also called erythrocytic schizogony. When the schizont bursts a number of erythrocytic merozertes (approx. 16) are set free into the plasma from where they enter new erythrocytes and repeat the erythrocytic schizogony once every 48 hours. However, some merozoites may again go from the blood to the liver cells and invade them to undergo another phase of asexual multiplication, called post- erythocytic schizogony. Formation of gametocytes : After many generations of schizogony in the blood some of the merozoites behave differently from those which repeat schizogony in RBCs. At the end of their trophic phase they do not divide but come out into the plasma by rupturing the blood cells. Some of them are transformed into rounded structures, called gametocytes or gamonts. Within 96 hours the haploid gametocytes become full grown and reach in the superficial or peripheral blood vessels. There are two forms of full- grown gametocytes—the feamle or macrogametocytes and male or microgametocytes. The macrogametocyte is larger in size (10-12 μm) than the microgametocyte, take deep stain and contain many pigment granules with a compact peripheral

NSOU CC - ZO - 03 89 nucleus. The male or microgametocyte is smaller in size (9-10 µm) with a centrally placed large diffused nucleus. It takes faint stain. Further development of the gametocytes does not take place within human body. They remain in the human blood for several weeks and it is necessary for them to be taken into the body of a female Anopheles mosquito. If they are not ingested by a mosquito, they degenrate and die within several weeks. Thus the sexual cycle of Plasmodium starts in the blood of human host with the formation of gametocytes. B. Sexual cycle in female Anopheles mosquito : In order to complete the life cycle Plasmodium requires another definite or primary host- the female Anopheles mosquito within which the sexual cycle is completed. Transfer to mosquito : When a female Anopheles mosquito bites an infected person, the ingested blood containing gametocytes fills her stomach. Gametogony–All other stages, except the gametocytes, are destroyed in the stomach of the mosquito by the digestive juice. Within the stomach, the macrogametocyte become spherical and transformed into the macrogamete or female gamete. The macrogametes are less active and are ready to be fertilized. The microgametocyte undergoes marked changes. Five minutes after ingestion by the mosquito the microgametes become spherical and undergo a process, called exflage llation, in the midgut of mosquito. The drop in temperature, due to transfer from warm-blooded human to cold-blooded insect, provides the stimulation for the process. In each microgametocyte, the nuclues divides by mitosiso produce 6-8 haploid daughter nuclei which assemble at the periphery. The cytoplasm of the microgametocyte pushes out forming long and thin flagella–like projections having a daughter nucleus in each. Thus 6-8 filamentous motile projections, calles male gametes or microgametes are formed from each microgametocytes. The microgametes, measuring 20-25 µm in length, become free and start moving in search of female gametes for fertilization. Fertilization : The microgametes are attracted towards macrogametes by a process of chemotaxis and fusion or fertilization takes place within the stomach of the mosquito. The other name of fertilization is syngamy meaning complete fusion of male and female gametes. Here the gametes are dissimilar (anisogametes), hence their fusion is called anisogamy. Ookinete : Fertilization results in the formation of zygote with a single diploid nucleus or synkaryon. The zygote remains rounded and motionless for about 24

90 NSOU CC - ZO - 03 hours. Then it becomes elongated in shape having pointed ends and motile in habit. In this new state it is called ookinete (G. oon = egg; knietos = motile). It performs wriggling or gliding movement. It measures 15-22 µm in length and 3µm in breadth. Migration of ookinete : Owing to the natue of its worm-like movement it is often called a travelling vermicule. Ookinete bores its way through the internal lining of the mosquito's stomach, penetrates into the tissues and finally comes to rest just under the outer layer of the stomach wall. The ookinete in this new site becomes rounded and encased in a covering or cyst derived partly from the stomach tissue and partly from its own secretion. It is now termed the oocyst or sporont. Oocyst formation becomes complete after 48 hours of ingestion. The oocyst increases in size and measures 6-7 µm. It bulges on the outer wall of the stomach towards the haemocoel and renders the stomach wall blisterred. As many as 50 or more such oocytes can be seen on the stomach of the host-mosquito. Howard (1906) observed that the ookinetes which do not succeed in boring the stomach wall pass out from mosquito's body with faecal matter. Sporogony : Each oocyst now enters a phase of asexual multiplication known as sporogony. After about 7 days a number of lobes are formed in the oocyst and sporogony starts. The nucleus of the mature oocyst divides first by meiosis and then by mitosis several times (Bano, 1959) producing an enormous number of Fig. 44 : Stomach or midgut of an infected female Anopheles mosquito with cocysts of plasmodium.

NSOU CC - ZO - 03 91 small haploid nuclei. Each daughter nucleus gets surrounded by a mass of cytoplasm of the oocyst. The resulting cells are called the sporozoites. Each oocyst may have 10000 sporozoites. Sporozoites have minute slender and sickled-shaped bodies with pointed ends. Each measures 15μm in length and 1-2 μm in breadth with a central nucleus. At the end of sporogony the muscular wall enveloping the oocyst bursts and cluster of sporozoites are liberated in the haemocoel of the mosquito, from where they find their way into the salivary glands of mosquito. In mosquito, whole sexual cycle is completed within 10-20 days dependng upon the temperature. The sporozoites within the salivary glands wait for their transmission into the human blood. The mosquito now becomes infective. According to one estimation salivary glands of a single infected mosquito may contain as many as 200,000 sporozoites. The infective sporozoites are introduced into a healthy person when the infected mosquito injects saliva during a bite and the life cycle of the parasite is repeated again. Pathogenicity : Malaria caused by Plasmodium is one of the most prevalent and debilitating diseases afflicting humans and it has played a major role in shaping history and civilizations. More than 50 species of Plasmodium infect a wide variety of animals, but only four, P. vivax, P. falciparum, P. malariae and P. ovale, commonly cause malaria in humans. Regardless the species responsible, certain facets of the disease, such as life cycle of the infective Fig. 45: The life cycles of Plasmodium in a mosquito and in a human, Reinvasion of liver cells in the tissue cycle does not occur in Plasmodium falciparum.
92 NSOU CC - ZO - 03 organisms and epidemiology are more or less similar enough but the dissimilaries are medically significant. 2.8 Types of Humans Malaria The following four types of human malaria are recognized on the basis of period of recurrence of fever. 1. Tertian, benign tertian or vivax malaria. The causative agent of this type of malaria is P. vivax. It is characterzed by the recurrence of fever every third day, i.e. after 48 hours. This appearance of fever paroxysm is related with rupture of merozoites from the infected erythrocytes synchronously every 48 hours. This type of malaria does not result in death of the patient. The incidence of the disease is worldwide, mainly in temperate regions. 2. Ovale or mild tertian malaria. This type of malaria resembles very much to the tertian malaria and is caused by P. ovale. Here also the fever recurs every third day or at interval of 48 hours. Ovale malaria is less harmful and is confined mainly to tropical Africa. Both P. vivax and P. ovale have a predilection for immature erythrocytes (reticulocytes). Less than 1 percent of the total erythrocyte population in each victim is parasitized by P. vivax or P. ovale. A diagnostically significant characteristic is the larger size of these infected erythrocytes, probably due to the fact that the parasites prefer to invade relatively larger reticulocytes. This enlargement of infected cells is less pronounced in P. ovale malaria than in P. vivax infections. 3. Quartan malaria. P. malariae is the causative organism of quartan malaria, which is characterzed by the recurrence of fever every fourth day, i.e. at intervals of 72 hours. It is well known for its longevity, 40 years or more in untreated persons. Though it ordinarily does not proove fatal to the patient, the chronic infections sometimes give rise to lethal kidney conditions. The disease is common in temperate regions. Unlike P. vivax and P. ovale, this parasite shows an affinity for older erythrocytes, parasitizing about 0.2 percent of the victim's total erythrocyte population. 4. Malignant tertian malaria. The causative organism is P. falciparum. The parasite is responsible for most cases of human malaria worldwide (80 percent) and is deeply extrenched in tropical Africa. Examination of blood smears of infected patients shows that the parasite differs significantly
NSOU CC - ZO - 03 93 from the preceding three species. Infected erythrocytes are not enlarged and represent about 10 percent of the total erythrocyte population. P. falciparum infects the erythrocytes of any stage indiscriminately. Multiple infections of single erythrocyte is not unusual. Rupture of merozoites from infected erythrocytes is erratic, with accompanying fever paraoxysms occuring at 48- to 72- hours intervals. Symptoms of malaria first appear several days after the infection of the malaria parasite in man. This interval of time or the incubation period is utilized by the parasites to increase their progeny. The incubation period varies from 11-14 days in P. vivax and 9-13 days in P. falciparum. To establish malarial symptoms, it is necessary that a large number of parasites must continue erythrocytic cycle at a time. The symptoms of malaria at the end of the incubation period are head aches, loss of appetite, limb pains, nausia, vomiting and sweating, Finally, the disease is characterized by peroxysm (attack of fever) which shows three successive stages : 1. Cold stage : At the onset of malaria fever, the patient suffers from a severe shaking chill. The patient feels so cold that his/her teeth chatter though he/she may covered with a huge pile of blankets. Cold stage lasts for 20 minutes to one hour. Fig. 46: Temperature cycle in malaria caused by plasmodium vivax (after Sharman). note the changes in the erythrocytic trophozoites corresponding to the changes in body temperature.

94 NSOU CC - ZO - 03 2. Hot stage : As the chill subsides, the body temperature rises as high as 41ºC or 106ºF. The patient feels very hot with a terrible headache. It last one to four hours. 3. Sweating stage : As the temperature lowers down, the patient sweats profusily. Finally the fever comes down, temperature becomes normal and the patient becomes comfortable until the next attack which takes place at regular interval of 48 hours in case of P. vivax malaria. The total duration of peroxysm is 6 to 10 hours depending on the spceies of Plasmodium. Malaria fever occurs when schizonts in red blood corpucles burst and set free their contained merozoites and malarial pigment (haemozoin) along with cellular debris and parasites' metabolic wastes in the blood plasma. Bursting out of schizonts tends to be synochronous as they all burst out at the same time. Haemozoin is said to be toxic and induces high fever and shivering. In infections with Plasmodium species, anaemia is inevitable. The reasons for anaemia are as follows: (a) Destruction of erythrocytes on liberation of merozoites. (b) Infected erythrocytes become more fragile, rupture easily and are destroyed. (c) The enlarged spleen due to malarial infection releases a lytic substances, lysolecithin, which destroys erythrocytes. (d) Malarial parasites produce haemolysin (an antibdoy), which brings about haemolysis of normal erythrocytes. In malaria infection the spleen becomes palpable and enlarged. As spleen is considered as the graveyard of erythrocytes, due to destruction of large number of them, the function of spleen increases many fold leading to its enlargement. The falciparum malaria infection (malignant malaria) often results in thrombosis of visceral capillaries. Death takes place when the capillaries of brain become plugged with both the parasites and malarial pigments. Another very serious outcome of the falciparum infection is black-water fever, which is characterized by massive destruction or lysis of patient's erythrocytes, abnormally high levels of haemoglobin in urine and blood. Fever, vomiting with blood and jaundice also occur, and there is a 20 to 50 percent mortality rate, usually due to renal failure. In case when death does not occur, the host's immune system destroys all or most of the erythrocytic schizonts, and symptoms of malaria gradually disappear. However, the parasites persist either in the liver cells (P. vivax, P. ovale, P. malariae), or in the capillaries of various viscera (P. falciparum).
NSOU CC - ZO - 03 95 2.9 Life Cycle of Entamoeba histolytica Systematic Position : (According to Levine et al. 1980) Sub-kingdom : Protozoa Phylum : Sarcomastigophora Sub phylum : Sarcodina Super class : Rhidopoda Class : Lobosea Genus : Entamoeba Species : histolytica Entamoeba histolytica is an amoeba-like microscopic disease-producing (pathogenic) endoparasite of human beings. The parasite was first of all reported by a Russion Zoologist Losch (1875), but he described it as Amoeba coli. Schaudinn established the species Entamoeba histolytica in 1903 and he differentiated the pathogenic and non-pathogenic types. The parasite has a very wide, almost cosmopolitan distribution and occurs especially in the tropical countries where sanitation is in bad state. It inhabits mainly in the mucuos and sub-mucous layer of large intestine of human beings. The endoparasite causes a serious disease known as amoebiasis or amoebic dysentery, the medical importance of which is well established. The name histolytica (Gr. histos = tissue; Luein = to disolve) is given to the parasite because of its power of dissolving (lysis) the tissues. Fig. 47 : Entamoeba histolytics. A–Trophozoite or magna form; B–Minuta form.

96 NSOU CC - ZO - 03 The endoparasite has also been recorded in orang-utang, gorilla, chimpanzee, gibbon, donkey, dog, cat, rat and pig. There are three stages in the life cycle of E.histolytica, namely trophozoite, pre-cystic and cystic stages. 1. Trophozoite or Vegetative Stage : The mature or adult, harmful and active stage of the parasite is called trophozoite (Gr. trophe = food; zoon = an animal. The growing or feeding stage). They are large, hence called magna, usually 20-30µm in diameter. They live in the intestinal mucosa and feed on fragments of tissue cells, erythrocytes, leucocytes and bacteria. Dobell (1919) and others have shown that the parasite has got two races, one large and the other small. Active or motile trophozoites resemble Amoeba in some structural details. Pseudopodia are either long finger like or short and rounded in shape (Fig. 48 & 49). 2. Pre-cystic Stage : When the parasite encounters shortage of food or any unsuitable environment, it assumes a colourless, round or slightly ovoid body with a blunt pseudopodia at one end (Fig. 48). The pre-cystic form is much smaller in size, measuring 10-12 µm in diameter. Owing to its small size it is also called minuta form. At this stage motility becomes slow and finally stops, the food vacuoles disappear. The precystic forms develop into mature cystic forms but if they are ejected in the stool no further development can take place. 3. Cystic Stage : The precystic form secretes a thin, tough and transparent covering around it and that is called cyst wall. The process of enclosing in a cyst is called encystment or encystation. The cysts of E.histolytica vary in size from 10-20 µm in diameter. At the early stage the cyst contains a single nucleus (i.e. mononucleate). The single nucleus divides mitotically forming two nuclei. This is called binucleate cystic stage. Ultimately the two nuclei divides again mitotically producing four nuclei. The nuclear divisions take place without cytoplasmic division and this tetranucleate cyst is called mature cyst. Presence of black rod like chromatid bodis is the characteristic of the cysts of E.histolytica. They occur either singly or in multiples of two or more. These chromatid bodies occur in the early stages of the cysts but disappear in the mature quadirnucleate cysts. Pitelka (1963) has suggested that the chromatid bodies are made of ribonucleoprotein and Neal (1966) believes that the disappearance of
NSOU CC - ZO - 03 97 chromatid bodies occurs because of the dispersion of their nucleoprotein in the substance of mature tetranucleate cystic form. In young cysts glycogen masses as reserve food are seen within the cytoplasm. The whole process of encystment takes a few hours and the mature cysts live in the lumen of intestine of host only two days. Life Cycle : Entamoeba histolytica is monogenetic parasite as it completes its whole life cycle within one host only and the host is human. Its life cycle consists of three stages, trophozoite or vegetative stage, pre-cystic stage and cystic stage (discussed earlier). The mature quadrinucleate cysts are the infective forms of the parasite. Encysted forms pass out with the faecal matter of the host. Transfer to new host. The infective cysts remain viable for a considerable length of time outside the human body, if environmental conditions are favourable.

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Infection of fresh human host takes place by swallowing the infective cysts with

Fig. 48 : Entamoeba histolytica. Life cycle.
98 NSOU CC - ZO - 03 contaminated or unprotected food, drinks and vegetables.

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Houseflies generally carry the cysts from the faeces to the foods. Cockroaches have also been found to transport cysts. Food-handers are also responsible (sometimes) for the contamination of food through touch by dirty fingers carrying the cysts under the nails.

Excystment : In the new human host, the ingested cysts pass unaltered through the stomach, as the cyst wall is resistant to the action of gastric juice. When the cysts reach

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the small intestine of the host excystment occurs, as the cyst wall is digested by the action of trypsin. The cyst wall ruptures and the terranucleate entamoeba, called metacystic form emerges out. According to Dobell (1924) the metacystic entamoeba emerges from the cyst through a minute pore in the cyst wall. The tetranucleate metacystic form produce a new generation of trophozoites by a series of nuclear and cytoplasmic divisions which result in the formation of eight uninucleate amoebulae. These are called metacystic trophozoites. The young, motile trophozoites pass into the large intestine, invade the tissues and enter through the crypts of Lieberkuhn, penetrate the muscularis mucosae and lodge themselves in the submucous tissue. They grow at the expense of living tissues to form the trophozoites of the next generation and after a particular period start the life cycle again. Pathogenicity : Entamoeba histolytica is cosmopolitan with an estimated incidence of human infection exceeding 50 million cases. The infection caused by the parasite is known as amoebiasis or amoebic dysentery. Symptoms of amoebiasis vary greatly, due to the strain of E.histolytica and the host's resistance and physical condition. Commonly the disease develops slowly with intermittent diarrhoea, cramps, vomiting and general body weakness and discomfort. Some infections may mimic appendicitis. Broad abdominal pain, fulminating diarrhoea, dehydration and loss of blood are typical of severe cases. Acute infections can result in death from peritonitis, the result of gut perforation, or from cardiac failure and exhaution. Hepatic amoebiasis Fig. 49: Entamoeba histolytica (from various sources). A. Living trophozoite. B. Stained trophozoite. C. pracystic stage. D. Cystic stage. E. Excystment.

NSOU CC - ZO - 03 99 results when trophozoties enter the mesenteric veins and travel to the liver through the hepato-portal system. They digest their way through the portal capillaries and form abscesses in the liver. The first sign of hepatic involvement is the formation of an early hepatic abscess containg a matrix of necrotic hepatic cells that eventually become liquefied. Hepatic abscesses may be single or multiple. Hepatic amoebiasis is the most serious consequnce, since abscesses may perforate the abdominal wall or extend through the diaphragm into the lungs. Any of these manifestations may be fatal. Apart from liver and lung other organs such as heart, brain, spleen, gonads and skin may also be invaded, resulting in secondary amoebiasis (Invasion of tissues other than the intestinal mucasa is known as secondary amoebiasis. It should be mentioned here that the term "amoebiasis" is used clinically to denote all those conditions which are produced in the human host by the infection with E.histolytica at different areas of its invasion. The term "amoebic dysentery" signifies a condition in which the infection is confined to the intestinal canal and is charaterized by the passage of blood and mucous in the stool. Thus "amoebic dysentery" is not a synonym of "amoebiasis". Dysentery is a symptom characteristic of extensive intestinal ulerations. The trophozoites of E. histolytica penetrate the mucosa and submucosa of intestine, rapidly multiply and causes necrosis of that part and form small wounds or abscesses which later become bleeding ulcers. The cavity of the ulcers is generally filled with mucous, bacteria, amoebae and cell-debris. The abscesses pour their contents into the lumen of the intestine. It has also been reported that the trophozoites secrete a battery of proteolytic enzymes, one of which is called hystolysin, that enables the organism to invade the submucosal tissue and to utilize the cytolysed material as their food. The mucosal ulceration may penetrate deeper into the intestinal tissue, causing vast areas of tissue to be destroyed. The overlying mucosal epithelium may be sloughed off, exposing those necrotic areas. Fig. 50: Section of human colon showing chronic amoebic ulcer.

100 NSOU CC - ZO - 03 2.10 Evolution of Symmetry A fundamental aspect of an animal's bauplan ("a structural plan or design") is its overall shape or geometry. Symmetry refers to the regular arrangement of the body structures relative to the axis of the body. In other words symmetry means an arrangement of body parts into geometrical designs. The concept of symmetry is fundamental to understanding animal organization. Symmetry describes how the parts of an animal are arranged around a point or an axis. Body symmetry can be generally determined from the external appearance of an animal but other features of a body plan typically require a more detailed examination. Animals that can be bisected or split along at least one plane, so that the resulting halves are similar to one another, are said to be symmetrical. For example, a prawn can be bisected vertically through its midline, head to tail, to produce right and left halves that are mirror images of one another. A few animals have no body axis and no plane of symmetry and they can not be divided into like parts by a plane, and are said to be asymmetrical. All animals are either asymmetrical or symmetrical. Examples of asymmetical animals are most sponges, some protists, particularly the amoeboid forms, and few others. In animal kingdom five types of symmetry are recognized. These are– 1. Asymmetry 2. Spherical symmetry 3. Radial symmetry 4. Biradial symmetry 5. Bilateral symmetry Fig. 51 : Diagrams showing the different forms of radial symmetry. A. Radial symmetry (hydra). B. Tetramerous radial. symmetry (Jelly fish). C. octomerous radial symmetry (a octocorallian polyp).

NSOU CC - ZO - 03 101 Fig. 52 : A diagram showing the bilateral symmetry in man. B. A fish showing the different planes of bilateral symmetry. Fig. 53 : For the convenience of study, the animal body is divided into a number of regions–dorsal, ventral, lateral anterior and posterior. The entire body may also be divided into three planes, transverse, frontal and sagittal.

102 NSOU CC - ZO - 03 1. Asymmetry or asymmetrical animals : Discussed earlier. 2. Spherical symmetry : It is seen in animals whose bodies lack an axis and have the form of a sphere, with the body parts arranged concentrically around or radiating from, a central point (Fig. 54). Here any plane passing through the centre divides a body into equivalent or mirrored halves. Spherical symmetry is rare in animals and is seen chiefly among some unicellular animals e.g. radiolarian protozoa. Spherical forms are best suited for floating and rolling. Organisms with spherical symmetry share an important functional attribute with asymmetrical organisms, in that, both groups lack polarity. That is, there exist no clear differentiation along an axis. In all other forms of symmetry, some level of polarity has been achieved; and with polarity comes specialization of body regions and structures (Brusca and Brusca, 2003). 3. Radial symmetry : A body displaying radial symmetry can be divided into two roughly equal halves by any one of many

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vertical planes passing through the central axis (Fig. 54), like the spokes of a wheel. The

animal exhibiting radial symmetry has the general body form of a cylinder with one main axis around which the 54 : 55 : NSOU CC - ZO - 03 103 various body parts are arranged equally around the axis in such a way that any plane passing through the central axis divideds the organism into equal or similar halves or antimeres.

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The animals with radial symmetry do not have anterior and posterior sides or dorsal and ventral surfaces. They have a mouth bearing oral side

or oral surface and the opposite side (side away from the mouth) is called aboral side or aboral surface. In the animal kingdom, radially symmetrical phyla are Porifera, Cnidaria, Ctenophora and Echinodermata. Out of these only Cnidaria and Ctenophora exhibit a fundamental radial symmetry. Both the phyla were grouped together under the Division Radiata. Special forms of radial symmetry are observed in different groups of animals such as– Tetramerous radial symmetry. Exhibited by

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many jelly fishes possessing four radial canals and the body can be divided into four equal parts (hence tetramerous). Pentamerous radial symmetry. Most echinoderms possess pentamerous radial symmetry where the body can be divided into five roughly equal parts.

Hexamerous radial symmetry. Exhibited by

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the sea anemones and true coral polyps belonging to the subclass Hexacorallia (class Anthozoa). The mesenteries and tentacles are arranged in

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the multiple of six. Octamerous radial symmetry. This type of symmetry is exhibited by the octocorallian polyps (subclass Octocorallia) having tentacles and mesentaries in multiple of eight. 4. Biradial Symmetry : It is variant form of radial symmetry in which, because of some specialized portions of body, only two planes passing through the longtudinal axis can divide the animal into two similar halves. Common examples of biradial animals are ctenophores and many sea anemones. Radial and biradial animals are usually sessile, free-floating or weakly swimming. Radial animals, with no anterior or posterior end, can interact with their environment in all directions. 5. Bilateral symmetry : Bilateral symmetry is the arrangement of body parts in such a way that a single plane (mid sagittal plane) passing between the upper (anterior) and lower (posterior) surface and through the longitudinal axis of an animal,
104 NSOU CC - ZO - 03 divides the animal into right and left mirror images (Fig. 52). Bilateral symmetry is characteristic of active, crawling or swimming animals and the animals which exhibit bilateral symmetry are called the Bilateria. They include acoelomates, psuedocoelomates and eucoelomates among invertebrates and both lower chordates and vertebrates. Because the bilateral animals move primarily in one direction, one end of the animal is continually encountering the environment. Associated with bilateral symmetry and unidirectional movement is a concentration of feeding and sensory structures at the anterior end of the body. The evolution of a specialized "head", containing those structure and the nervous tissues that innervate them is called cephalization (differentiation of a head). This is an obvious advantage to an animal moving through its environment head first. Cephalization is always accompanied by differentiation along an anteroposterior axis, although the evolution of this axis preceded cephalization. The entire body of a bilaterial animal can be divided into three planes such as– –(a) Mid sagittal, (b) Frontal and (c) Transverse (Fig. 53).

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A longitudinal plane that passes along the axis of the body to separate the animal in right and left halves, is called the mid sagittal plane.

Any longitudinal plane passing perpendicular to the mid-sagittal plane and separating the upper (dorsal) from the underside (vental) is called a frontal plane. Any plane that cut across the body perpendicular to the main body axis and the mid sagittal plane is called a transverse plane (or simply, a cross section). In bilaterally symmetrical animals the term lateral refers to the sides of the body, or to structures away from (to the right and left of) the midsagittal plane. The term medial refers to the midline of the body, or to structures on, near, or toward the mid sagittal plane. Besides lateral (right and left sides), an upper or dorsal surface and a lower or ventral surface, an anterior end (the end which usually moves forward during locomotion and bears head and mouth) and posterior end (the end opposite to anterior) are also recognizable in most bilateral animals. Grade of Organization : In addition to body symmetry other patterns or grades of animal organization are recognizable. In a broad context, these patterns may reflect evolutionary trends although these trends are not exact sequences in animal evolution. Followings are the grades of organization : (1) The unicellular or protoplasmic grade of organization : Protoplasmic (also called cytoplasmic) grade of organization characterizes unicellular organisms. All the functions are confined within the boudaries of a single cell, the fundamental unit of life. Unicellular body plans are characteristics of the protista. Some zoologists prefer to use the designation cytoplasmic. Unicellular organization is not "simple".

NSOU CC - ZO - 03 105 All unicellular organisms must provide for the functions of locomotion, food collection, digestion, water and ion regulation, sensory perception and reproduction in a single cell. Within a cell protoplasm is differentiated into organelles capable of performing specialized functions. 2. Cellular grade of organisation : Cellular organization is an aggregation of cells that are functionally differentiated. A division of labour is evident, so that, some cells are concerned with, for example, reproduction and others with nutrition. Some flagellates, such as Volvox, that have distinct somatic and reproductive cells are placed at the cellular level of organization. Many zoologists (authorities) also place sponges at this level. 3. Cell-tissue grade of organization : A step beyond the preceding is an aggregation of similar cells into definite patterns or layers and organized to perform a common function, to form a tissue. Sponges are considered by some authorities to belong to this grade, although jelly fishes and their relatives (Cnidaria) more clearly demonstrate the tissue plan. Both groups are still largely of the cellular grade of organization because most cells are scattered and not organized into tissue. An excellent example of a tissue in cnidarians is the nerve net, in which the nerve cells and their processes form a definite tissue structure, with the function of coodination. 4. Tissue-organ grade of organisation : An aggregation of tissues into organs is a further step in complexity. Organs are usually composed of more than one kind of tissue and have a more specialized function than tissues. This is the organizational level of flatworms (Platyhelminthes), in which well-defined organs such as eyespots, probosis and reproductive organs occur. In flat warms, the reproductive organs transcend the tissue organ grade and are orgnized into a reproductive system. 5. Organ-system grade of organization : When organs work together to perform some functions, we have the highest level of organization—an organ system. Systems are associated with basic body functions such as circulation, respiration and digestion. Most animal phyla demonstrate this type of organization. In addition to these grades of organization there are diploblastic organization and triploblastic organization. Diploblastic organization is the simplest tissue level organization. Body parts are organized into layers derived from two embryonic tissue layers. Ectoderm (Gr. ektos = outside; derm = skin) gives rise to the epidermis, the outer layer of the body wall. Endoderm (Gr. endo = within) gives riese to the gastrodermis, the tissue that lines the gut cavity. Bewteen the epidermis and gastrodermis is a noncellular
106 NSOU CC - ZO - 03 layer called mesoglea. In some diploblastic organisms, cells occur in the mesoglea, but they are alwys derived from ectoderm or endoderm. Cnidarians and Ctenophores exhibit diploblastic condition. Next to diploblastic organization, rest of the metazoans (from Platyhelminthes to Chordata) are triploblastic (Gr. treis = three; blaste = to sprout); that is their tissues are derived from three embryonic layers. As with diploblastic animals, ectoderm forms the outer layer of the body wall, and endoderm lines the gut. A third embryological layer is sandwitched between the ectoderm and endoderm. This layer is Mesoderm (Gr. meso = in the middle), which gives rese to supportive, contractile and blood cells. Most triploblastic animals have an organ-system level of organization. Tissues are organized to form excretory, nervous, digestive, reproductive, circulatory and other systems. Triploblastic animals are usually bilaterally symmetrical (or have evolved from bilateral ancestors) and are relatively active. 2.10.1 Segmentation of Metazoa Segmentation, also called metamerism, is a common feature of metazoans. Segmentation is a serial repetition of similar body segments along the longitudinal axis of the body. Each segment is called a metamere or somite. In forms such as earthworms and other annelids, in which metamerism is most clearly represented, the segmental arrangement includes both external and internal structures of several systems. Although in the past zoologists considered that true segmentation was found in only three phyla, namely the annelids, the arthropoda and the chordates, it is widely recognized that segmentation is more widespread than previously thought. Some other animals, such as onychophores (velvet worms), tardigrades (water bears), and kinorhynchs (mud dragons) are also segmented. Discussions of the evolution of segmentation are complicated by the fact that there does not appear to be a concensus on what constitute a "segmental" body plan. Generally a distinction is made between true segmentation and serial repetition. Serial repetition includes simple repeated structures. For example, a strobilizing cnidarian (e.g. scyphozoan) is composed of repeated units, each of which will bud off to become a complete individual. Also, rotifers have an annulated outer cuticle and chitons contains serially repeated shell plates. "True" segmentation includes repeated units along with anterpor-posterior body axis of an animal and each unit is composed of combination of structures from both ecdoderm and mesodermal origin such as excretory organs, muscles, gonads, blood vesssls, nerves, appendages, coelomic cavities and septa (Scholtz, 2002). This definition suggests a certain

NSOU CC - ZO - 03 107 amount of integration of a reiterated developmental program that is not likely have arisen by fragmentation or simple modification of existing structures. The body plans of annelids, arthropods and chordates are usually distinguished from other animals with serial repetition and are known as the “eusegmented” animals. Among the distnict proposals explaining the origins of segmentation is the hypothesis that there is a single origin of segmentation in the Metazoa. In this case, the Urbilateria, the ancestral primitive bilateral animal that gave rise to both the protostomes and the deuterostomes (De Robertis and Sasai, 1996), was a segmented animal. Monophyly of segmentation has been proposed historically and has recently received support based upon molecular data of developmental characters (Kimmel, 1996; De Roberitis, 1997; Carroll et al. 2001). But if segmentation is monophylatic, we are faced with the challenge of explaining loss of segmentation in numerous taxa throughout the Metazoa. Independent origins of segmentation have also been proposed, in which chordates evolved segmentation independently from annelids and arthropods, which shared a common segmented ancestor. This theory has had support through most of the 20 th century. Support for an independent origin of segmentation between chordates and annelids/arthropods has been based in part on functional arguments, in which segmentation arose for distinct locomotory purposes in the ancestor of modern day annelids and arthropods and chordates (Clark, 1964). In annelids, a segmented body plan has been cited as advantageous for burrowing, because the hydroskeletal advantages of isolating a subset of segments from the rest of the body. This proposal is also not universally accepted i.e. not beyond criticism. 2.11 Questions a) What is the important characters of Protozoa? b) How many phylums are present in Levine classification? c) What are the locomotary organs in protozoa? d) Why conjugation in Paramoècium is considered as a type of sexud reproduction? e) What is the difference between multiple fissicn and sporulation in Amoeba? f) What is the locomotery organ in Paramoècium? g) What is the function of contractile vacuole in Paramoècium h) What is the difference between Ookinete and Oocyt in Plasmodium? i) Distinguish between hypnozoite, trophozoite and mesozoite j) How Plasmodiums are infected in human?
108 NSOU CC - ZO - 03 Uni –3 ??Porifera, Cnidaria and Ctenophora Structure 3.0 Objective 3.1 Introduction 3.2 General Charactertistics 3.3 Classification of phylum Porifera 3.4 Canal system in sponges 3.5 Spicules in sponges 3.6 Phylum cnidaria 3.7 Classification of cnidaria 3.8 Phylum Ctenophora 3.9 Metagenesis in obelia 3.10 Polymorphism in Cnidaria 3.11 Corals and Coral Reefs 3.12 Questions 3.0 Objective By studying this unit learners would be able to understand about primitive metazoan animals. 3.1 Introduction The animals belonging to phylum Porifera are generally called the sponges. In the history of animal evolution, the sponges are regarded as the first step towards multicellularity. In otherwords, they are the most primitive of multicellular animals. The spones are distinct from the protozoans in having cellular grade of structural ortanization and from other metazoans in lacking the tissue grade of construction. Sponges have many unusal features, but the most obvious characteristic is the porous nature of the body, from which the name Porifera comes (L. porous = pore; ferre = to bear). Robert E. Grant (1836) studied the sponges quite extensively and gave the phylum name. Sponges are aquatic, predominently marine animals (out of approximately 5000 described species of sponges only 200 species are adapted to freshwater). They occur most abundantly in shallow coastal waters, attached to the bottom or to sub- merged objects, but some groups, including most glass sponges, prefer deeper waters. Adult spongs are always attached and motionless.

NSOU CC - ZO - 03 109 3.2 General Characteristics 1. Multicellular organisms with cellular grade of body organization without forming distinct tissues or organs. 2. All are aquatic, mostly marine, a few are freshwater (Family Spongillidae). 3. Solitary or colonial, all sessile in adult. 4. The body shape is variable–cylindrical, vase-like, tubular or branched, radially symmetrical or asymmetrical. 5. The body is perforated by a number of pores, hence the name of the phylum is Porifera (L. porous = pore; ferre = to bear). 6. Sponges posses a peculiar and vital system of passage ways and chambers through which water passes, called Canal system. Water enters the body through numerous small dermal or incurrent pores, the ostia and after circulating through the canal system passes out through one or more larger excurrent pores, the oscula (Singular Osculum). 7. The body wall with outer dermal epithelium (pinacoderm) inner gastral epithelium (choanoderm) and a non-cellular mesenchyme or mesohyl in between. The mesohyl consists of gelatinous proteinaceous matrix containing skeletal materials and free amoeboid cells. Sponges are not diploblastic as they lack true endoderm. 8. The skele ton is relatively complex and provides a supportive framework for living cells of the animal. The skeleton may be composed of clacarious spicules, siliceous spicules, protein spongin fibers or a combination of these. The spicules exist in a variety of forms and are important in identification and classification of species. 9. Sponges possess one or many internal cavities (spaces) lined by special colared, flagellated cells, the Choanocytes. These are most characteristic of sponge cells and also the most important of sponge cell types. 10. Digestion is entirly intracellular as in the Protozoa. 11. A functional nervous system with overall coordination is lacking. 12. Sponges are ammonotelic i.e. their chief excretory product is ammonia. 13. Gas exchange by diffusion. 14. Most sponges are monoecious (hermaphrodite) but dioeceous forms also exist. Reproduction occurs asexually by buds and gemmules and sexually by typical ova and sperms.
110 NSOU CC - ZO - 03 15. Fertilization internal but cross fertilization is the rule. 16. Cleavage is holoblastic and development is indirect through two types of free-swimming cliated larvae, the amphiblastula and Parenchymula (also called Parenchymella). Majority of the sponges possess the second type of larva. 17. Spongs possess great power of regeneration. 3.3 Classification of Phylum Porifera (upto class) Opinions very regarding the classification of phylum Porifera. The classification is based almost entirely on microscopic skeletal structures, like nature and shape of spicules and presence or absence of spongin fibres. The classificaiton scheme followed here is based on Brusca and Brusca (2002) in their book "Invertebrate Zoology", 4th edition. Phylum Porifera includes three classes–1. Class Calcarea, 2. Class Hexactinellida and 3. Class Demospongiae 1. Class : Calcarea or calcispongiae Members of this class, known as calcareous spongs, are distinct in having spicules composed of calcuim carbonate (L. calcarius = limy; spongia = sponge) generally as calcite, although sometimes as aragonite (these are two distinct crystal forms of calcium carbonate). The class is also named as Calcispongiae (L. calcis = lime or chalk). Characters : 1. Comparatively smaller in size, most are less than 10 cm in height, solitary or colonial. 2. Body shape is usually cylindrical or vase like but may be lamellate or massive type. 3. The osculum is narrow, terminal and provided, with oscular fringe. 4. All the spicules are of same size (not differentiated into megascleres and microscleres) and are usually separate. Spicules are monaxons or tetraxons. Tetraxon spicules loss one ray to become triradiate. 5. Spngin fibers are absent. 6. All three forms of body organization (or grades of structures) such as asconoid, syconoid and leuconoid, occur among calcarians).
NSOU CC - ZO - 03 111 7. Mostly dull coloured, although brilliant yellow, red and lavender species are known. 8. Exclusively marine, exist throughout the oceans of the world, but most are restricted to relatively shallow coastal waters. Examples : Leucosolenia, Clathrina (asconoid sponge), Grantia, (Scypha) Sycon (syconoid sponge). 2. Class Hexactinellida or Hyalospongiae : Representatives of this class are commonly known as glass sponges. The skeleton is of siliceons spicules (Sio 2) which are only triaxon with six rays (G. hex = six; actin = rays). Hence the name Hexactinellida. The class is also named Triaxonida due to the presence of triaxon spicules only. Furthermore, some of the spicules often are fused to form a skeleton that may be lattice-like and built of long, siliceous fibres that look like the loose fibreglass. Hence the class is also known as Hyalospongiae (G. hyalos = glass), and the members are called glass sponges. Characters : 1. The glass sponges, as a whole, are the most symmetrical and most individualized of the sponges, that is, they show less tendency to form interconnecting clusters or large masses with many oscula. 2. The shape is usually cup, vase-, or urn like and the height varies from 10 to 30 cm. The colour of most sponges is pale. 3. The spongocoel is well developed and it opens through a wide osculum which is sometimes covered by a sieve-plate–a gratelike covering formed from fused siliceous spicules. 4. Dermal epithelium or pinacoderm is lacking. 5. The choanocyte cells (flagellated cells) are restricted to finger-like chambers. 6. Songin fibers are absent. 7. They are exclusively marine and occur chiefly in deeper waters of all seas and in the Antartic they are the dominant sponges. Examples : Euplectella (Venus's flower basket), Hyalonema (glass rope sponge), Pheronema (bowl sponge)

112 NSOU CC - ZO - 03 3. Class Demospongiae : (G. demos = frame; spongos = sponges) This largest class of phylem Porifera contains 90% of total sponge species and includes most of the common and familiar forms. Characters : 1. Members of this class are highly organized, varying from small to large size and may be solitary or colonial. 2. The body is compact, often massive and brightly coloured. Shape is variable being rounded, oval, cup-like, funnel like or cushion like. Fig. 1 : A few examples of Phylum Porifera (after Hyman). A. Laucosolenia, B. Oscarella, C. Hyalonema D. Craniella (A part removed to show inner radiating appearance). E. Poterion (Neptune's goblet). F. Euptectella (Venus's flower basket). G. Microciona. H. Spongilla (Freshwater sponge). 1. Haliclona. J. Halichondria (not drawn up to scale).
NSOU CC - ZO - 03 113 3. The skeleton is composed of siliceous spicules or spongin fibers or a combination of both or none i.e. skeletonless (Genus Oscarella is unique in lacking both spicules and spongin fibers). 4. The spicules are monaxon or tetraxon, never triaxons (hexactines). 5. The spicules (when present) may be divisible into large megascleres and smaller microscleres. 6. The canal system is complicated and of leuconoid type only. 7. Choanocyte cells are restricted to small, rounded flagellated chambers. 8. Most widely distributed sponges occuring from the tidal zone down to abyssal depths. Examples : Oscarella, Chondrilla (chicken liver sponge), Cliona (boring sponge), Plakina, Halichondria (crumb-of-bread sponge), Spongilla (freshwater sponges), Haliclona (finger sponge), Euspongia (bath sponge), Hippospongia (horse sponge). 3.4 Canal System in Sponges The passage through which water constantly flows from outside the body to the interior of the body and then outside again, collectively from the canal system in sponges. The structural complexities in sponges are primiarily due to possession of canal system. This system constitute the most vital system because all the cell types in sponges work on the background of this system and the entire physiolocgical activities of the animal depend on this canal system. Sponges bear a large number of pores (Ostia) on their body surface that lead into a system of channels permeating almost the whole body and ultimately open to the exterior through osculum or oscula. Canal system in sponges ranges from a very simple grade to highly complex type.Accordingly the system has been divided into three types : 1. Asconoid or Ascon type 2. Syconoid or Sycon type 3. Leuconoid or Leucon type Asconoid Type : The asconoid type is regarded as the simplest of all the types of canal system. This type is found in those sponges whose body is vase-like and radially symmetrical. The body wall is very thin enclosing a large central cavity, the spongocoel. The spongocoel opens at the free end by a narrow circular aperture, the osculum. The spongocoel is lined internally by flagellated collared cells or
114 NSOU CC - ZO - 03 choanocytes, which from the choanoderm. The body wall of the sponge is pierced by numerous microscpic openings or porees, called the

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incurrent pores or ostia which extend from the external surface to the spongecoel.			

These pores are actully intracellular speces within tube-like cells, the porocytes. The asconoid type of canal system is characteized by the presence of a complete and continuous lining of choanocytes in the spongocoel, interrupted only by the porocytes (Fig. 2) Surrounding sea water enters the canal system through the ostia. Flow of water is maintained by the beating of flagellae of the numerous choanocyte or collar cells within the spongocoel. The water finally leaves the spongocoel through the osculum. The course of water is as follow : Surrounding water → Ostia → Spongocoel → Osculum Asconoid type of canal system is found in some adult calcareous asconoid sponges like Leucosolenia, Clathrina, and in olynthus stage in the development of all syconoid sponges. 2 :
NSOU CC - ZO - 03 115 Fig. 3A: Canal system of sponges. A–Ascon type. B–Simple sycon type. C'Complex syconoid type with cortex, D–Leucon type. Fig. 3B: Body complexity in sponges. (Arrows indicae flow of water). (A) The asconoid condition. (B) A simple syconoid condition. (C) A complex syconoid condition with cortical growth. (D) A leuconoid condition.
116 NSOU CC - ZO - 03 Syconoid type : In the canal system of sponges the syconoid type represents the transitional grade between the simplest asconoid type and more complex ones. Thus it is a step forward in the evolution of canal system. This type of canal system

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is formed by out pushing of the body wall at regular intervals into finger-like projections, called

the radial canals. The radial canals being out pushings of the spongcoel are lined by flagellated collar cells or choanocytes. The radial canals are thus also called flagellated chambers. Syconoid type canal system is represented by three grades–– (a) First grade or simple syconoid type (b) Second grade or complex syconoid type (c) Third grade or more complex syconoid type First Grade : In the simple type of syconoid canal system (first grade) the radial canals are simple out-pockeing of the spongocoel and are exposed directly to the surrounding water (outside water surround their whole length). The spaces between them are not organized into definite incurrent canals (as in higher grades), and the spaces may Fig. 3C : Grades in leucon type of canal system. A–Eurpylous. B–Aphodal type. C–Diplodal type. NSOU CC - ZO - 03 117 be referred to as incurruent spaces (not as incurrent canals of higher grades). Here the course of water is as follows : Surrounding water → Incurrent spaces → Dermal ostia ↓ ↓ Osculum ← Spongocoel ← Radial canals This simple type of syconoid canal system is found in a heterocoelous calcareous sponge named Sycetta. But most of the syconoid sponges do not have this type of canal system. Second grade : In the majority of the syconoid sponges the outpushings fuse by the increase in the amount of mesenchyme or mesohyl in a manner as to leave between the radial canals tubular spaces lined by pinacocytes. Such tubular spaces are called

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incurrent canals which open to the exterior between blind outer ends of the radial canals.

The Fig. 4 : Sectional view of Sycon (Diagrammatic). A. A portion of the body to illustrate the arrangement of canals. B. Part of 'A' is magnified to show the histological details (after Parker & Haswell). 118 NSOU CC - ZO - 03 openings or apertures are termed dermal ostia or dermal pores, or incurrent pores. The radial canals and incurrent canals are arranged alternately.

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The wall between incurrent canal and radial canal is pierced by numerous minute pores, called prosopyles (

G. pros = near; pyle = gate). The radial canal is lined by flagellated choanocytes, it opens into the spongecoel by an opening, called apopyle (G. apo = away from; pyle = gate). There may be a short passage connecting the radial canal with the spongocoel which is called excurrent canal (Fig. 3). Both excurrent canal and spongocoel are lined by flattened pinacocytes (endopinacocytes). The spongocoel is narrow tubular or cylindrical and it opens to the exterior through osculum. The course of water current is as follows : Surrounding water → Dermal ostia → In current canals ↑ ↓ Osculum presopyles ↑ ↓ Spongocoel ← Excurrent canals ← Apopyles ← Radial canals This type of canal system is seen in Sycon (Scypha). Third grade : The third grade of syconoid canal system is foung in many genera of Calcareous sponges like Grantia, Grantiopsis, Heteropia, etc. The complecation is due to further addition of mesenchyme (mesohyl) to form a thick dermal cortex which spread over the entire outer surface of body. The incurrent canals become narrowed and traverse along irregular courses through the cortex before reaching the flagellated radial canals and connect with the latter by prosopyles. Sometimes large irregular cortical spaces of subdermal spaces are developed. The course of water is as follows : Surrounding water → Dermal osita → Dermal spaces → Incurrent canals ↑ ↓ Osculum Prosopyles ↑ ↓ Spongocoel ← Excurrent canals ← Apopyles ← Radial canal Leuconoid type : The most complex type of canal system in sponges is the leuconoid type. This type of canal system is characterized by–(a) folding and outpocketing of radial NSOU CC - ZO - 03 119 Fig. 5 : Sohematic representation of cnal system in sponges. The sycon type of canal system drawn here actually represents the syconoid (Stage 1) type. Dark bands indicate choanocyte layers nd arrows denote the course of water flow (after Hyman)

120 NSOU CC - ZO - 03 canals to maximum extent to form clusters of small and round or oval flagellated chambers or choanocyte chambers (as the choanocytes are limited to these chambers), (b) a very thick wall, thickness being increased by enormous development of mesenchyme or mesohyl forming dermal and gastral cortex, (c) a narrow or completely obliterated spongocoel and (d) complexity of incurrent and excurrent canals and flowing out of water through several oscula. In leuconoid sponges the cortex contains a system of branching incurrent canals. In many cases dermal pores open into subdermal spaces. The subdermal spaces and incurrent canals deliver water to the choanocyte chambers by way of small pores, the prosopyles. The flagellated chambers, in their turn, communicate with the excurrent canals through apopyles. Smaller excurrent canals unite to form larger ones, all eventually unite to form a major excurrent canal through which water reaches to osculum or osucula. The leuconoid type of canal system exhibits following three evolutionary gradations : (i) Eurypylous type; (ii) Aphodal type; (iii) Diplodal type (i) Eurypylous type : It represents the simplest type of leuconoid canal system and occurs in Leucilla and Plakina. It may be regarded as an intermediate condition called sylleibid stage between the syconoid and the more complex leuconoid. In euryphylous canal system the flagellated chambers are thimble shaped and open to the excurrent canal directly through wide apopyles (Fig.). (ii) Aphodal type : In certain leuconoid sponges such as Geodia, Stelleta, the flagellated chambers do not open into the excurrent canal directly. The apopyles, instead of being wide opeings, are drawn out as narrow tubes, called aphodus which connect the flagellated chambers to the excurrent canals (Fig. 3) (iii) Diplodal type : In some sponges like Spongilla, Oscarella, besides the aphodus another narrow tube, called prosodus, is present between each incurrent canal and flagellated chambers. Thus here both apopyles and prosopyles are drawn out into narrow tubes (Fig. 3, 4, 5) The course of water is as follows : Dermal ostia → Subdernal spaces and → Prosodus (when present) → Flagellated chambers ↑ many in current canals ↓ Surrounding water Apophyles ↑ ↓ Osculum (Oscula) ← Large excurrent canals ← Many excurrent canals ← Aphodus (when present) Rhagon type canal system : In Demospongiae (e.g. Spongilla), the existing leuconoid type canal system is not derived by way of asconoid or syconoid stages
NSOU CC - ZO - 03 121 as are evident in calcareous sponges. Instead the leuconoid structure is derived from a larval stage rhagon whose canal system is rhagon type. The sponge with rhagon type canal system has a flat broad base and it is conical in shape (looks like a pyramid)

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with a single osculum at the summit. The basal wall is termed hyposphere which is devoid of flagellated chambers. The upper wall with many small, oval flagellated chambers,

is called sphongosphere. The spacions spongocoel of rhagon is surrounded by the flagellated chambers opeing into it through very wide apopyles. Between the flagellated chambers and the pinacoderm Fig. 7 : Spongilla. Diagrammatic V.S. of body showing rhagon type of canal system. Fig. 6: Rhagon Larva. V. S. of body showing rhagon type canal system. 122 NSOU CC - ZO - 03 lies a considerably thickened mesenchyle (mesohyl) which is traversed by incurrent canals and subdermal spaces (Fig. 5 & 6). Functions of canal system : Canal system plays a very important or vital role in the life of sponges. All the vital physiological processes like nutrition, respiration, exeretion and reproduction are performed by this single system. The beating of flagellae of choanocyte cells create water current which flows through the canal system and

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brings the food and oxygen and takes away the CO 2 , nitrogenous wastes and

undigested food. During reproduction the water current

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carries the sperms from one sponge to another for fertilization of the ova. 3.5 Spicules in sponges The skeleton of sponges

is relatively complex and provides a supporting framework for the living cells of the animal. It is formed of spicules or spongin fibres or a combination of both, and serves as the basis of identification and classification of sponges. Spicules are crystalline shiny needle-like structures primarily located in the mesohyl but they frequently project throgh the pinacoderm, in some forms. The spicules (or sclerites) have definite bodies consisting of spines or rays that radiate from a point. These are secreted by specieal mesenchymal amoebocytes called scleroblasts. All kind of spicules have a core or central axis of organixc substances around which inorganic substances are deposited either in the form of calcium carbonate (calcite or aragonite) or hydrated silica (hydrated silicon dioxide). Thus spicules are basically of two types–calcareous spicules and siliceous spicules, based on their chemical nature. Calcareous spicules are characteristic of the class Calcarea and siliceous spicules are characteristic of the class Hexactinellida or glass sponges. Based on their size spicules are divided into two types–Megascleres and Microscleres. The megascleres are large structural specules, constituting the main skeleton. Microscleres are small to minute reinforcing (or packing) spicules occuring interstitially within the mesohyl. The demosponges and hexactinellids have both types but calcareous sponges often have only megascleres. The suffix–axon refers to the number of axes a spicules has, while–actine refers to the number of rays or points. A. Megascleres : Megascleres or larger "skeletal spicules" may be divided into following six types based on their shape. 1. Monaxons : These spicules have single axis and are shaped like straight needles or rods or may be curved. Their ends may be pointed, kuobbed or hooked. When growth of spicules take place in one direction only, the spicules are called monactinal monaxons (Fig. 8) or styles. Styles are
NSOU CC - ZO - 03 123 typically rounded at one end (called strongylote) and pointed at the other end (called oxeote). Styles in which broad end is knobbed are called tylostyles; those with minute spines or thorny processes on surface are called acanthostyles. Monaxon spicules that develop by growth in both direction from a central point are named diactinal monaxons, or simply diactines or rhabds. These may be of following four types : (i) Oxeas which are pointed at both ends, (ii) Tornotes which are lance-headed on both ends, (iii) Strongyles which are rounded at both ends, (iv) Tylotes which are knobbed at both ends like pin heads. Fig. 8: Spicules and spongin 1 to 9—Megascleres. 10, 10–microscleres. 1–monactinal monaxon. 2–Diactinal monaxon 3–Curved monaxon. 4–Triacnes. 5 & 6–Tetraxon calthrops. 7–Triradiate. 8–monaxon with ends hooked (anphidise0. 9–hexactinal triaxon. 10 & 11–polyaxons. 12–Spongin fibres. 2. Triaxon spicules : The triaxon (three-axes) or hexactional (six-rayed) spicule consists of three axes crossing at right angles, producing six rays extending at right angles from a central point. These spicules can be modified secondarily to produce many varieties by loss or reduction of rays. Triaxon spicules occure only in the class Hexactinellida. 3. Tetraxon spicules : These four-rayed spicules are also called tetractines or quadriradiates. Four rays of a tetraxon spicule radiate from a common point but not in the same plane. When four rays are more or less equal in size, the spicule is called calthrops. When one ray is elongated (called rhabdome) bearing three smaller rays (cladome), the tetraxon spicule is called triaene. If one smaller ray is lost it becomes diaene. When the elongated ray or rhabdome bears disc at both the ends, it is called 124 NSOU CC - ZO - 03 amphidisc. Loss of elongated ray results into a triradiate or triactinal spicule, called a triod and it is characteristic of calcareous sponges. 4. Polyaxon spicules : In polyaxon spicules several equal rays radiate from a central point. 5. Spheres : These are almost round spicules in which growth takes place concentrically around a centre. 6. Desma : Desma is a special kind of megascleres consisting of an ordinary minute monaxon, triradiuate or tetraxon spicules called crepis on which 9 : layers of silica are irregularly deposited. Based on different shapes of crepis, desmas may be named monocrepids, tricrepids and tetracrepids. In the begining silica deposition follows the crepis but later develops elaborate branches and when they are united into a network then it is called lithistid. B. Microscleres Microscleres are minute flesh spicules which are scattered in the mesohyl and sometimes are seen projecting in the canals. They support the pinacoderm lining the water canals. Microscleres are of following types : 1. Spires : Spires are curved in one plane or spirally twisted. They exhibit many shapes. The most common types are the C-shaped forms, called sigmas. Spirally twisted sigmas are called sigmaspires. Bow shaped spires
NSOU CC - ZO - 03 125 are called toxas, chelas have curved hooks or plates at both ends, when two ends are alike the chelas are called isochelas, when unlike they are anisochelas. 2. Asters : Asters include types with small centres and long rays. Among the small centered asters are oxyasters with pointed rays, strongylaster with rounded ends and tylaster with knobbed rays. The large centered forms include spherasters with definite number of rays and sterrasters with rays reduced to small projections. Short spiny microscopic monaxons are known as streptasters. 3.6 Phylum : Cnidaria The phylum Cnidaria is a diverse group with cosmopolitan distribution. It includes familiar hydras, transparent jelly fishes, beautiful and bright coloured sea annemones, and a variety of corals. While the poriferans or sponges are 10 :

126 NSOU CC - ZO - 03 regarded as first group of multicellular animals, the cnidarians are definitely one more step advanced groups in having tissue grade of structural organization, i.e. tissue grade of construction first appeared in Cnidaria among the metazoans. General Charadcteristics of Cnidaria : 1. Cnidarians are multicellular animals with tissue grade of organization. 2. They are aquatic, mostly marine except a few freshwater forms. 3. They are sessile or free swimming and solitary or colonial. 4. Body radially symmetrical, some are biradial. 5. Cnidarians are diploblastic with outer epidermis (developed from embryonic ectoderm) and inner gastrodermis (developed from embryonic endoderm) separated by a non-celllular jelly-like layer called mesoglea or partly cellular mesenchyme derived primarily from ectoderm. 6. The body wall encloses a single, central, blind sac-like body cavity lined by the endoderm, called gastrovascular cavity or coelenteron, with the mouth as the only opening. Mouth is encircled by short and slender tentacles arranged in one or more whorls. Mouth also functions as anus. 7. Presence of highly specialized intra-cellular structures–the cnidoblasts (or nematoblasts) containing stinging organelles called namatocysts or cnidae. Cnidoblasts are located in epidermis specially in tentacles. Cnidoblasts are unique to the members of the phylum and the phylum name Cnidaria has been cointed for them. They serve for defence, offence, food capture and adhension. 8. Cnidarians are carnivorous, digestion is both intracellular and extracellular. 9. Respiratory, circulatory and excretory organs are absent. Gas exchange is performed by diffusion. 10. Nervous stystem is of primitive type consisting of diffused network of unpolarized nerve cells. 11. In cnidaria two different body forms may exist–a “medusa” (representing sexual phase) adapted for pelagic existence and a “polyp” (asexual phase) adapted for benthic existence. 12. Reproduction by

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both asexual and sexual modes. Asexual reproduction by budding and sexual reproduction by the formation of

ova and sperm. Development often involves a bilaterally symmetrical ciliated “planula” larva. 13. In some forms life cycle exhibits the phenomena of

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metagenesis in which the asexual polypoid, sessile generation alternates with sexual medusoid, free swimming generation,

both being diploid phases.

NSOU CC - ZO - 03 127 3.7 Classification of Cnidaria The classification scheme followed here is based on the scheme outlined by Ruppert and Barnes (1994) in their book “Invertebrate Zoology” (6 th edition). According to them the phylum Cnidaria includes four classes–– Class Hydrozoa Class Scyphozoa Class Cubozoa Class Anthozoa Classification with characters (upto classes) Class Hydrozoa : 1. Exclusively polyploid or exclusively medusoid or both forms in the life cycle. 11 :

128 NSOU CC - ZO - 03 2. Mesoglea acellular or non-cellualr and jelly like. 3. Gastrovascular cavity without stomodium, septa or nematocysts bearing gastric filaments. 4. Namatocysts are confined to the epidermis only. 5. Medusa with a true muscular velum which improves swimming efficiency. 6. Reproductive cells usually ectodermal in origin and discharged to the exterior directly. 7. Metagenesis distinct. 8. Mostly colonial and marine, a few solitary and freshwater. 9. Phenomonon of polymorphism is common. Class Hydrozoa includes about 3000 species. Exmaples : Hydra, Obelia, Physalia, Valella, Porpita Class Scyphozoa : 1. Medusoid form is dominant in the life cycle; polypoid form is very insignificant. Medusa is bell or umbrella-shaped. Fig. 12 : Nematocyst discharge.

NSOU CC - ZO - 03 129 Fig. 13 : Some Important Cnidarians. (a) Protohydra, (b) Stylaster, (c) Millepora, (d) Clavularia, (c) Clytia, (f) Cerianthus, (g) Anthomustus, (h) Gorgonia, (i)Telesto, (j) Praya, (k) Acropora, (l) Nausuthar, (m) Corallium, (n) Hydra, (o) Velella, (p) Physalia, (q) Pennatulla, (r) Taelia, (s) Durelia, (t) Fungia

130 NSOU CC - ZO - 03 2. Mesoglea is cellular and thick. 3. Endodermal gastric tentacles are present. 4. Nematocyst containing cnidoblast cells are found both in the epidermis and gastrodermis. 5. Gastrovascular cavity without stomodium but with endodermal gastric filaments or tentacles. 6. Velum absent. 7. Sense organs usually in the form of tentaculocysts. 8. Gonads are endodermal in origin and gametes are shed in the gastrovascular cavity. 9. Polypoid stage usually absent or represented by small polyp, the scyphistoma which gives rise to medusae by transverse fission or strobilization. 10. All are marine, solitary, free swimming or attached by aboral stalk. The class Scyphozoa includes about 200 species. 14 :

NSOU CC - ZO - 03 131 Examples : Aurelia (Moon jelly), Pilema, Pericolpa, Cyanea Class Cubozoa : 1. Small medusoid cnidarians with a highly transparent cuboidal swimming bell. 2. Bell margin simple. 3. Presence of velum along the margin of the medusa. 4. There are four tentacles or four clusters of tentacles at four corners of the bell margin. The class cubozoa includes about 20 species. The members are known as sea wasps or box jellies. Examples : Tripedalia, Chrybdaea, Chironex, Chiropsalmus Chironex fleckeri (sea wasp) is found in the coastal waters of Australia. It is considered one of the most deadly of all marine animals. Death takes place within 3 to 20 minutes of stinging. 15 :

132 NSOU CC - ZO - 03 Class Anthozoa or Actinozoa : 1. Exist only in polypoid form, medusa phase is absent. 2. Body cylindrical with hexamerous or octamerous biradial or radiobilaterial symmetry. 3. Mesoglea cellular with fibrous connective tissue and amoeboid cells. 4. Stomodaeum strongly developed and posses siphonoglyphs (ciliated grooves in the stomodaeum). 5. The oral end of the body is expanded radially into an oral disc bearing hollow tentacles surrouding the mouth in the centre. 6. Gastrovascular cavity is divided into compartments by complete or incomplete septa or mesenteries. 7. Mesenteries bear nematocysts at their free inner edges (gastrodermal or endodermal) 8. Skeleton either external or internal. Exoskelton may be of calcium carbonate which often forms massive corals. 9. Gonads are gastrodermal (endodermal) in origin and develop in the mesenteries. 10. Gametes are discharged into coelenteron, fertilization external. 11. The fertilized eggs develop into a planula larva that metamorphoses to form the polyp. 12. Members are solitary or colonial, mostly colonial, exclusively marine. Class Anthozoa is the largest class of Phylum Cnidaria. It includes about 6000 species of sea anemones, corals, sea fans, sea pens, etc. Examples : Adamsia, Metridium (both are sea anemones), Gorgonia (sea fan), Pennatula (sea-pen), Tubipora (organ-pipe coral), Corallium (red coral). Fig. 16: Different tyhpes of Anthozoan Corals. (After Kaestner). A. Fungia (Mushroom coral). B. Meandrina (Brain coral). C. Tubipora (organ Pipe coral).

NSOU CC - ZO - 03 133 3.8 Phylum : Ctenophora The members of phylum ctenophora are a small group of free-swimming, planktonic marine animals with transparent, delicate, gelatinous bodies. In the history of metazoan evolution, the ctenophores stand a step ahead of the cnidarians by having a low grade of triploblastic construction. They are commonly known as sea walnuts or comb jellies (Gr. Ktenes = combs; ophora = bearing). They are abundant in coastal water. General Characters : 1. Ctenophores are exclusively marine and most are planktonic. 2. Body is soft transparent, pear-shaped, cylindrical or flat or ribbon like and biradially symmetrical with oral-aboral axis. 3. Body wall consists of an outer epidermis, inner gastrodermis and a middle gelatinous and thick mesoglea containing mesenchymal muscle cells. 4. Cnidocytes absent but special adhesive cells, called colloblasts or lasso cells are present on the tentacles and help in food capture. 5. Eight meridional rows of ciliary plates or comb plates are present that help is locomotion. 6. They are predatory (carnivorous) animals feeding on other planktonic forms. Digestion both extracellular and intracellular. 7. Nervous system is diffuse having a sub epidermal nerve net and aboral end bears sense organ, the statocyst. 8. Skeletal, respiratory, circulatory and excretory systems are absent. 9. Mostly hermaphroditic (monoecious), gonads endodermal. 10. Development indirect with a distinctive cydippid larva. 11. Nearly all ctenophores are bioluminescent. Classification : It was Hatschek (1839) who put all the ctenophores under a distinct phylum. The scheme of classification followed here is based on the scheme outlined by Ruppert and Barnes (1994) in their book “Invertebrate Zoology”, 6 th edition. The Phylum Ctinophora is divided into two classes––Class 1. Tentaculata; Class 2. Nuda

134 NSOU CC - ZO - 03 Fig. 17: Some Important Ctenophorans (a) Beroe, (b) Cestum, (c) Ctenoplana, (d) Pleurobrachia, (e) Velamen (d - 1) (e)

NSOU CC - ZO - 03 135 Class Tentaculata : 1. Adults nearly always with two long aboral tentacles. In some only the larva has tentacles, while adults possess oral lobes. 2. Mouth narrow and pharynx small. 3. Body may be round or oval or elongated, may be laterally compressed or ribbon like. Example : Hormiphora, Pleurobranchia, Velamen. Class Nuda : 1. The members of this class lack tentacles and oral lobes. 2. Body large, conical and laterally compressed. 3. Mouth wide and pharnx or gullet is large occupying greater portion of the interior of the body. 4. Voracious feeders feeding on other ctenophores. This class includes only one one order and only one genus of that order is Beroe. Beroe is available in all seas and measures about 20 cm in height (Fig. 17) 3.9 Metagenesis in Obelia The term metagenesis was first introduced by Haeckel in 1866. Metagenesis is a phenomenon where diploid (2n) sexual and diploid (2n) asexual generations alternate each other cyclically to complete the life cycle of a sexually reproducing individual. Amongst Cnidarians this phenomenon of metagenesis is excellently shown by Obelia. The Obelia colony represents the fixed hydroid or asexual stage (2n) which produces medusa buds (2n) by budding (Fig.). These medusa-buds subsequently transform into full-fledged medusae which represent the solitary, free swimming sexual stage (2n) and possess male or female gonads. The male and female gametes (n) are produced in the respective gonads. Fertilization of mature egg with sperm results into the formation of zygote (2n), which in turn passes through the usual development stages. The zygote ultimately gives rise to a free swimming larval stage, the planula larva, which, after a brief period settles down and fixes itself to the substratum and transforms into the next stage, the hydrula stage. The hydrula then forms the obelia colony. So in the life-cycle of Obelia, there is a distrinct alternation of two diploid phases (Fig.). One phase is completely engaged in the growth of the colony, the asexual phase or polyp phase, while the other phase is engaged in the
136 NSOU CC - ZO - 03 production of haploid (n) gametes, the sexual phase or medusa. Such a phenomenon is called metagenesis. The life cycle of Obelia does not represent the alternation of generations because alternation of generation is a phenomenaon where diploid (2n) asexual generation alternates with the haploid (n) sexual generation cyclically to complete the life cycle. Fig. 19 : Life-cycle of obelia. Note the chromosome constitution of different life stages for understanding metagenesis Fig. 18: Life-history of Obelia. Note the presence of asexual and sexual phases in life-history. The free- sdwimming medusae and planula larva assist in the dispersal
NSOU CC - ZO - 03 137 3.10 Polymorphism in Cnidaria Polymorphism (Gr. poly = many; morphe = form) is the occurance of different types of individuals or zooids in a single species during its life cycle. It may be defined as the "phenomenon of existence of different physiological and morphological forms represented by an extensive range of variation within a single species." In polymorphism the different forms or zooids perform different functions so that there is a division of labour amongst the zooids. Amongst the cnidarians, the representatives of the class Hydrozoa provides good examples of polymorphism. Two basic forms : In Hydrozoa (or Cnidaria), which may be solitary or colonial, there occur two main types of forms or individuals or zooids–polyp form and medusoid form 1. Polyp form : A polyp has

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a tubular body with a mouth opening surruounded by tentacles at one end

and the other end is blind and usually atached to the substratum by a pedal disc. 2. Medusoid form : A medusa has a bowl or umbrella-shaped body with convex exumbrellar and concave subumbrellar surfaces. Subumbrellar surface with centrally located mouth on a porjection (manubrium). Medusa bears marginal tentacles. Polyp performs vegatative or nutritive functions while the free swimming medusa are reproductive in nature. Polyps and medusae are considered as Fig. 20: (a) Physalia, the portuguese man-of-war, a siphonophore; (b) part of a Physalia colony showing the division of labour between individuals.

138 NSOU CC - ZO - 03 homologous structures. These two forms alternate with each other in the history of a typical cnidarian–the polyp produces medusa asexually and the medusa producces polyp sexually. Polymorphic variabilities : Polyp and medusa occur in a number of morphological variations, several of which may be found in a single species. In the class Hydrozoa both polypoid and medusoid forms occur; in the class Scyphozoa the medusoid form is predominent while in the class Actinozoa, zooids are exclusively polypoid. Extreme specialization and variation of forms is exhibited by the members of the order Siphonophora (Fig. 21) and suborder Chondrophora of the class Hydrozoa. Their colonies exhibit the highest degree of polymorphism, which is not found anywhere else in the animal kingdom. Modifications of polypoid form. The polypoid zooids are as follows : 1. Gastrozoooids or Trophozoids or Nutritive zooids : These are tubular or cylindrical zooid with a mouth and a long contractile hollow tentacle arising at or near the base. Tentacle bears lateral fine contractile branches called tentilla.Each tentilla terminates in a knob or coil of nematocysts. Gastrozooids are also called siphonozooids. 2. Dactylozooids or Tasters or Feelers : These zooids are actually derived from the gastrozooids by reduction or total loss of mouth. They are elongated and highly extensible usually with a long unbranched basal tentacle. They are protective zooids as they bear many nematocysts. They exhibit many structural variations and are also called tentaculozooids, palpons, testers or feelers. Modified dactylozooids associated with Fig. 21: A few representatives of the order Siphonophora

NSOU CC - ZO - 03 139 genophores of gonozooids are termed gonopalpons. In Vallela and Porpita the dactylozooids arise from the margin of the colony in the form of long, hollow tentacle like fringing bodies (tentaculozooids). In Physalia the dactylozooids are excessively long. 3. Gonozooids or Blastostyles or Gonangia : These are reproductive zooids of the colony. They have club-shaped bodies without mouth and tentacles. Gonozooids give rise to male and female medusa buds, called gonophores, by budding. The living tissue of gonozooid is called blastostyle (Fig.) They are enclosed by gonotheca. In Physalia, gonozooids take the form of branched stalks, called gonodendra and bear grape like clusters of gonophores or medusae. Gonodendra are usually provided with a long retractile gonopalpon. In Valella and Porpita (Fig. 22) the gonozooids resemble gastrozooids and may even possess a mouth. Modifications of Medusoid form : The medusoid individuals exist in following forms : 1. Nectophora or Nectocalyx or Swimming bell : These are bell-shaped medusoids with a velum and radial canals and circular canal. They have no mouth, manubrium, tentales and sense organs. A nectocalyx is muscular and brings about locomotion of the colony by swimming. This form is present in Siphonophora except Physalia. 2. Bracts or Hydrophyllium or Phyllozooid : These forms do not resemble the medusa, though they are actually medusoid in origin. They have thick gelatinous shield-like, leaf-like, helmet-shaped or prismatic appeaance. The gastrovascular catity is simple or branched. Bracts are studded with nematocytes, serving for protection of other zooids of the colony, as found in Siphonophora. 3. Pneumatophore or Float : These are bladder-like or vesicle-like structures filled with gas. Each pneumatophore represents an inverted medusa bed; it is devoid of mesoglea and consist of an outer (exumbrellar) wall called pneumatocodon and an inner (subumbrellar) wall called pneumatosaccus or air sac. The opeing of the air-sac is directed upwards and reduced to a small pore, the pneumatopore which is guarded by a sphincter muscle. At the bottom (orginal roof) of the air sac, the epidermis is modified into a gas gland that secretes gas having composition similar to that of air. The air sac or float keeps the colony affloat. Float shows great variation in its structure and size in different siphonophores (Physalia, Halistemma, Agalma). 4. Gonophores : These reproductive zooids may occur singly on separate stalk or in clusters (e.g. Velella). They look like medusae in having bell, velum,

140 NSOU CC - ZO - 03 Fig. 22 : Differenttypes of zooids (after various sources). A. Gastrozoold with tentacle and bundle of memstocysts. B. Central gastrozooid of Velella. C. Dactylozooid with tentacle. D. Conozooid. E. Female Gonophore (medusold form). F. Male gonophore (medusold form). G. Nectophore or swiming bell. H. Bract or hydrophyllum. l. Physalie, Portuguese man-of-war, showing the pneumatophore of float. J. Part of Physalia.

NSOU CC - ZO - 03 141 radial canals and manubrium but lack mouth, tentacles and sense-organs. Gonophores are dioecious but the colonies are hermaphroditic bearing both type of gonophores in the same or separate clusters. In some cases, the female gonophores are medusa-like (e.g. Physalia, Porpita) but the male gonophores are sac-like. The gonophores produce gamates. Significance of Polymorphism : Polymorphism is essentially a phenomenon of division of labour in which different funtions are performed by diffeerent members or zooids of the colony viz. the polypoid forms are related to feeding and asexual reproduction, while the medusoid forms are related to sexual reproduction. Amongst all Cnidarians the members of the order Siphonophora (Halistemma, Physalia, Vellela, Porpita, etc.) represent the most specialized of class Hydrozoa, attaining the highest degree of polymorphism and presenting the greatest number of medusoid and polypoid zooids. Fig. 23: Polymorphic colonies of onidaris. A—Obeliad, B—Hydractina; C—Velella; D—A single connidum of Physalia; E—Generalized calycophoran Siphonophora showing different zoolds.

142 NSOU CC - ZO - 03 3.11 Corals and Coral Reefs Coral animals or corals are a group of marine, mostly colonial, polypoid (occur only in polyp stage) cnidarians, looking like miniature sea anemones and living in a secreted skeleton of their own. Their calcarious horny skeleton is commonly known as coral. The skeleton of a single polyp is known as corallite and many corallites combine to form the skeleton mass which as a whole, is known as corallum. Structure of a coral polyp : In structure the coral polyp is much like a small sea anemone except the skeleton portions. A typical coral polyp is cylindrical in shape, about 10 mm long and 1-3 mm in diameter. Actually the soft part of the body is somewhat like sea anemone but the basal disc is absent because the basal region of the polyp is surrounded by a calcareous skeleton cup. The basal cup is called theca. From the theca the polyp projects outside and into which it can be retracted. The oral disc bears a crown of tentacles, arranged in several rows around an elongated, oval or circular mouth. Tentacles are simple and of moderate length ending in a terminal knob bearing nematocysts. Pharynx or stomodaeum is short and without siphonoglyphs. There are complete and incomplete septa or mesentaries restricted to the upper part of the gastrovascular cavity. Fig. Structure of a corallite, Astroides. (After Kaestner).

NSOU CC - ZO - 03 143 The polyps of colonial corals are all interconnected but the attachment is lateral rather than aboral. The column wall folds outward above the skeletal cup and connects with the similar folds of adjacent polyps. Thus, all the members of the colony are connected by a horizontal sheet of tissue which represents folds of body- wall and so it contains an extension of the gastrovascular cavity with endoderm and ectoderm. The living coral colony thus lies entirely above the skeleton masses or coral masses i.e. they are found only on the surface layer of coral masses. Structure of Coral Skeleton : Skeleton of an individual coral polyp is known as corallite. It is a calcareous exoskeleton secreted by the ectoderm or epidermis of the polyp and it increases gradually during the life of the animal. In a colonial coral, corallites of individual polyps fuse together to form a skeletal mass, called corallum. According to Voucoch, the skeleton of coral is made up of calcareous crystals in a collodal matrix secreted by the ectodermal cells outside the body wall for the protection of the polyp. Each corallite is like a stony cup (Fig.) having the following parts : 1. Basal plate : The bottom of the skeleton cup of a polyp is basal plate. The wall of the cup enclosing the aboral portion. 2. Theca : The wall of the cup enclosing the aboral portion of the polyp is theca. From the theca the polyp projects outside and into which it can be retracted. 3. Sclerosepta : The cavity of the theca contains a number of calcarious ridges or partitions arranged vertically or projecting radially inwards. These ridges are called skeleton septa or sclerosepta, and these are connected at the base by basal plate and at the sides with the theca. The sclerosepta usually alternates with the mesenteries of the polyp and are commonly spiny or throny with toothed upper edges. 4. Columella : It is a pillar-like central skeletal mass which may arise independently as the outgrwoth from the basal plate or may be formed by the union of central ends of the sclerosepta. The columella formed by latter process is termed psuedocolumella. The collumella may be solid or trabeculae. 5. Epitheca : It is a distinct calcareos layer which surrounds the base of the theca in a ring like manner. 6. Costae : The epitheca is separated from the theca by a space and this space is crossed by continuations of the sclerosepta, called costae.

144 NSOU CC - ZO - 03 7. Pali : Small ridges between the columella and the main parts of the sclerosepta are called Pali. 8. Synapticula : These are skeleton bars connecting adjacent sclerosepta. 9. Dissepiments : These are horizontal plates between sclerosepta, which, when incomplete, are called dissepiments. 10. Trbeculae : When the horizontal plates between sclerosepta are large and extend completely across the corallite, they are termed as trabeculae. In living condition, the polyp fills the whole of the interior of the corallite and project beyond its edge. The proximal portion of its body wall is in contact with the theca which is a product of the epidermis. The free part of the body-wall of polyp is folded over the edge of the theca so as to cover its distal portion. Coral Reefs Vaughan (1917) has defined coral reef as "a ridge or mound of lime stone, the upper surface of which is near the surface of the sea and which is formed of calcium carbonate by the action of organisms, chiefly corals." The coral reefs are, in fact, Fig. 25 : Diagrammatic V.S. of a coral polyp with its corallite.

NSOU CC - ZO - 03 145 Fig. 26 A : Barrier reet, B. Sectional view of a barrier reef. Fig. 26 B. Fringing reef. B. Sectional view of fringing reef Fig. 26C. Atoll, B. Sectional view of an atoll.

146 NSOU CC - ZO - 03 produced by corals belonging to class Anthozoa, particularly by stony corals belonging to order Madreporaria. Hence the stony corals are considered as principal builders of coral reefs although other important contributors are the hydrocorallines, alcyonarians, coralline algae and foraminifera (shelled portozoa). In addition, sponges, starfishes, sea-urchins, crabs, some snails and bivalves also take part in the formation of compact structure of the coral reefs. The coral reefs are formed by incrusting their skeletal parts on the deposited lime. Coral reefs composed of multiple organisms vary in shape and colour. Reef building or hermatypic corals contain gastrodermal symbiotic algae (zooxanthellae) and thse are responsible for the rich colouration of corals which may be brown, yellow or green. Formation of coral reefs needs some particular environmental conditions. As the symbiotic algae require light for photosynthesis, the vertical distribution of living reef corals is restricted to the depth of light penetration. Hence coral reefs occur in shallow water, ranging to depths of 60 meters. Because of their dependence on light, reef corals require clear water. Thus, coral reefs are found only where the surrounding water contains relatively small amount of suspended material, that is, in water of low turbidity and low productivity. Reef building corals are further restricted by water temperature and occur in tropical and semi-tropical seas, where the average minimum water temperature is not less than 20ºC. Thus the reef building corals require warm, clear and shallow water. They can tolerate salinities between 30 to 40 ppt. Distribution of coral reefs is limited to continental and island shores in tropical and semitropical regions (latitude 28ºN-28ºS. i.e. about 28º on either side of the equator). Reef development is greatest in the Indo-Pacific region. The coral reefs grow very slowly. Most of them expand at the rate of 10-200 mm per year. The existing reefs seem to have been formed in 15,000 to 30,000 years. Coral reefs are estimated to cover 284,200 km 2 , about 0.1% of the oceans' surface area. The Indopacific region (including the Red Sea, Indian Ocean, Southeast Asia and the Pacific) account for 91.9% of this total. Southeast Asia accounts for 32.3% of that figure, while the Pacific including Australia accounts fot 40.8%. Atlantic and Caribbean coral reefs account for 7.6%. Coral reefs are thus limited to the Indopacific, the Central-Western Pacific and the Caribbean regions north of Bermuda. The Great Barrier Reef of north east Australia, extending from the east coast of Africa to the northeastern coast of Australia, is the largest barrier reef of the world. Six of world's seven species of marine turtle, over 1500 species of fish and almost 5000 species of mollusc have been recorded in this reef. It comprises over 2900 separate reefs and 900 islands streatching over 2600 km and covering over 348,000 km 2 . Besides Fiji islands of Pacific Ocean and those situated in Bahama islands region are the best known coral islands of the world. Bermuda is a coral

NSOU CC - ZO - 03 147 island where houses are built of coral blocks. Around India, coral reefs are found off Port of Okha and Dwarka in the Gulf of Kutch and also off Rameshwaram in the Gulf of Mannar between India and Sri Lanka. The coral reefs are also located at Andaman and Nicobar Islands and at Lakshadweep Islands. Types of Coral Reefs : On the basis of structure and underlying substratum Charles Darwin (1831) classified three types of coral reefs–(i) Fringing reefs or shore reefs, (ii) Barrier reefs, (iii) Atolls. Fringing reefs : The fringing reefs, also referred to as shore reefs, lie close to the shores of some volcanic island or part of some continent. A fringing reef may extend from the shore a few metres to 400 metres. (1/4 mile) seaward. The fringing reef consists of mainly three regions, namely (i) reef front or fore reef slope (ii) reef crest and (iii) the back reef, sometimes referred to as the reef lagoon or reef flat area. The seaward side of the fringing reef has a reef edge, called reef front or fore reef slope where the most active coral growth occurs. The coral growing areas represent a narrow belt like structure and is about 20 to 40 meters wide and subject to continuous surf. Below to this zone contains dead corals, rubble and sand. At the upper part of the reef front there is an elevated or emergent part, called reef crest. The seaward side of the reef crest takes the brunt of the wave action. Between the reef crest and the shore there lies a more or less flat area often eroded and uncovered at low tide, called back reef area or reef flat area. This area is shallow 27:

148 NSOU CC - ZO - 03 and is usually 50 to 100 metres or more broad (it may be a few kilometer). Fringing reefs are quite common in East Indies. 2. Barrier reef : The barrier reefs are somewhat like fringing reefs but they are located some distance away from the shore, in deep water. A barrier reef develops around island or along the edges of continental shelves and is separated by a wide and relatively deep channel, called laggon. The lagoon may be 20 to 40 fathoms deep and ½ to 10 miles or more wide through which ships can easily navigate. Like the fringing reefs the barrier reefs are divided into (i) reef front area, (ii) reef crest and (iii) back reef area or flat reef area containing lagoon. The most notable example of barrier reef is Great Barrier Reef on the north-east coast of Australia. It is the world's largest coral reef system composed of over 2900 individual reefs and 900 islands stretching for over 2300 km over an area of approximately 344400 km 2 . It is situated nearly over 160 km away from the shore. 3. Atoll : The atoll, also referred to as coral island or lagoon island is more or less circular or horse-shoe shaped coral reef enclosing a central area of water, called the lagoon. The lagoon varies from a few hundred meters to 90 kilometers in diameter and 20 to 90 metres in depth. The atoll reef may be complete or broken by a number of channels of which a few are navigable in between lagoon and outer seas. The outer side of the reef slopes off rather steeply into the depth of the ocean. Atolls are not connected with the main land but are usually separated from the main land by hundreds or thousands of kilometers. More than 300 atolls are present in the Indopacific region and the largest atoll of the world is Kwajalein atoll in the Marshall island of the Pacific Ocean that surrounds a lagoon over 97 km. Lakshadweep islands are an example of Indian atoll. The atoll of Bikine, famous for atomic and hydrogen bomb tests, lies in the Pacific Ocean. 3.12. Questions a) What is the function of Canal system in sponges? b) Write two important difference between asconoid and syconoid canal system? c) What do you mean by Sylibid stage? d) Where do you find choanocyte cells in Porifera? e) Write three important characters of phylum ctenophora? f) What are the important characters of class Hydrozoa g) What is the difference between Barrier and Fringing reefs? h) What do you mean by polymorphism i) Which class of Coelentrate animals are able to produce coral reefs?

NSOU CC - ZO - 03 149 Unit– 4 ?? ?Phylum : Platyhelminthes Structure 4.0 Objective 4.1 Introduction 4.2 General characteristics 4.3 Classification 4.4 Life cycle of Fasciola hepatica 4.5 Life cycle of Taenia solium 4.5.1 Pathogenecity of Taenia solium 4.6 Questions 4.0 Objective By studying this unit learners would be able to learn about the more advanced metazoan animals which are diploblastic and pseudocoelomate in nature. Fig. 1 : Three representatives of Platyhelminthes with a part of their body wall to show triploblastic organsation.

150 NSOU CC - ZO - 03 4.1 Introduction The term Platyhelminthes was first proposed by Gangenbaur (1859) meaning flatworms, because of their characteristic contour of flattened body. The term has been derived from two Greek words, platys means flat and helminthes means worms. They are a diverse group comprising of about 18500 living species, exhibiting evolutionary achievements over the diploblasts in having a structural body plan based on bilateral symmetry, in having a third layer of cells, the mesoderm and in having definite organs or system of organs. They, however, lack coelom, the body being compact (acoelomate) and the blood vascular system is absent. 4.2 General Characters of Phylum Platyhelminthes 1. Triploblastic, acoelomate (without a body cavity) and bilaterally symmetrical animals. 2. Body soft, unsegmented and dorsoventrally flattened. 3. Body shows organ grade organization. 4. Body shape

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varies from moderately elongated flattened shape to long flat ribbon-like and leaf-like.			

Length of the body may be extremely elongated in some and may reach as much as 10 to 15 metres. 5. Metameric segmentation and skeletal structures are absent. Psdudometamerism is seen in some members.

NSOU CC - ZO - 03 151 6. The anterior and of the body is differentiated into a head. 7. Body is covered with syncytial one layered partly ciliated epidermis; while in parasitic forms (trematodes and cestodes) the outer body covering is cuticle. 8. Adhesive structures like hooks, spines and suckeers and adhesive secretions common in parasitic forms. 9. Mouth is the single opeing of the digestive tract and the anus is absent. Digestive tract is totally absent in some. 10. No respiratory and circulatory systems. Respiration is aerobic in free living forms but anaerobic in parasitic flatworms. Gaseous exchange by diffusion. 11. The nervous system is most primitive type, ladder like, comprising of a pair of anterior gaglia with longitudinal nerve cords connected by transvers nerves. 12. Sense organs in the form of eye spots and chemoreceptors in free living forms. 13. The excretory system consists of protonephridia with flame cells. Absent in some primitive forms. 14. Sexes are mostly united; i.e. hermaphrodite or monoecious, but the digenean flukes are gonochoristic (separte sexes). 15. Reproductive system is complex and highly evolved in most forms. Asexual reproduction by fission also occurs in many free living forms. 16. Fertilization internal, may be cross or self fertization. 17. Development may be direct or indirect. In some parasitic forms development is very elaborate, involving several larval stages and hosts. 18. Parthenogenesis and polyembryony are common in trematodes and cestodes. 19. Flatworms are either free-living (turbalarians) or ecto or endocommensals or endoparasites. 20. They occur in all major habitats, aquatic and terrestrial and in the tissues of other animals. 4.3 Classification : In this text the classifactory scheme followed is based on the scheme outlined by Ruppert and Barnes (1994) in their book “Invertebrate Zoology” (6 th edition).

152 NSOU CC - ZO - 03 According to them the phylum Platyhelminthes is devided into four classes. 1. Class Turbellaria 2. Class Trematoda 3. Class Monogenea 4. Class Cestoidea Classification with Characters (upto Classes) : Class Turbellaria (L. turbella = a little string) 1. Turbellarians are mostly free-living and aquatic, great majority are marine and mostly benthic, a few are terrestrial but confined to humid areas. Some are brightly colourd. 2. Body size ranges from a few milimetres to 50 centimetres. 3. Body unsegmented, flattened and covered with ciliated cellular or syncytial epidermis, containing mucous secreting cells and rod-shaped bodies called rhabdites. 4. Locomotion by cilia and muscular undulations. 5. Presence of epidermal gland cells which help in adhesion, mucous secretion and other secretory functions. 6. Mouth opeing ventral, located at the end of an eversible pharynx which leads into a sac-like lobed or much branched intestine. Suckers absent. 7. Respiration by body surface. 8. Several pairs of longitudinal nerve cords, associated with peripheral nerve nets and cerebral ganglion constitute the nervous system. 9. Number of pigment cups, ocelli and statocysts are the sensory organs. 10. Excretory system includes flame cells in most cases. 11. Mostly hermaphrodite, with internal fertilization. Many reproduce asexually by means of budding or transverse fission and show high power of regeneration. 12. Development is direct in most speices. A free-swimming larval stage Muller’s larva is present in some forms (in a few polyclads). Examples : Planeria (fresh water flatworm), Bipalium (land planarian), Oligoclado (marine polyclad flatworm), Bdelloura (commensal on book gills of horse-shoe crabs), Dugesia (fresh water flatworn).

NSOU CC - ZO - 03 153 Fig. 3 : A showing the excretory system and male reproductive system of Ascaris, B. Female reproductive system of Ascaris. C. Spematozoon of Ascanis. D. Egg of Ascaris. Fig. 4 : Representatives of Phylum Platyhelminthes (not drawn up to scale). A. Convolute. B. Plaglostomum. C. Notaplana. D. Amphiline. E. Phyllobothrium. F. Dugesia. G. Echinococcus. H. Stenomum. I. Schislosoma. J. Aspidogaster. K. Gyrocolyle. L. Sphyranura.

154 NSOU CC - ZO - 03 Class Trematoda : (Gr. trematodes = perforated/having pores) 1. All are parasites, occuring especially in vertebrates. 2. Unsegmented dorsoventrally flattened leaf-like body, hence they are called "flukes". 3. Body covering is cuticle, cilia and rhabdites are absent Cuticle or tegument is thick and protects the parasite against hosts enzyme action. 4. One or more well developed suckers are present. Oral sucker for feeding and Ventral sucker (acetabulum) for attachment. 5. Mouth is anteriorly placed, gut well developed, with phrynx and branched intestine. 6. Excretion by flame cells. 7. Three pairs of longitudinal nerve cords. Sense organs are poorly developed. 8. Mostly monoecious or hermaphrodites. In most cases the testes are two or many but always single ovary. No asexual reproduction. 9. Development direct (in ectoparasites) or indirect (in endoparasites) with alternation of hosts, involving many larval forms. Examples : Fasciola hepatica (liver fluke), Schistosoma (blood fluke), Aspidogaster, Cotylapsis. Class Monogenea : (Gr. monos = single; genos - a race) 1. Mostly ectoparasites (some endoparasites) of aquatic vertebrates particularly on fishes and also on amphibians and reptiles (turtles). 2. Body dorsoventrally flattened and the posterior end of the body is provided with large attachment organ or adhesive disc, called opisthaptor or haptor. It bears hooks and suckers, allowing the parasite to cling tenaciously to the skin of the host. 3. Anterior end also has adhesive organ, called prohaptor, with adhesive glands and suckers. 4. Gut present but mouth lacks a sucker. The pharynx secretes a protease that digests the host's skin. 5. Inconspicuous protonephridia having paired excretory pores situated anteriorly on the dorsal side.

NSOU CC - ZO - 03 155 6. All are hermaphrodite. 7. Life cycle simple with single host i.e. no intermediate host. One egg gives rise to one adult worm, hence the name "Monogenea", meaning "one generation". 8. Ciliated "oncomiracidium" larva in the life cycle. Examples : Polystoma (in urinary bladder of frogs and toads), Polystomoidella (in urinary bladder of turtles), Dactylogyrus (on the gills of freshwater fishes), Gyrodactylus. Class Cestoidea : (Gr. kestos = a girdle, L. cestus = ribbon; eidos = form) 1. All are highly specialized endoparasites of vertebrates, and are commonly called tapeworms. 2. Body flat elongated and ribbon like, covered by a non-ciliated syncytial tegument (cuticle) having microvilli-like projectons. Rhabdites are absent. 3. Body is differentiated into three regions-head or scolex, neck and strobila or body. 4. Scolex usually with hooks and suckers for adhesion or attachment to the host. Fig. 5A : A terrestrial triclad flatworm, Bipalium, B. A marino Polyclad flatworm, oligoclado.

156 NSOU CC - ZO - 03 5. Neck is very short and narrow. It is proliferative giving rise to the body or strobila. 6. Strobila consists of linearly arranged number of segment-like sections called proglottids. 7. Mouth, digestive tract and sense organs are absent. 8. Each mature proglottid contains one or two sets of male and female sex organs. Thus tapeworms are hermaphrodite. 9. Life cycle complicated with one or more intermediate hosts. 10. Embryos and larvae posses hooks. Examples : Taenia solium (pork tape worm), Taenia saginata (beef tapeworm), Echinococcus granulosus (hook worm), Diphyllobothrium (fish tapeworm), Hymenolepis nana (dwarf tapeworm in the intestine of man). 4.4 Life Cycle of Fasciola hepatica Fasciola hepatica (L. fasciola = small bandage; Gr. hepar = liver), the sheep liver fluke, lives as an endoparasite in the bile passage of sheep. They are called flukes on account of their flat, leaf-like structure. It is the first trematode whose life history was described by A.P. Thomas in 1883. The parasite is of much importance as it causes fascioliasis or liver rot—a disease that causes immense damage to the liver tissues and bile ducts of sheep. A single sheep may harbour as many as 200 liver flukes in its liver. F. hepatica has a cosmopolitan distribution and is common in areas where sheep and cattle are being reared. The life cycle of Fasciola hepatica is completed in two hosts, hence it is called a digentic trematode. The primary host of this animal is sheep while the secondary host is a snail (gastropod mollusc) of the genus Limnaea. Sometimes the adult fluke invade other vertebrates like goat, horse, dog, ass, ox, rabbit, monkey and even man. Development of F. hepatica is indirect involving four types of free- swimming and parasitic larval stages between egg and adult. The completion of life cycle depends upon transfer of the parasite 6 :

NSOU CC - ZO - 03 157 from one host to the other. The life cycle can be described under the following headings : 1. Copulation and fertilization : Fasciola is hermaphrodite (monoecious) but cross fertilization is the rule, and self fertilization is very uncommon. Copulation takes place in the bile duct of the host. During copulation the cirrus or penis of of one worm is inserted into the opening of Laurer's canal of the other individual and the sperms are deposited in the oviduct. The eggs are fertilized by the biflagellate sperm in the lower part of the oviduct and then pass on to the uterus. 2. Formation of egg capsules and release of eggs. The fertilized eggs are brownish in colour, oval in shape and measure about 130- 150 μm in length and 63 to 90 μm in width. The fertilized egg receives a fair amount of yolk from the yolk cells and vitelline secretions. It finally becomes enclosed in a proteinaceous shell or capsule secreted by the shell glands. The shell becomes hard when it enters the uterus. The hardening is caused by the action of quinone. One pole of the egg capsule bears a small lid or operculum for the exit of the future larva. The egg thus bccomes complete and remains for sometime in the uterus. The egg capsule then leaves the fluke's body through its gonopore and passes down the bile duct of the sheep into the intestine, from where eventually it is discharged to the exterior along with faeces of the host. Fig. 10 : Liver fluke. A. Digestive system (after Kaestner). B. Nervous and reproductive systems (major part of the lateral nerve cords is removed).

158 NSOU CC - ZO - 03 Fig. 8 : Fasciola hepatica. Details of male and female reproductive organs in anterior region. Fig. 9 : Fasciola hepatica. Clevage and larva formation. A–Fertilized egg; B–Two cell stage; C–Many cell stage (morula); D–Miracidium.

NSOU CC - ZO - 03 159 The egg can survive if only it falls on damp soil or in water. 3. Cleavage and development : Cleavage or segmentation of the fertilized egg starts when the egg remain inside the uterus. The first cleavage is complete but unequal and produces two unequal cells–(i) a small granular propagatory cell and (ii) a large somatic or ectodermal cell. The Somatic cell by repeated divisions lead to the formation of ectoderm of larva. The propagatory cell divides further and forms two group of cells—propagative cells and somatic cells. Somatic cells form the larval body and the propagative cells form a mass of germ cells at the posterior end. Encapsulated embryos or capsules or simply eggs do not develop further in flukes uterus. Further development also remains arrested while the embryos remains in the faeces and they may survive in wet fecal matter for several months. If washed free the development of the embryos proceeds. The optimun Fig. 10: Fluke reproductive systems. (A) Reproductive structures of fasciola hepatka. (B) The region of the obtype in F. Hepatica. (C) Male copulatory apparatus with cirrus extended.

160 NSOU CC - ZO - 03 temperature for development ranges from 20-30ºC. The encapsulated embrys differentiates into a micracidium larva within eight to nine days at 30ºC, but at lower temperatures it may take 3 to 6 weeks. Availability of oxygen is also a factor. The miracicium hatches out of the capsule by forcing off the operculum. The larva produces a proteolytic enzyme which dissolves the cementing material by which the operculum is attached, thus releasing the operculum. Miracidium larva: The miracidium is a minute (0.13 mm long) somewhat oval or conical body, covered all over with cilia.

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The anterior end of the body is broader than the posterior end.			

The anterior end is produced into a non-ciliated apical lobe or apical papilla (also known as head lobe and terebratorium). The apical lobe bears openings of a pouch-like multinucleated apical gland and a pair of unicellular penetration glands or cephelic glands. These glands produce histolytic enzymes that help the larva during penetration in the host tissue. Behind the apical lobe there is a pair of eye spots or pigmented spots situated above the brain. These are considered as primary receptors of the larva. A large brain or nerve ganglion is situated antero- dorsally near the anterior end. Except the apical lobe the entire body of miracidium is ciliated and is covered with 21 closely fitted hexagonal epidermal plates which are arranged in five rows or tiers (Fig. 11). In the first row there are 6 plates, second 11 :

NSOU CC - ZO - 03 161 row also has 6 plates, third row consists of 3 plates, fourth row with 4 plates and fifth row has 2 plates. Within the body just below the epidermis there are delicate layers of circular and longitudinal muscle fibres. In the interior of the body, there is a pair of protonephridia, each with two flame cells. The protonephridia open to the exterior by two separate excretory pores or nephridiopores which are located laterally in the posterior half of the body. Towards the posterior side there are some propagatory or germ cells (or germ balls), which are developing embryos. The miracicium larva does not feed, it swims freely in water or crawl over damp surface for sometimes. It dies in eight hours unless it can reach a suitable intermediate host, which is some species of amphibious snail, of genus Limnaea (or even Bulinus or Planorbis). After getting a suitable host the miracidium adheres to it by its apical papilla, bores into the body by the operation of the penetration glands through the skin and reaches the internal organs, specially the pulmonary sac. From the pulmonary sac the larva penetrates into the body tissues with the help of penetration gland and finally reaches the snail's digestive gland. Within the intermediate or secondary host the miracidium casts off its ciliated epidermis, loses its sense receptors and swells up ans changes its shape to become next larval form, called sporocyst. Sporocyst : This is the second larval stage of Fasciola. It is an elongated germinal sac about 0.7 mm long and is covered with a thin cuticle. Below the cuticle, there are circular and lingitudinal muscles and some mesenchymal cells. The hollow interior of the sporocyst has a pair of protonephridia each with two flame cells. It also has some (about 25-40) germ cells or germ balls. The sporocyst moves about the host tissues and its germ cells divide and passess through embryogenesis to give rise to third larval stage, called radia larva. Each sporcyst produces 5 to 8 radiae. Some of the germ cells of sporocyst are set aside within the radiae for the development of next larval forms. The radia larvae come out of sporocyst and migrate to the hepatopancreas of the host. 12 :

162 NSOU CC - ZO - 03 Radia larva : The radia is an elongated (about 1.3 to 1.6 mm in length) cylindrical sac-like larva. It has a small anterior mouth, a muscluar pharynx with unicellular pharyngeal glands and a small sac like gut or intentine. The body wall consists of cuticle, mesenchyme and muscle layers. Near the posterior end there are two ventral porcesses, called procruscula or lappets. Near the anterior end of the body there occurs a ring like muscular ridge or swelling called collar. Collar helps in locomotion of larva. Behind the collar is present the birthpore. There is a pairs of protonephridia, each with many flame cells, which open to the exterior through a single nephridiopore on each side. Within the interior of the body there are undifferentiated germ balls. These germ cells give rise to a second generation of daughter radiae during summer months, but in winter they produce the fourth larval stage, the cercaria larva. Thus, either the primary radia or daughter radia produce cercaria larvae which escape through the birth pore of the radia into the snail tissue. Each radia forms about 14 to 20 cercariae. Cercaria larva : The larva is oval in shape with a long contractile tail. It measures about 0.25 mm to 0.35 mm in length. The body is covered with a thin cuticle. Below the cuticle are muscles and cystogenous glands. It has rudiments of organs of an adult. There are two suckers (oral sucker and ventral sucker) and an alimentary canal consisting of mouth, muscular pharynx, oesophagus and a bifid intestine. There is a pair of excretory ducts each with several flame cells. These open near the hind end of the larva into a bladder that leads out through a pair of nephridiopores. Cercaria larva also contains germ cells near the hind end. Rudiments of reproductive organs develop from the germ cells. A large number of unicellular Fig. 13 : Fasciola hepatica. A–Redia with daughter rediae, B–Redia with cercariae. Fig. 14 : Fasciola hepatica. A–Cercarie in vertral view; B–Cercaria in lateral view.

NSOU CC - ZO - 03 163 cystogenous glands are found beneath the cuticle. Secretion of these glands forms the cyst around the larva when it is transformed into metacercaria. On maturation the cercariae migrate from the digestive gland of the snail to the pulmonary sac from where they pass out into the surrouding water. The time taken in snail, from the entry of miracidium to the exit of cercaria, is five to six weeks.Cercaria swims about in the surrounding water for sometimes and settles down on the blade of grass or on leaves of some other aquatic weeds or plants. It sheds off tail and a cyst is formed around it. Thus, a metacarcaria representing a juvenile fluke is formed. Metacercaria : It measures about 0.2 mm in diameter and somewhat rounded in shape. It resembels cercaria larva but differs from later in the absence of tail, cystogenous glands and presence of a thick cyst wall. Its excretory bladder opens directy through a single pore. The germ cells and genital rudiments are present as such. The cyst provides protection against short periods of desiccation. The cyst wall consists of four layers. The metacercaria on vegetation may survive one year at low temperatures but two to three weeks at 25ºC. Infection to the final (primary) host : As mentioned earlier, the metacercaria remains attached to blades of grass or leaves of other plants. When the sheep feeds on metacercaria infested leaves or weeds, the metacercaria larva enters the gut. In the alimentary canal of the sheep, the cyst wall is digested and a young fluke emerges out and bores through the wall of the intestine and migrates to the liver through the hepatic portal system. The young fluke stay in the liver for 5 to 6 weeks feeding on its tisues and finally settles in the bile duct and grows into an adult fluke. The sexually mature fluke starts egg laying 12-14 weeks after infection. It can live in host's body for several years and a new cycle begins with the liberation of fertilized eggs. Pathogenicity of Fasciola hepatica : Infection by Fasciola hepatica, the liver fluke is a common occurance in sheep and some other domestic and wild animals feeding on vegetation. In general, the disease caused by the infection of Fasciola hepatica is referred to as fascioliasis. The effect of the parasite on its vertebrate host 15 :

164 NSOU CC - ZO - 03 is of significant economic importance and sometimes it may cause a serious economic problem. The animal causes serious damage to the bile duct and liver of its host. During migration of young worms throgh the liver they cause extensive damage to the liver tissue and in heavy infections may lead to portal cirrhosis. This is accompanied by haemorrhage (caused by cuticular spines of the worms), inflamation and loss of parenchyma tissue of liver. Thus during heavy infection the liver fluke seriously affect the liver of sheep, upsetting the normal metabolic functions of liver. The disease thus caused is called liver rot or acute fascioliasis as it occurs during the pre adult migration of the flukes in the parenchyma of the liver for about 8 weeks. Fig. 16 : Life history of liver fluke (after various sources)

NSOU CC - ZO - 03 165 Chronic fascioliasis : occurs beyond 12 weeks, when the flukes have reached the bile ducts and mature sexually. In the biliary passages, they may interfere with normal flow of bile, causing obstructive jaundice. The mature worms cause marked pathological changes in the bile ducts by mechanical irritation as well as by their toxic secretion. The bile ducts become thickend, which is followed by calcification and finally resulting in the formation of gall stones. Symptoms of liver-rot are more acute in lambs than in sheep, and appear about a month after infection. Frequently death may soon result due to cerebral apoplexy. However, if the host survives few weeks of infection it becomes a victim of acute anaemia due to suppression in production of new red blood corpuscles. Its appetite declines, rumination (chewing the cud) becomes irregular and at times there is fever and increase in respiratory activity. There will be failure to gain weight in young animals, weight loss in older animals, reduced milk production, conjunctiva becomes whitish yellow, wool become dry and brittle and fall off. Large oedemas or swellings appear on jaws. Rarely does the host survive this period. Thus, the infection by Fasciola hepatica causes heavy mortality in sheep population. In addition to cattle and sheep, F. hepatica has been reported from horses, goats, rabbits, pigs, dogs and squirrels. Human cases, of fascioliasis are also known. It is especially common in some Caribbean islands and South America, as well as southern France, Great Britain and Algeria. Humans become infected when they eat salads prepared by vegetables, particularly by watercress (eating raw or poorly cooked watercress with attached metacercariae). Fig. 17 : Life cycle of Fasciola hepatica.

166 NSOU CC - ZO - 03 It is to be mentiond that infection to the secondary host (snail) also causes partial and complete destruction of the affected site, which is preferably the digestive gland (liver) or gonad. Sometimes the infected snail attains gigantic size i.e. increase in size considerably. 4.5 Life Cycle of Taenia solium (Pork tape worm) Taenia solium is commonly known as pork tape worm. It is an endoparasite, the adult lives in the intestine of human beings. It has a cosmopolitan distribution. Taenia solium is a digenetic cestod (class Cestoda under phylum Platyhelminthes) i.e. its life cycle is completed in two hosts, human being is the primary host and pig is the secondary host. Taenia is found attached to the intestinal mucosa of humans by its scolex (head region) while the rest of the body lies free. It is most common in pork eating population of tropical and subtropical regions where pork is consumed as food without being properly cooked. The body is very elongated (varies from 3-5 metres), dorsoventrally flattened and looks like a ribbon or tape. The body of tapeworm is differentiated into three regions–head or scolex, neck and strobila. Scolex bears hooks and suckers for attachement to the host, neck is very short and proliferative, strobila consists of a large number lineraly arranged segments-like sections called proglottids. Fig. 18 : Taenia solium. An adult tapeworm.

NSOU CC - ZO - 03 167 The life cycle of Taenia solium may be described under the following headings : 1. Copulation and fertilization : Taenia is hermaphrodite. Each mature proglottid, after first 200,

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contains a complete set of male and female reproductive organs.

Taenia practices self-fertilization, i.e. eggs are fertilized by sperms from the same proglottid or one proglottid may be inseminated by a proglottid situated anterior to it. Taenia, in fact, is protandrous, and its male reproductive organs develop first in the anterior most mature segments. Thus, the anterior mature proglottids can copulate with the posterior proglottids. This is achieved by the bending of the strobila into folds. The possibility of cross fertilization is remote as no host is in a position to house two adult and large tapeworms at a time. Sperms injected into the vagina swim down to the seminal receptacle where they are stored temporarily till ova are released by the ovary. Fertilization occurs inside the ootype. 2. Formation of egg capsules : Just after fertilization, the fertilized egg or zygote gets surrounded by yolk cells in the ootype, received from the vitelline glands through the vitelline duct. The fertilized egg and yolk cells are subsequently enclosed in a thick, resistant egg shell secreted by the shell glands. The egg capsule or egg shell then passes into the uterus. The Fig. 19 : Taenia solium–entire specimen and enlarged view of different parts (after various sources) Hook Rostelium Sucker (Acetabulum) Scolex Progiottid B Sperm cuct Cimus or penis Genital pore Vagina Ovary Oviduct Sexually matured proglottid Cotype Uterus Testes Nerve Seminal receptacle Excretory canals Mehlis's gland Yolk gland Uterus Never cord Genetal pore Gravid proglottid A

168 NSOU CC - ZO - 03 secretion of Mehlis's gland facilities the passage of capsule in the uterus. The uterus grows in size and becomes branched laterally as it receives more and more egg capsules. The egg capsules are very small, about 40 μm in diatmeter. 3. Development (Onchosphere formation) : In Taenia solium development is indirect and includes a single larval stage. Development of fertilized egg starts in the uterus. The first cleavage is unequeal, producing a large megamere and a small embryonic cell. The megamere divides repeatedly to form many megameres. The embryonic cell divides repeatedly and produces two types of cells, larger mesomeres and smaller micromeres (Fig. 20). The micromeres form a ball of cells, called morula, in the centre. Mesomeres forms an envelope around the morula, while the megameres form an outer covering around the mesomere envelop. The megameres absorb yolk from the yolk cell and supply nourishment of the developing embryo. The large yolky megmeres fuse to form an syncytial nutritive envelope. With time the yolky envelope reduces and gradually disappears. Fig. 20 : Taenia solium. Stages in life cycle. A–Young onchosphere; B'Mature onchosphere; C–Free hexacanth; D–Bladderworm with invagination; E–Bladderworm with proscolex; F–Bladder worm with evaginated scolex; G–Cysticercus with neck budding off proglottids. morula vitelline cell embryophore hooks egg-shell embryophore hexacanth A B hooks bladder invagination D hooks proscolex invagination wall of bladder evaginated scolex rostral hooks E suckers suckers G suckers F rostral hooks scolex neck budding of proglottids bladder egg-shell

NSOU CC - ZO - 03 169 As development proceeds, the middle mesomere layer forms a thick, hard cuticularized and striated inner embryonic membrane called embryophore, around the morula. Beneath the embryophore a thin basement membrane is formed. The morula forms the embryo proper. Later on six chitinous hooks develop in the posterior pole of the embryo. These hooks are secreted by the onchoblast cells of the embryo. This six-hooked embryo is called hexacanth embryo. It also possesses a pair of large penetration glands in between hooks. Hexacanth is surrounded by two hexacanth membranes.The hexacanth embryo

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together with all the membranes surrounding it is known as onchosphere. The onchosphere loses the

outer shell so that the embryophore forms its outermost covering. By the time onchospheres are formed, the proglottid becomes gravid and increases in size. Its uterus forms 7-13 lateral branches on each side and fills the entire proglottid. The uterus of a gravid proglottid contains 30,000 to 40,000 onchospheres. Infection to secondary (intermediate) host : The gravid proglottids containing onchospheres at the posterior most part of strobila detach or break off (apolysis) in groups of 4 to 5 and pass out of the body of the host (human) along with the faeces. Fig. 21 : Taenia solium. Diagrammatic life cycle.
170 NSOU CC - ZO - 03 A newly shed proglottid wriggles for sometimes but eventually disintegrates setting free thousands of onchospheres. The secondary host pig acquires infection by ingesting the human faceal matter containing the onchospheres. On reaching the stomach of pig, the egg-shell and the embryophore get digested by the gastric juices and the hexacanth embryo is released. The hexacanth then passes into the small intestine. It is now activated by the presence of bile salts, bores its way through the intestinal opithelium to reach the sub mucosal blood vessels. This is accomplished, jointly by the penetration glands and six hooks.

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Hooks merely anchor the hexacanth to the intestinal wall, while secretion of penetration glands dissolves the intestinal tissues.

Entire process takes about 10 minutes, after which the hooks are of no use and are shed off. Submucosal blood vessel carries the hexacanth to liver via hepatic portal vein. From liver it reaches heart and enters the arterial circulation. It finally reaches the striated muscles in any part of the body. They usually settle in the muscles of the tongue, neck, shoulder, thigh,heart etc. Once settled in muscle each embryo absorbs a large amount of watery fluid from host tissue and grows to sphrerical, pea-size sac like cyst, called bladderworm or cysticercus larva. The cysticercus of Taenia solium is called cysticercus cellulosae. The flesh of pig or pork containing many cysticerci appear white spotted resembling something that of measles, hence it is characteristically called measly pork. Cysticercus or bladderworm : The hookless bladderworm gradually becomes encysted by the connective tissue of the host (pig). All cells of the cysticercus larva fall into two layers around the fluid-filled central cavity. Cells of the outer layer coalesce to form a syncitial tegument (layer of thick syncitial protoplasmic mass). The inner layer of cells is mesenchymal layer or germinal layer. At the future anterior end (opposite to the side where hooks were present) the wall of the larva thickens and then invaginates into the cavity (Fig. 21), as hollow nob. The invaginated knob develops four suckers on its inner surface and hooks and rostellum are developed at its bottom. Now this inverted knob is called proscolex. In fact, the embryo at this stage is called cysticercus or bladderworm, whose further development does not take place unless it is eaten up by the primary host. Thus fully formed cysticerci or bladderworms are infective to human hosts. They usually survive (in dormant state) in the flesh for several years. It has been seen that one kilogram of measly pork may contain 500 or more cysticerici. Infection to primary host (human) : Pork eating people get the infection of Taenia solium by eating raw or imperfectly cooked measly pork. The cysticercus becomes active on reaching the small intestine. Actually their bladder is digested and the proscolex everts or evaginates (tunred inside out) so that the suckers and rostellum come to lie on the outer surface as in the adults. Thus a scolex and a small

NSOU CC - ZO - 03 171 neck is formed. The scolex anchors itself to the mucous membrane of the intestine by the help of suckers and hooks. The neck begins to proliferate proglottids and gradually a series of proglottids are formed as strobila and ultimately an adult tapeworm is developed. In about 10 to 12 weeks the parasite attains adult condition with gravid proglottids. The life cycle of Taenia solium is not so complicated becaue it does not involve any asexual generation. The complete life cycle may be represented with the help of the following flow-chart : Adult tapeworm in human gut → Fertilized egg in mature proglottids → Egg capsules within gravid proglottids → Oncospheres in gravid proglottids → Gravid proglottids or onc spheres in human faeces → Onchospheres outside human body in faeces → Hexacanths in the gut of pig → Hexacanths in the intestinal blood vessels → Hexacanths in the heart → Hexacanths in the muscle → Cysticercus in the strited muscles → Measly pork → Cysticercus in the gut of human beings → Adult tapeworm in human intestine. 4.5.1 Pathogenicity of Tacnia Solium The infection of adult Taenia causes a disease called taeniasis in human beings while the condition caused by the infection of its cysticerici is called cysticercosis. The armed scolex may cause irritation of the mucosal lining and there have been cases in which the scolex perforated the intesitne leading to pertitonitis. Taeniasis is characterized by abdominal discomforts like pain, indigestion, vomiting, constipation, excessive appetite, diarrhoea, increase of eosinophil cells in blood and above all nervous disorders like nervousness, insomina, nausea and epileptic fits, etc. These disorders are caused by toxins produced by the parasite. Mechanical injury caused by hooks and suckers may initiate irritation in intentime, causing reverse peristalsis which lead to auto infection. Usually a single tapeworm is found to parasitize a host. This is because of the presence of one tapeworm provides a kind of immunity to the host against fresh infection. Cysticercosis is far more dangerous than taeniasis. Self infection or auto infection with eggs can result either from contaninated fingers or from eggs hatching in the intestine and carried to the stomach by reverse peristalsis (Cheng 1986). The bladder worms may reach different parts of the body through circulation. Cysticerci in humans may form in the muslces or subcutenious tissues, where they do little damage, although tissue responses generally occurs. If cysticerci develop in the eys, heart, spinal cord, brain, or some other important organ, the mechanical pressure exerted by these larvae (cyst) may cause, severe neurologic symptoms. Violent
172 NSOU CC - ZO - 03 headaches, convulsions, epileptic behaviour, local paralysis, vomiting and optic disturbances are common, sometimes so severe that death results. When a cysticercus dies, it elicits a severe inflametory response which in brain can cause death. Rarely a cysticerecus may become proliferative, developing branches that infiltrate and destroy the surrounding host tissues. Because of the ability of the cysticerci of T. solium to develop in practicelly every organ in the body, and because of the severity of the resulting pathology, this tapeworm must be considered among the most pathogenic of the human-infecting species. 4.6 Questions a) Describe the excretery system of Fasciola b) What do you mean by polyembrony? c) How many larval stages are present in Fasciola? d) What is scolex? e) What do you mean by qravid proglotid? f) Write short notes on i) Glycocalyex ii) Polyp iii) Prladder worm iv) Proscolex v) Rostellum vi) Hexacanth embryo vii) Heteromorphosis g) What do you mean by Psendocoèlom?
NSOU CC - ZO - 03 173 Unit – 5 ?? ?Ascaris & Wuchereria Structure 5.0 Objective 5.1 Introduction 5.2 General characters 5.3 Classification of Phylum Nematoda 5.4. Life cycle of Ascaris lumbricoides 5.4.1 Pathogenecity of Ascaris 5.5 Life cycle of Wuchereria bancrofti 5.5.1 Pathogenecity of Wuchereria 5.6 Parasitic adaptation in helminthes 5.7 questions 5.0 Objective The representative of the phylum Nematoda are commonly called nematodes or roundworms and they form the largest aschelminth phylum (12,000 described speices but there are probably many more undescribed than described species) and include some of the most wide spread and numerous of all multicellular animals (Ruppert and Barnes, 1994). Free living nematodes are found in the sea, in fresh water, and in the soil, and there are many parasitic species. They occur from the polar regions to the tropics, in all types of environments, including deserts, high mountain elevations, and great ocean depths. They may inhabit some unusal aquatic environment like hot springs in which the water temperature may reach 53ºC. The parasitic forms dispaly all degrees of parasitism and attack vitually all groups of plants and animals. The numerous species that infest food crops, domesticated animals, and humans make this phylum one of the most important of the parasitic animasl groups. The phylum also contains one of the most intensely studied laboratory animals, Caenorhabditis elegans, whose every cell has been traced throughout the course of development, and whose genome is one of the best known of any organisms. 5.1 Introduction These animals are commonly known as Nemathelminthes / Aschelminthes : Gegenbaur (1859) created a group Nemathelminthes to place some groups of psuedocolomate ani-

174 NSOU CC - ZO - 03 mals. However, Grobben (1910) introduced the term Aschelminthes in place of Nem- athelminthes. The Aschelminthes (G. askos = cavity; helmins = worm) are a heterog- enous assemblage of marine and freshwater animals having some characters in com- mon. These are : (a) possession of non coelomic body cavity, (b) distinctive types of pharyngeal and body wall construction (c) a through gut with a terminal or subterminal anus (d) lack of circulatory system (e) sexes separate (f) absence of asexual reproduc- tion and regeneration of body segments (g) cleavage asymetrical type that is neither radial or spiral (h) determinate type of development (i) absence of a larval stage (j) many species have an invarient and genetically fixed number of cells–a phenomenaon called eutely. In eutelic animals, mitosis normally ceases following embryonic devel- opment and growth contnues only through increase in size of cells, not through the number of cells. These charcters had led R.S.K. Barnes (1998) to assign Aschelminthes a superphylum status with seven phyla under it. Previous authors like Parker and Haswell (1972), had given the phylum status (consisting of five classes) to Aschelminthes. How- ever, Meglitsch and Schram (1991), Ruppert and Barnes (1994) and other recent au- thors do no longer consider Aschelminthes as either a superphylum or a phylum. The informal name Aschelminthes, however, is still a convenient terms of referance for the entire assemblage. Ruppert and Barnes, 1994 (6th edition) not only include all eight phylums (Gastrotricha, Nematoda, Nematomorpha, Rotifera, Acanthocephala, Kinorhyncha, Loricifera and Priapulida) of Meglitsch and Schram (1991), but also the phylum Tardigrada. The tardigrades or water bears, traditionally grouped with the arthropods, show evolutionary relationship and aspect of their biology very similar to some aschelminthes. For this reason Ruppert and Barnes (1994) have placed tardi- grades under the assemblage of Aschelminthes. 5.2 General Characteristics 1. Nematoda (G. nema = thread; eidos = form) include widely distributed aquatic or terrestrial, free living or parasitic roundworms. 2. Body is slender, elongated and cylindrical (hence the name roundworm) with both ends gradually tapering. 3. Bilaterally symmetrical, triploblastic unsegmented animals. 4. A thick and flexible cuticle enclosed the body and lines the pharynx, hindgut and other body openings. Cuticle moulted periodically. 5. Mouth is located at somewhat rounded anteror end and is surrounded by lips and sensila of various sorts. There may be six lip like lobes in primitive marine forms and only three lips in terrestrial and parasitic species. Primitively the anteriour end and lips bear 18 sensilla.

NSOU CC - ZO - 03 175 6. Body wall without circular muscles and made entirely of longitudinal muscle fibres arranged in four bands. 7. Body cavity is pseudocoel filled with parenchyma in most cases. Pseudocoel is small or non-existent in most small free living species but voluminous in large forms (e.g. Ascaris). 8. Complete digestive tract with distinct mouth and anus. Digestion extracellular. 9. Blood vascular system and respiratory orgns absent. 10. Excretory system without flame cells or nephridia. Excretion is performed by general body surface, excretory canal system or by excretory gland cells (called renette cells). 11. Nervous system comprises of a brain in the form of a circumpharyngeal nerve ring with dorsal, ventral and lateral nerves. 12. Principal sense organs (sensillae) are papillae, setae, amphids and phasmids, all of which are associated with cilia. 13. Sexes are separate (dioecious) but hermaphrodites, such as the well studied Caenorhabditis elegans, are not uncommon. Males are often smaller than females, and the posterior end of the male may be curved like a hook or broadened into a fan-shaped copulatory aid, called a bursa. 14. Fertilization internal, sperms lack flagella and are amoeboid. 15. Cleavage pattern neither spiral or radial but strongly determinate. Development is direct. 16. Nematodes have successfully adapted to nearly every ecosystem and are very widely distributed invertebrates. 5.3 Classification of phylum Nematoda The classification of phylum Nematoda presented below is based on Ruppert & Barnes (1994). They classified the phylum into two classes and 20 orders. 1. Class Adenophorea (Aphasmida) 2. Class Secernentea (Phasmida) Class Adenophorea (Aphasmida) : 1. Phasmids (caudal sensory organs) are absent. 2. Presence of variously shaped amphids (paired chemosensory pits) behind the lips. 3. Presence of cephalic setae and papillae.

176 NSOU CC - ZO - 03 4. Excretory organs are only renette cells but without collecting tubules. 5. Usually two testes in male. 6. Most representatives of this class are free living, some are parasitic. The free-living species include terrestrial and freshwater forms and almost all of the marine forms. Examples : Euoplus, Monochus, Enophus, Dorylaimus, Trichordis Class Secernentea (Phasmida) : 1. Presence of pore-like amphids in the lateral lips (amphids open to outside by pores). 2. In the caudal region presence of paired phasmids. 3. Excretory system canal-like and comparatively more complex. 4. Males possess single testis. 11. Many parasitic forms are members of this class and the free-living speices largely inhabit soil. Examples : Ascaris lumbricoides (human round worm), Wuchereria bancrofti (filaria worm), Ancylostoma duodenale (hook worm), Loa loa (eye-worm), Rhabditis, Dracunculus medinensis (guinea worm) 5.4 Life Cycle of Ascaris lumbricoides Systematic Position : Phylum : Nematoda Class : Secernentea or Phasmida Genus : Ascaris Species : lumbricoides Ascaris lumbricoides is one of the most familiar endoparasite in the small intestine of man. The worm may migrate to other neighbouring areas. It has also been reported from apes, pigs, cattle, sheep and squirrels. It remains free in the intestine and feeds on partly digested food (chyme) of the host. It is common particularly among children and has a cosmopoliton distribution but is much more common in tropical and subtropical coutries.

NSOU CC - ZO - 03 177 The body of Ascaris is fairly large, males measure about 15-25 cm in length and 3-4 mm in diameter, while femals are 25-40 cm in length and maximum 5 mm in diameter. The body is elongate, cylindrical and grdually tappring at both ends. The adult worms are light brown or pinkish in colour when alive, but gradually changes to white outside the intestine. The mouth opening is guarded by three conspicuous lips-one dorsal and two ventral. The tail of male is shaprly curved ventrally while in female it is nearly straight. In female a little in front of the tail end lies a mid-ventral transverse aperture or anus, guarded by thick lips. Females can also be distinguished by the presence of separate and independent genital aperture situated on the ventral surface at about one-third of body length from the anterior end. In male there is a cloacal aperture at the curved portion of the tail and pair of needle-like chitinous penial setae protrudes through the cloacal aperture. Life Cycle : Ascaris passes its life cycle (Fig. 4) in one host and no intermediate host is required (hence it is a monogenic parasite). Human being is the only host. Eggs are produced in large numbers by the mature females (prodigious egg producer), depositing about 20000 eggs daily and the uterus may contain upto 27 million eggs at a time. Copulation or mating takes place when the parasites remain in the intestine of the host (human). Penial setae of male help to open the female genital pore and transfer of sperms to the oviduct of female. Eggs are fertilized in the upper part of the uterus. When the fertilized eggs move downwards through the 1A :

178 NSOU CC - ZO - 03 uteri, they are surrounded by a highly resistant chitinous egg shell and an outer irregualar albuminous coat. Actually the tough covering of the fertilized egg consists of three layers––(i) an inner lipoid layer formed by the fat globules of the egg, (ii) a middle chitinous layer formed by the glycogen globules of the egg and (iii) an outer quinone-tanned protein layer formed by the secretion of uterine wall when the fertilized egg passes down through the uteri. This protein layer represents as wart- like structure. A fine net-like fibrous layer is also present outside of the protein layer. The eggs at this stage are elliptical and measure about 60-70 μm in length and 40- 50 μm in width (Cheng, 1986). The fertilized eggs leave the mother's body through gonopore into the host's intesitne and finally pass out with the host's faeces. The outer covering of the egg is now golden brown in colour due to bile pigment adsorbed from faeces. Among the oval fertilized eggs are found numerous unfertilized eggs, indetifiable by their elongated shape and absence of the albuminous coat. When the fertilized eggs are expelled from host's body, the zygote is uncleaved, and it remains in this state until the eggs reach soil. Eggs deposited in soil are resistant to desiccation but are, at this stage of development, very sensitive to environmental temperatures. The zygote within the eggshell develops at an environmental (soil) temperature between 15.5ºC and 35ºC and development ceases at temperatures below 15.5ºC, and eggs can not Fig. 1B :

NSOU CC - ZO - 03 179 survive temperatures more than slightly above 38ºC (Bogitsh et.al.2005). Other factors such as moist soil and oxygen are necessary for development of embryo. Smyth (1994) reported that development of the embryo takes place between the temperatures of 22ºC to 33ºC and eggs gradually degenerate above 38ºC. They can remain alive for years in moist soil. The cleavage is spiral and determinate type. The 16-celled embryo attains the form of a hollow ball the blastula. Its cavity is blastcoel. Blastula transformed in to gastrula by the processes on invagination and eipboly and ultimately develops into a tiny active juvenile in about 10-14 days from the beginning of cleavage. Structurally the

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juvenile possesses an alimentary canal, a nerve ring and a larval exeretory system. This juvenile resembles very much with Rhabditis (a soil nematode), hence it is also termed rhabditiform larva or

rhabditiod (first stage). This larva moults within the egg shell in about seven days

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and becomes the second stage juvenile or second stage rhabditoid.

This stage of the life history of Ascaris is infective to the host. The larva remains in coiled condition within the egg shell. 2 :
180 NSOU CC - ZO - 03 Under suitable conditions of moisture, oxygen and temperature, infective eggs of Ascaris lumbricoides are known to remain viable in the soil for two years or longer. The larva remains quiescent within the egg shell until it reaches a new host. As there is no intermediate host, man acquires infection directly by ingesting Ascaris eggs with contaminated food or water. The infective eggs are not hatched until they reach the small intestine (duodenum). They hatch within two hours of reaching the intestine. The larvae measures about 0.2 to 0.3 mm in length and 13 to 15 μm in breadth. The newly hatched larvae burrow their way through the mucous membrane of small intestine and enter the circulatory system, and are carried via the venous system to the liver. Here they live for a period of 3 to 4 days. Then after passing through interlobular veins, central veins, sublobular veins and hepatic veins, they are drained into the inferior vena cava which opens into the right atrium of the heart. From heart they are transported to the lung via pulmonary artery. In the lung they enter the alveoli and settle down for sometimes. Here they moult twice, the first moulting takes place after 5-6 days (third stage larva) and second moulting after 10 days. From the alveoli of lungs the larva reach bronchi, trachea, larynx and finally to pharynx, from where they are coughed up (irritation causes caughing) and then 3 :
NSOU CC - ZO - 03 181 swallowed for second time and pass again to the small intestine. In the intestine they moult for the fourth and last time to become adult. During this migration the worms increase their lenght about 10 times from their initial length (from 0.2 to 0.3 mm to 2 to 3 mm). The young Ascaris becomes sexually mature adult within 8-10 weeks, and begins its life cycle again. The interval from ingestion of infective eggs to the apperance of sexually mature worms in the small intestine is about three months (Bogitsh et.al. 2005). 5.4.1 Pathogenicity of Ascaris Infection of Ascaris lumbricoides in human is known as ascariasis. Children are more susceptible to ascariasis than adults. The symptoms attributed to Ascaris infection may be divided into two groups : (a) those produced by migrating larvae and (b) those produced by the adult worms. 4 :

182 NSOU CC - ZO - 03 Symptoms due to the migrating larvae : Little damage is associated with the penetration of host's intestinal mucosa by newly hatched larvae. However, aberrant larvae migrating in such organs as the spleen, liver, lymph nodes and brain (through general circulation) usually elicit inflametory responses and unusual clinial symptoms. When the larvae escape from capillaries in the lungs and enter the respiratory system, they cause small haemorragic foci accompanied by coughing, fever and difficulty in breathing. Larvae in large numbers can produce many small blood clots, leading to Loffler's pneumonia (or Asaris pneumonitis). If large areas of lungs are affected it may lead to potentially fatal pneumonitis. Disturbances have been reported due to presence of larvae in the brain, spinal cord, heart and kidneys. Symptoms due to the adult worms : As the adulworms inhabit the upper part of the small intestine, the symptoms are therefore mostly related to the gastro- intestinal tract. Unless large number of adulworms are involved, there is little pathology associated with their presence, but symptoms such as abdominal pain, asthma, insomnia and eye pain may occur. Except for abdominal pain, these symptoms represent allergic responses to metabolic excretions and secretions by the worms. "Toxins" produced by the worm may cause irritation of mucous membrane, nervous symptoms like convulsions, delirium (light headedness), coma (deep sleep), and nervousness. Antienzymes liberated by the parasite interfare with protien digestion which leads to protein deficiency and stunted growth especially among children. Loss of appetite and insufficient absorption of digested food also occur as a result of heavey infections. When large numbers of adults are present, mechanical blockage of the intestinal tract may occur. The worms frequently migrate and may enter the stomach and may be vomitted out or pass up through the oesophagus at night, coming out through the mouth or nose. During migration Ascaris may accidentally enter into the respiratory passage causing suffocation or they may even enter into a bronchus. Furthermore, worms may penetrate through the intestinal wall or may enter the lumen of appendix, causing appendicitis. If peritonitis develops, death is common. The adult worm may even wander up the bile duct to the liver, causing abscesses, or down the pancreatic duct, causing fatal, haemorrhagic pancreatitis.
NSOU CC - ZO - 03 183 5.5 Life Cycle of Wuchereria bancrofti (Filarial worm) Systematic Position : Phylum : Nematoda Class : Secernentea or Phasmida Order : Filarioidea Genus : Wuchereria Species : bancrofti Wuchereria bancrofti is a widely distributed human parasitic roundworm, lives in the lymphatic vessels and lymph nodes of human and causes lymphatic filariasis or Bancroft's filariasis. It is one of the three parasitic nematodes, together with Brugia malayi and B. timori, that infect the lymphatic system to cause lymphatic filariasis. These filarial worms are spread by a variety of mosquito vectors. W.bancrofti is the most prevalent of the three and affects over 120 million people, primarily in central Africa and the Nile Delta, Turkey, India, South East Asia, the Philippines, many Pacific islands, Indonesia, Australia, the Caribbean islands and parts of South America. Wuchereria is a digenetc parasite completing its life cycle in two hosts. The definitive host is human harbouring the adult worms while the intermediate host is a blood sucking insect, the female mosquito of the genus Culex pipiens (in India). Fig. 5 : Distribution of Wuchereria bancrofti. (+Islands, black areas, concurrent Brugia Malayi)
184 NSOU CC - ZO - 03 Unlike the malaria organisms, filarial worms show little specificity in regard to mosquito hosts. W. bancrofti can utilize Culex spp. Aedes. spp., Mansonia spp. Anopheles spp. and Psorophora spp. as vectors equally well (Cheng 1986). As a dioecious nematode W. bancrofti exhibits sexual dimorphism. The adult worms are long, cylindrical with both ends terminate bluntly. They are creamy white in colour or almost transparent.

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Males and females can be differentiated by size and shape of their tail tips. The

males are smaller measuring 40 mm in length and 0.1 mm in diameter. The tail is curved and carries two spicules of unequal length. It also contains number of genital papillae or caudal papillae. Females are 80-100 mm in length and 0.24-0.30 mm in diameter. Its tail gradually tapers and rounded at the tip. No additional sensory structures are seen. The valva or genital pore lies ventrally towards the anterior part in the pharyngeal region and is provided with a pyriform ovijector.

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Adult males and females are most often coiled together and are difficult to separate. Females are ovoviviparous and

lay eggs containing well developed larvae. The hatched larvae or juveniles are known as microfilariae (Fig. 6). Though they are commonly called microfilaria larvae but they should appropirately be termed embryo (Cheng 1970) becasue their internal organization represents an early developmental stage and they are also not comparable to other nemtode larvae. Life Cycle : The stages in the life cycle of Wuchereria bancrofti are depicted in Fig. As mentioned earlier the life cycle of this parasite is completed in two hosts (digentic). The primary or definitive host is human being and the secondary or intermediate host is female mosquito belonging to genus Culex, Aedes and Anopheles. Culex quinquefasciatus (Culex fatigans) and in some places a closely related species Culex pipiens play a leading role as vectors in different parts of the world. Life cycle in human beings : The adult parasites resides in the lymphatics of the human host. They are found mostly in the afferent lymphatic channels of the lymph glands in the lower part of the body. The adult males measure 40 mm in length and 0.1 mm in diameter, while the adult females are 80-100 mm in length and 0.24- 0.30 mm in diameter. Copulation takes place when individuals of both sexes are present in the same lymph node or lymphatic vessel. Adult males and females are most often coiled together. Females are ovoviviparous i.e. lay eggs with well deveolped larvae or juveniles. Each gravid female gives rise to numerous (about 1000) minute larvae or juveniles called microfilaria which are surrounded by delicate membranes or sheaths and measure 127-320 μm long. They are born in a very immature state. They are colourless and transparent when living. Body of a microfilaria consists of a surface covering of flattened epidermal cells and an inner column of cytoplasm containing nuclei. Important structures from anterior end to
NSOU CC - ZO - 03 185 backwords are : future mouth or oral stylet, nerve ring, nephridiopore, renette cells, darkly staining inner mass, 4 large cells (G-1, G-2, G-3 and G-4) and future anus (Fig. 6). The caudal end is pointed and without nuclei. The microfilariae, discharged into lymph vessels, soon enter blood vessels and circulate with blood showing active movements. These larvae are unable to develop futher in human body unless they are sucked up by the intermediate host, the female mosquito. If they are not ingested by mosquito they will die within 70 days (Rao 1933). In order to infect mosquitoes there must be about 15 or more microfilarie per drop of blood, a high concentration of 100 or more per drop of blood is fatal to mosquitoes. 6 :
186 NSOU CC - ZO - 03 Life cycle in mosquito : The microfilaria are sucked up by the mosquito (Culex pipiens/Culex fatigans) along with blood meal. The larvae pass to the midgut of the insect and lose their sheaths or cast off their sheaths quickly, penetrate the gut wall within an hour or two and migrate to the thoracic muscles. Here they rest and begin to grow. In the next two days the slender, snake-like organism changes to a thick, short sausage-shaped form with a short spiky tail, measuring 124 to 250 μm in length and 10 to 17 μm in breadth. This stage of development represents the first larval stage. It possesses a rudimentary digestive tract. Within 3 to 7 dyas the larva grows rapidly, molts (shed cuticle) once or twice and at the end of this stage measures 225 to 330 μm in length and 15 to 30 μm in breadth. This stage represents second stage larva. On 10th or 11th day the metamorphosis becomes complete within muscle. The tail atrophies to a mere stump and the digestive system, body cavity and genital organs are now fully developed. This is the third stage larva which measures 1500 to 2000 μm in length and 18 to 23 μm in breadth. At this stage the larva is infective to man and migrates to the proboscis sheath of the mosquito on or about 14th day. There may be several larvae remaining coiled up, waiting for an opportunity to infect human host while the mosquito is having its blood meal. The time taken for the complete developement of microfilaria in the mosquito varies from 10 to 20 days or more, depending however on the atmospheric temperature, humidity and also to a certain extent, on the species of the mosquito. 7 :
NSOU CC - ZO - 03 187 Infection to human and development into adult worms : When the infected mosquito bites a human being, the third stage larvae are not directly injected into the blood stream like malarial parasites but are deposited on the skin near the site of puncture (

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the larvae creep out of the labium to the human skin).

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Later attracted by the warmth of the skin, the larvae either enter through the puncture wound or penetrate through the skin of host. Unlike the malaria parasites, filarial worms show little specificity in regard to mosquito hosts. W. bancrofti can utilize Culex spp. Aedes spp, Mansonia spp., Anopheles spp., Psorophora spp. as vectors eqully well (Cheng, 1986) The third-stage larvae (infective larvae) after entering through skin, reach the lymphatic channels, settle down at some spots (inguinal, scrotal or abdominal lymphatics), and begin to grow into adult forms. In course of time, probably after a period of 5 to 18 months they become sexualy mature. The male fertilizes the female and the gravid females releases the new generation of microfilariae which passess either through the throracie duct or the right lymphatic duct, to the venous sysem and pulmonary capillaries and then to the peripheral circulation (capillaries of the systemic circulation), thus completing the life cycle. Nocturnal and diurnal periodicity : The phenomenon of nocturnal periodicity– that is occurence of microfilariae in the peripheral circulation of the host at night– - 8 :
188 NSOU CC - ZO - 03 has been reported in most instances. The microfilariae of W. bancrofti of oriental countries (periodic strain) exhibit periodical appearance in the peripheral blood at night mostly between 10 p.m. and 4 a.m. thus showing nocturnal periodicity. It has been reported that during daytime they retire principally inside the capillaries of lungs, kidneys, heart and the big arteries, such as carotid. The evolution of microfilarial periodicity is of survival value, for it enhances chances for the ingestion of microfilariae by the insect vectors. Interestingly, the so-called Pacific strain of W.bancrofti, unlike the periodic strain, exhibit a certain degree of dirunal periodicity. Here the microfilariae appear in greater numbers in the peripheral blood during the day. The South Pacific strain is said to be subperiodic. This opposite rhythmic pattern coincides with the feeding habit of its mosquito vectors, Aedes pseudoscutellaris, Aedes polynesiensis, etc. which feed on day time. Several hypotheses have been contributed to explain nocturnal periodicity. (1) There is chemotactic attraction between the microfilariae and the saliva of mosquito hosts (vectors), which are more plentiful at night. (2) The relaxation of the host during sleep induces the microfilariae to migrate into the peripheral circulation. (3) The migration results from a response to oxygen and carbon dioxide supply. (4) The microfilariae sruvive for only a short period, and it is during the nocturnal period - 9 :
NSOU CC - ZO - 03 189 that they are most abundant and are readily found in the peripheral circulation. None of these hypotheses is completely satisfactory (Cheng 1986). 5.5.1 Pathogenicity of Wuchereria Wuchereria bancrofti is one of the classic cousative agents of elephantiasis in human. Elephantiasis is also known as filariasis or Bancroft’s filariasis. Pathology in W.bancrofti infection is due largely to living, dead and degenerating adult worms. Blocking of the lymph vessels by large number of worms results in serious short- term hymphatic inflamation and edema marked by pain and fever. Over a long period, the accumulation or deposition of connective tissue cells and fibres contributes to terrible enlargement of the legs, scrotum, breast and other extremities. Such enlargement is called elephantiasis (Fig. 10). Pathogenesis in filariasis is heavily influenced by the immune responses and the degree of inflamation. Clinically, the deisese can be divided into incubation, acute (or inflamatory) and obstructive (chronic) phases. The incubation phase is largely asymptomatic and may last for a year or more. Symptoms that do appear are usually mild and may include low-grade fever caused by lymphatic inflamation. This phase lasts until the first microfilariae appear in the blood. Fig. 10 : South Pacific native severely affected by Bancroft's filariasis.

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190 NSOU CC - ZO - 03 The acute phase is initiated when the females reach maturity and begin to release microfilariae. This phase is actually an allargic response to the products of dying and degenerating adult worms and is characterized by intense inflamation of the lymph areas usually in the lower parts of the body of patient. In males, scrotum is frequently affected. Chills, fever and toxemia, accompanied by localized swelling in the arms and legs, may persist for days, and/or recur at frquent intervals. The obstructive phase is characterized by blockage of lymph flow resulting from acute granulomatous response in the lymphatic system to dead and degenerating adult worms. This phase eventually lead to the condition known as elephantiasis. However, only about 10 percent of the inflected population manifests this chronic condition. Elephantiasis is rarely seen in people less than 25 years old and is more prevalent in people older than 40. The injurious influence excited by the adult worm and developing larva on its host is an inflamentaroy reaction of the lymphatic system, known as lymphangitis which forms the basic lesion in classical filariasis. Lesion in occult filariasis is caused by microfilariae and is found not only in the lymph nodes but also in lungs, liver and spleen. The metabolites of the growing larvae in highly reacting individuals may give rise to allergic mainfestation such as urticaria, "fugitive swellings" (painful, tender, red areas of the skin at the extrimites) and lymphoedema. 5.6 Parasitic adaptation in helminthes The term helminthes is derived from Greek word "Helmins" meaning worms. The term is not correct because it is applied to all elongated invertebrates without appendages and with bilateral symmetry. The term helminthes is restricted to a few phyla of invertebrate animals all of which are superficially worm like but they differ markedly in their morphology, life history and binomics. The helminthes ae restricted to three phyla of animal kingdom. These are : 1. Platyhelminthes (flatworms) 2. Nemathelminthes (round worms) 3. Acanthocephala (spiny headed worms) Parasitism is an association of two organisms of different sizes and differeent
NSOU CC - ZO - 03 191 species, in which the smaller organism (the parasite) is benefited and the larger organism (the host) is harmed. Adaptation to environments is one of the most important and dynamic features of living organisms.

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Adaptation may be defined as the fitness of an organism to live in its specific habitat or environment.

The term is also applied to "the process of adjustment involved and to a characteristic that so adjusts an animal." Of the different categories of adaptation, parasitic adaptation is important since it presents a peculiar condition in which a fortituous freeliving existence is altered to one in which protection from enemies and a good supply of food are guaranteed. The main changes that occur in the structure and life cycle of a parasite with the help of which it is capable of leading a parasitic life successfuly in its specific environment is called parasitic adaptation. This parasitic adaptation has brought about profound modifications in helminthes. Parasitism undoubtedly began as a chance of contact of one organism with another. Sooner or latter the guest began to partake the food produced by the host, becoming more and more dependent on such food and shelter and finally transformed into either an ectoparasite (outside the body of host) or an endoparasite (within the body of the host). The helminthes are modified morphologically, anatomically as well as physiologically to live in their particular environments of host body. The structural and functinal modificatious in parasites depend on the degree of parasitism. A. Morphological adaptations : Though helminthes come at the bottom of organ grade organization of animals, yet every part of the body of a helminth parasite exhibit twist due to parasitic mode of life. The structural modifications or adaptations of helminthes have taken place along two distinct directions– (a) Degeneration or loss of organs or organ system/s. (b) Attainment of new organs. (a) Degenerations : The endoparasites undergo loss or simplification of unused organs or parts. In helminthes loss or degeneration involves particularly the locomotory, digestive and the sensory organs 1. Organs of locomotion : Locomotion is actually an effort for procuring food, getting, mate and escaping from enemies. But the helminth endoparasites habitually inhabit such

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places in the host's body where sufficient food is available without effort. They need

no protection from enemies. Hence total reduction of locomotory structures is observed in adult except in the free-

192 NSOU CC - ZO - 03 living larval forms of parasites–miracidium possesses cilia and cercariae possess tail for locomotion. 2. Alimentary canal or organ of nutrition : Since the helminth parasites consume digested or semi-digested food or body fluid

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of the host, the alimantary canal and digestive glands are partly or wholly lost. In the adult trematodes there is an incomplete gut, in

adult tapeworm (cestodes) there is total disappearance of alimentary canal. In cestodes the food is readily availabe in the gut of the host. Stages such as rediae in lymph spaces of molluscs, microfilariae in blood vessels and Trichinella and cysticercus larva in vertebulate muscles occur in such locations that they are constantly surrounded by rich nutritious food, which is absorbed through the outer sruface of their body. 3. Sensory organs : The sensory organs, necessary for quick and efficient response to the stimuli are associated with free active life. In the host body the enviroment is more or less uniform and so the sense organs are not essential. Hence in helminthes they are either reduced or absent. In trematodes,

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sense organs are absent but are generally provided with tangoreceptors (

bulb like nerve endings sensitive to touch and pressure). Nematodes have reduced or poorly developed sensory

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organs on the lips (amphids) and on the tail (phasmids).

There are no sense organs in cestodes.

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Absence of complicated sensory structures can also be correlated to sedentary life in a sheltered habitat, espcically endoparasites. 4. Circulatory system

and respiratory

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system : Circulatory system is absent because circulatory system is primarily meant for transporation of nutrients that is not required

by the parasites. Similarly due to living in internal envirnoment without oxygen the helminthes, like other endoparasties, exhibit anaerobic respiration. (b) New attainment or Specializations : Parasitic existence of helminthes (like other endoparasites) leads to modification of old structures and attainment of new structures helpful in food absorption, protecion, attachement and vast reproduction. 1. Body form : The body form of parasites is such that they offer least resistance to the fluids of the host otherwise they might be explled out, e.g. Fasciola is dorsoventrally flatened and leaf-like, Schistosoma is thin and cylindrically elongated. Taenia is very elongated like a ribbon and dorsoventrally flattened. NSOU CC - ZO - 03 193 - 11 : 12 :
194 NSOU CC - ZO - 03 2. Integument : The integument (also called tegument) covering the body of helminthes has become greatly modified to serve the following three important functions : (i) Absorption : The integument

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is semipermeable and allows the fluids to enter the body. It becomes thin, serving partly or wholly for food absorption in parasites living in rich nutritious environments,

such as the adult liver flukes (in bile), blood flukes (Schistosoma) in the hapatic portal system, tapeworms (Taenia) in the intestine, Trichinella and cysticercus in vertebrate muscles and several larval forms developing in lymph spaces of mollusca or in blood stream. In Taenia the integument is thrown into minute projections known as microtriches which enhance the absorption by increasing the surface area. (ii) Protection against the digestive juice of the host : In case of larval forms of liver fluke which have to pass through for further development, a cyst capsule is provided as a protection against the digestive juice. In the gut parasites, such as tapeworms, certain gnathostomes (nematodes in cats, dogs and horses) and amphistomes (stomach or rumen flukes in ruminats) which remain attached to the gut wall,

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the cuticle becomes thick, impregnated with impermeable chitin-like substances and enzyme resistant, so that it is not digestible by the host's digestive juices

but is permeable to water. Some cestodes (e.g. Taenia) stimulate mucous lining of their host's intestine and enjoy a protective covering of mucous over them. These intestinal parasites also produce antienzymes to neutralize the action of digestive enzymes of their hosts. (iii) Protection against abrasion : Many trematodes living in the intestinal tracts are provided with spinous integument to guard against the abrasive action of the food and roughage flowing around them or passing through the gut. These spines may be accicular, dentate or placoid types and are rooted into the subintegumental layer. In the chinese liver fluke, Clonorchis sinensis, the larval stage possesses a spinous cuticle, suggesting that it was probably a gut parasite before converting into a parasite of the bile passage. 3. Modification for attachment/Organs for attachment : Essential prerequisite for parasitic life is the possession or attainment of

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suitable mechanisms for attachment with their hosts. Helminths are variously modified for adhesion to the body of their hosts.

Following modifications for attachment are often encountered : (i) Acetabula or suckers : These are found in all adult parasitic flatworms.
NSOU CC - ZO - 03 195 Fig. 13 : 14 :
196 NSOU CC - ZO - 03 Monogenetic flukes typically have an anterior and a posterior adhesive organs called the prohaptor and opisthaptor, respectively. The prohaptor consists of suckers and adhesive pads or glands (e.g. Gyrodactylus). The opisthaptor is usually the major organ of attachment, and include one or more well developed suckers with hooks (e.g. Polystomum, Polystomoidella, Diplozoon, Gyrodactylus). The digenetic flukes possess two hookless suckers. One, the oral suckers, surrounds the mouth and the other, the acetabulum (e.g. Fasciola hepatica). These suckers are usually supplied with adhesive gland cells, although the well developed ones operate mainly on suction produced by muscle action. The aspidogastrean flukes lack an oral sucker but have a large subdivided ventral sucker (Fig.). Schistosoma (blood fluke) also possesses two suckers.

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In tapeworms, the scolex bears either four sucking cups or large suckers (

e.g. Taenia solium) or accessory suckers (e.g. Myzophyllobothrium) or leaf-like outgrowth on the scolex, called bothridium. Phyllobothrium has four bothridia. These leaf-like structures are often equipped with suckers on their anterior ends. Another adhesive sucker like structures are bothria which are elongate longitudinal and shallow sucking grooves on the scolex. Echinobothrium and Diphyllobothrium bear two bothria, and Tetrarhynclus bears four bothria. (ii) Hooks :

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In some cestodes and nametodes, hook or hook-like structures also develop in or near the cephalic

and, which further help in attachement. In Taenia solium the hooks are arranged in double circlet at the base of the rostellum. In dog tapeworm (Diphylidium caninum) several rows of hooks are peresent around the retractile rostellum. In Macracanthorhynchus (an acanthocephalan parasite) a buccal armature is present bearing tooth-like structures which serve for tissue aberration and anchorage. In the hexacanth embryo of Taenia solium six hooks are there and the embryo with the help of the hooks bores into the wall of gut of host to reach the blood stream. In addition, the embryo has a pair of penetration glands which also helps in penetration. (iii) Glands : (Penetration glands or Histolytic glands) : In order to penetrate into the host the helminths have develop ceratin strutures or glands. Miracidia larva of fluke

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has a conical process at the anterior end called apical papillae.

There are

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a pair of penetration gland at the anterior end. These glands secrete histolytic enzymes that help in dissolving the host's tissue to penetrate into it.

In hookworms (Ancylostoma) there are glands in
NSOU CC - ZO - 03 197 the buccal region and the secretion of which are supposed to have anti- coagulative and histolytic properties. In most cercaria a large number of dark or brown unicellular cystogenous glands are present beneath the cuticle. These glands help in secreting a protective cyst around the cercaria tranforming it into metacercaria. These cysts help the metacercaria to overcome unfavourable conditions and protect them till they are finally eaten by their host. 4. Modification for reproduction : (Vast or excessive reproduction) : Reproductive system in helminthes, like other endoparasites, is highly developed as the parasites live in the hostile environment. It can be discussed under following heads– (i) Enormous development of reproductive organs : Large numbers of testes, ovaries, vitelline follicles and other associated structures are present in helminthes. In cestodes about 90% of the avaiable space of the body is occupied by reproductive organs. (ii) Hermaphroditism : All tremtodes and cestodes are hermaphrodites except a few like Schistosoma. Hermaphroditism is an adaptation, advantageous to the parasitic mode of life, to overcome the search of the mate. Many of the parasites have adopted self-fertilization to escape the failure of cross fertilization. (iii) Multiplication of reproductive organs : In cestodes reproductive organs are much more elaborate and are repeated in each proglotid. Each mature proglotid possesses one (T. solium) or two sets (Diphylidium) of male and female reproductive Fig. 15 : Monogenean parasites. A. Entire view of a Choriocotyle sp. showing the complex haptor. B. Polystomoidella sp. showing the hooks and haptor (From Pechenik).

198 NSOU CC - ZO - 03 organs. In each gravid proglotid, all other organs of the system degenerate to make room for the uterus which is greatly enlarged and branched to accomodate a large number of eggs. (iv) Enormous number of egg production : The egg production in helminthes is astronomical. The female Ascaris lumbricoides (round worm) lays about 2 lac eggs per day. Trematodes usually produce a few thousand eggs daily. The human hook- worm. Ancylostoma duodenale produces 25000-30000 eges per day. Cestodes produce very large number of eggs. Each gravid segment of tape worm Taenia contains 30,000-50,000 eggs and there may be 50-100 such gravid segments in one individual. Production of such an enormous number of eggs is an important adaptation of endoparsites to keep the continuity of their race because the chances of survival of most of the eggs are very remote and the parasites used to face a number of hazards to reach the host. (v) Larval multiplication : In addition to large number of egg production some helminths also practice asexual reproduction at larval stage. Each sporocyst of liver fluke produces 5-8 radia, from each of which 14-20 cercaria are produced. In cestodes larval multiplication takes place in some forms, e.g. a hydatid cyst developing from a single egg may contain thousands of scolices. B : Physiological adaptations : There are many physiological adjustments of parasites to cope up with their host or their environment. Most of the parasitic helminthes live within the body of the hosts and hence have to protect themselves from various substances produced by the host. The parasite living in the alimentary canal of the host has to protect itself from the action of diegestive juice of the host. Some cestodes stimulate mucous lining of their host's intestine and the secreted mucous then forms a protective clothing around the parasite (e.g. Taenia). Lime cells in the body wall of tape worms neutralize the acids formed in the host's gut. The gut or intestinal parasites also produce antienzymes to neutralize the action of digestive enzymes of their host. Green in 1957 reproted the presence of trypsin and chymotrypsin inhibitors in the body wall of Ascaris. Hymenolepis diminuta (a common tapeworm of rats and mice) releases proteins (enzyme inhibitors) that appear to inhibit trypisin activity. The tapeworms can also regulate the pH of its immediate environment to about 5.0 by secreting organic acids and this acidic output may also inhibit the activity of trypsin (Uglem and Just, 1983). Endoparasites normally possess a high range of pH tolerance of 4—11. Blood parasites are known to withstand the effects of anti-bodies and phagocytes by some mechanisms.

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The intestinal parasites live in an environment completely devoid of free oxygen, NSOU CC - ZO - 03 199 the respiration is thus of anaerobic type, consisting of extracting energy from the food

absorbed by the parasite. In the absence of oxygen, energy is obtained by the fermentation of glycogen which is broken through glycolysis. Endoparasitic flatworms seem to possess a considerable osmotic adaptability, as they can live successfully in different media. Liver fluke of sheep, for example passess through the stomach, body cavity and liver before reaching the bile duct. High fertility or excessive multiplication of helminthes, as mentioned earlier, is also a physiological adaptation to keep the continuity of the race. In conclusition can be said that the parasitic helminthes are intelligent enough as other organisms and they have accepted the challange of changing environment of host and have constantly modified/changed during the course of their evolution in order to survive in an efficient way in the host's hostile environment. But the specializaton and degeneration of structures or organs of parasites for life in peculiar environments, make them completely unfit for life in any other environment. Thus parasitism is a highly successful way of life in itself but it is a blind alley as far as any further evolutionary change is concerned. 5.7 Questions a) Write the Pathogenicity of Ascaris b) What is the name of disease produced by Wuchena? c) What do you mean by primary host and secondary host? d) Write the name of Vector of Wucheria bancrofti e) In which organ of human body Wucheria prefers to live? f) Is Coèlom is present in Ascaris? g) How humans are infested with Ascaris? h) Write the life history of Wucheria i) Describe the anatomy of Ascaris.

200 NSOU CC - ZO - 03 Unit – 6 ??Phylum : Annelida Structure 6.0 Objective 6.1 Introduction 6.2 General Charactersistics 6.3 Classification of Annelida 6.4 Locomotory Organelles in Annelida 6.5 Circulatory System in Annelida 6.6 Reproduction in Annelida 6.7 Questions 6.0 Objective This chapter elaborates the structure of first triploblastic animals and their structural peculiarities. From the chapter learness will learn the diversity of the animals belongs to the phylum Annelida. 6.1 Introduction The phylum Annalida comprises the segmented worms and includes the familiar earthworms, leeches and a number of marine and freshwater speices. A distinguishing characteristics of the phylum is segmentation (metamerism), the division of the body into similar parts, or segments which are arranged in a linear series along the anteroposterior axis. They range from a deep sea species measuring less than 1 mm in length to giant tropical earthworms (of Australia) which measure upto 4 metres in length. Annelids are soft-bodied, elongated, cylindrical, bilaterally symmetrical, metamerically segmented coelomate worms having a thin covering of cuticle often with segmental chitinous setae. 6.2 General characteristics 1. Triploblastic and bilaterally symmetrical coelomates. 2. Body soft, elongated, vermiform (worm-like) and ringed appearance (L. annellus = a ring).

NSOU CC - ZO - 03 201 3. Metamerically segmented body (i.e. body is divided into similar parts or segments which are arranged in a linear series along the anteroposterior axis). The segments are marked externally by transverse groovs and internally by transverse septa. 4. The body cavity or coelom serves as a hydrostatic skeleton against which muscles contract. 5. Body wall consists of a fibrous collagenous cuticle, glandular epidermis in which the nerve fibres are situated, and a connective tissue dermis of varying thickness. Below the dermis there are outer layer of circular muscles and inner layer of longitudinal muscles. 6. Head comprised of prostomium and peristomium. Prostomium contains brain and in some forms sensory appendages. Terminal part of body is pygidium that bears the anus. 7. Locomotory organs are segmentally arranged, paired chitinous lateral bristles called setae or chaetae. They are absent in leeches and in some polychaetes. 8. Digestive tract is a straight tube running from the anterior mouth to the posterior anus. Digestion extracellular. 9. Respiration through general body surface (provided that it is kept moist) and/or by gills in some tube dwellers. 10. Circulatory system is well developed and closed type. Blood is usually confined to small vessels but larger sinuses may also occur. 11. Respiratory pigments in blood are red haemoglobins or green chlorocruorins. Both pigments are found in blood plasma, not in blood cells, as found in vertebrates. Haemerythrin (a non haem red protein pigment lacking porphyrin) is also present in some polychaetes. 12. Nervous system consists of a pair of cerebreal ganglia (supra pharyngeal ganglia) or brain and a double ventral cord bearing ganglia and lateral nerves in each segment. 13. Excretory system consisting of metamerically disposed and paired coiled tubes, called nephridia. 14. Annelids are often provided with coelomoducts which are channels for the outward passage of reproductive elements. 15. Gonads develop from coelomic epithelium. 16. Sexes may be united (monoecious or hermaphrodite) or separate (dioecious).

202 NSOU CC - ZO - 03 17. Development is direct in monoecious forms and is indirect with trochophore larva in dioecious marine forms. 18. Cleavage spiral and determinate. 19. Power of regeneration is well noticed in many annelids. 20. Mostly aquatic, some terrestrial, burrowing or tubicious (living in tubes), sedentary or free living. Some commensal and parasitic. 6.3 Classification of Annelida The annelids were previously termed as "worms" and were grouped under the old phylum Vermis. Cuvier in 1798 pointed out the fundamental difference and separated them from Vermis. Later in 1909, Lamarck coined the name Annelida. Phylum Annelida includes about 17000 living species. The classification described here is according to the classification scheme outlined by Ruppert and Barnes (1994) in their book "Invertebrate Zoology", 4th edition. Phlylum Annelida includes three classes– 1. Class Polychaeta; 2. Class Oligochaeta; 3. Class Hirudinea Class Polycheata (G. poly = many; chaete = bristles). Characters : 1. Predominantly marine, mostly carnivorous with errant (free-moving) or sedentary habit. Sedentary forms are either burrowers or tube-dwellers. 2. Body usually elongated, cylindrical and distinctly segmented into many similar metameres. 3. Anterior end is modified into a distinct head which bears many, sensory structures like eyes, tentacles, cirri and palps. 4. Each body segment carries a pair of fleshy, lateral paddle-like outgrowths or appendages called parapodia which bear many large setae or chaeta (in bundles). Parapodia are locomotory organs. 5. Clitelum absent. 6. Alimentary canal is usually straight with an eversible buccal region and a muscular protrusible pharynx. 7. Cirri or branchiae (gills) are highly vascular and act as respiratory organ. In some parapodia are used for gas exchange. 8. Blood vascular system well developed and does not communicate with coelom. Respiratory pigments are haemoglobin (most common),

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NSOU CC - ZO - 03 203 Chlorocruorin and haemerythrin. 9. Principal specialized sense organs are eyes, nuchal organs and statocysts. Nuchal organs consists of a pair of ciliated sensory pits or slits, often eversible, situated in the head region of most polychaetes. Statocysts are found in many sedentary burrowers or tube dwellers. 10. Segmental metanephridia for excretion. Protonephridia in some. 11. Sexes separate in most. Gonads are localized, may be temporary, exetending throughout whole body. 12. Epitoky, a reproductive phenomenon, seen in some polychaetes. 13. Fertilization external. Free swimming larval forms is trochophore. No cocoon formation. Examples : Nereis, Aphrodite (sea mouse), Chaetopterus, Arenicola, Sabella, etc. Class Oligochaeta (G. oligos = few; chaete = bristles) 1. Mostly terrestrial and fresh water forms with secondarily marine representatives. 2. Head indistinct, prostomium small, without eyes and other sensory structures. 3. Body segmented, parapodia absent but possess segmentally arranged setae embedded in the integument. 4. Clitelum present. It is glandular and secretes cocoon for the eggs. 5. Usually no respiratory organ except a few. Gas exchange through moist body wall by diffusion. 6. Most are scavengers, feed on dead organic matters, particularly vegetation. Digestive tract straight. 7. Excretory system metanephridial type. 8. Circulatory system well developed (basically similar to that of polychaetes). Respiratory pigment haemoglobin, dissolved in plasma. 9. Hermaphrodites with well developed reproductive systems, limited to a few anterior segments. 10. There is copulation and reciprocal transfer of sperm (cross fertilization occurs externally within a cocoon). 11. Development direct and takes place within cocoon secreted by the clitellum. Examples : Pheretima, Lumbricus, Tubifex, Chaetogaster, Dero, Megascolex. Class Hirudinea (L. hirudo = leech)

204 NSOU CC - ZO - 03 1. Most are freshwater, some are marine or terrestrial some are ectoparasites, blood suckers or carnivorous (predaceous). 2. Dorsoventrally flattened and elongated body with definite number of segments. Each segment subdivided externally into 2 to 4 secondary rings or annuli. Head indistinct. 3. Parapodia, setae and cephalic appendages are absent. 4. Presence of two suckers–a small anterior or head sucker surrounding the Fig. 1 : External views and transverse section (T.S.) diagrams to show the characteristic features of the three main classes of annelids: (a) Trypanasyllis zebra, a polychaete; (b) T.S. Nereis; (c) Lumbricus terrestris, an obligochaete. Fig. 1 : (cont.) (d) T. S. Lumbricus; 9e) a leech, viewed dorsally; (f) T. S. leech.

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206 NSOU CC - ZO - 03 mouth and a large powerful posterior sucker, both are situated ventrally. Clitellum present but never conspicuous except during reproductive periods. 5. Mouth opens on the ventral surface of anterior sucker, while anus opens dorsal to the posterior sucker. Just within the mouth cavity are three large, oval blade—like jaws each bearing a large number of small teeth along the edge. As the animals suck blood their salivary glands secrete an anticoagulant called hirudin. In most forms the stomach is provided with 1 to 11 pairs of lateral caeca. 6. Coelom is greatly reduced due to the presence of connective tissue, called botryoidal tissue and is represented by haemocoelomic sinuses. 7. The septa are greatly reduced. Metamerism is shown by paired nephridia and ganglia of the ventral nerve cord. 8. Hermaphrodite, with several pairs of testes, a pair of ovaries and a single genital opeing. Gonads and gonoducts restricted to anterior few segments. 9. Fertilization internal (cross fertilization). 10. Development direct (no larval form), eggs are usually laid in cocoons, secreted by the clitellum. Examples : Hirudinaria, Hirudo, Acanthobdella, Glossiphonia, Placobdella, Pontobdella etc. Fig. 4 Polycheat body Part: A. Prosotomium, B: Neries, C: Parapodium

NSOU CC - ZO - 03 207 6.4 Locomotory Organelles in Annelida The chief locomotory organelles in annelida are– Parapodia, Setae and Suckers Parapodia : Parapodia (Fig.) are principal locomotory organelles of free living polychaetes. Parapodia are segmentally arranged fleshy lateral hollow extensions of the body into which also extends the coelomic cavity.

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Each parapodium basically consists of two lobes (biramous) a dorsal notopodium and a ventral neuropodium, and each lobe bears a bundle of bristles or setae supported internally by

one or more chitineous rods, each called an aciculum. Both notopodium and neuropodium may bear additional projected parts (dorsal cirrus and ventral cirrus) and they may be variously modified in different polychaetes (Fig. 3, 4). As the coelomic cavity extends into parapodia, the hydrostatic pressure is exerted by the coelomic fluid.

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Associated with parapodium are dorsal and ventral sets of oblique muscles,

originating from the midventral line of the body wall. In addition to these muscles, there are intrinsic protactor and retractor muscles. The point of attachment of the parapodia with the body wall acts as a hinge for forward and backward movements.

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During movement, two parapodia of a segement always remain in opposite phases of motion and thus cause a sort of paddling activity through water. The bristiles and acicula are protruded and withdrawn through the action of the

protractor and retractor muscles. The parapodia exhibit variations in form among different

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polychaetes in accordance with the different functions they perform. Creeping and swimming forms have well developed parapodia; the burrowing forms and tube dwellers have feebly developed parapodia especially in the posterior part of their body.

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Setae : Setae are the main locomotor structures in oligochaetes, but they are also present in polychaetes. Setae are implanted directly in the

body muscles and are Fig. 5 : External features of Nereis— dorsal view (afer Bloom and Krekeler)
208 NSOU CC - ZO - 03 mostly oriented in the ventral region of the body segments. Setae are secreted by setal sacs. The extension and withdrawl of the setae during movement are caused by a pair of setal muscles and the associated circular

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muscles. Like parapodia, setae may also show variations in form reflecting their functional significance. Burrowing forms have short, simple and blunt setae,

white the swimming forms have characteritically long, forked or plumose setae (Fig.). Suckers : Suckers are characteristics of class Hirudinea which lack parapodia and setae. Anchorage on the substratum during locomotion is caused by two muscular suckers, one is situated at the anterior end (anterior sucker)
and the other is located

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at the posterior end (posterior suckers) of the body. They are formed by the fusion of several body segments.

Suckers are circular disc shaped and the posterior sucker is larger and more powerful than the anterior sucker. Anterior sucker bears mouth opening at its ventral surface. Adhesion or attachement of the suckers to the substratum is assisted by the secretion from the specialized epidermal sucker glands present in masses in both the suckers. 6 :

NSOU CC - ZO - 03 209 6.5 Circulatory System in Annelida Circulatory system is one of the most important systems of the living bodies because through this system exchanges of essential elements between the tissues of the body and the external environment take place. Not only that but the transport of materials from one part of the body to different parts also take place through this system. The circulatory system in annelids is closed type and consists of blood vessels through which blood is distributed and collected from different parts of the body. The circulatory system in annelids differs from one class to another, hence the system may be described separately classwise. Clas Polychaeta : Circulation in most polychaetes results from fluid movement in both blood vascular system and the coelom. A common variation on this pattern occurs in many polychaetes that have reduced septa, for example, the glycerid blood worms. In these, the coelomic system replace the blood system and transport substance throughout the body. Very small species also typically lack a blood system and sometimes also the coelomic cavities. In most polychaetes there exists a well developed blood-vascular system, in which the blood is enclosed within vessels. In a typical blood vascular system, blood flows anteriorly in dorsal vessel situated over the digestive tract. At the anterior end of the body, the dorsal vessel is connected to a ventral vessel by one to several vessels or by a network of vessels passing around the gut. The ventral vessel carries blood posteriorly beneath the alimentary tract (Fig.). In each segment the ventral vessel gives rise to one pair of ventral, parapodial vessels, which supply the parapodia, the body, and the nephridia and to several ventral, interstinal vessels, which supply the gut (Fig.). The dorsal vessel, in turn, 7 :
210 NSOU CC - ZO - 03 receives a corresponding pair of dorsal parapodial vessels and a dorsal intestinal vessel. The dorsal and ventral parapodial vessels and the dorsal and ventral intestional vessles are interconnected by a network of smaller vessels. Polychaete blood is confined to small-and large-diameter vessles and in some species, large- volume sinuses, which typically occur on the wall of the gut (Fig. 8). In polychaetes the blood contains few cells compared to coelomic fluid. In small polychaetes it is usually colourless but in larger species and those that burrow in soft bottoms, the blood contains respiratory pigments dissolved in the plasma. In them three of the four respiratory pigments of animals are found. Haemoglobin is the most common of these pigments, next common is chlorocruorin. It is a kind of haemoglobin but a slight difference in side chains gives it a green colour rather than a red colour. The less common respiratory pigment is haemerythrin. It is an iron-bearing but nonhaeme (not a porphyrin) protein pigment. Here the two iron atoms are bound directly to the protein and not to a haeme. The chlorocruorin (blood of Serpula contains both haemoglobin and chlorocruorin), Haemerythrin is found within enucleated blood corpuscles of Magelona. Class Oligochaeta : The circulatory system of Oligochaetes (Fig.) is basically similar to that of polychaetes with some modifications in structure and pattern of blood flow. The differences are largely adaptations to living in terrestrial and freshwater enviroments. In Lumbricus and many others three main longitudinal blood vessels extend most of the body length and are connected to one another in each segment by additional segmentally arranged vessles (Fig.). The largest longitudinal blood vessel is the dorsal vessel, the wall of which is quite thick and muscular and provides much of 8 :
NSOU CC - ZO - 03 211 the pumping force for blood movement. This vessel with it valves functions as heart. It collects blood from the vascular areas of the intestine and drives it towards the anterior end. Suspended in the mesentary beneath the gut is the longitudal ventral vessel in which blood flows from anterior to the posterior region. The third longitudinal vessel lies ventral to the nerve cord and is called the subneural vessel, in which blood flows posteriorly. Exchanges between the longitudinal vessles occur in each segment through various routes supplying the body wall, gut and nephridia. Most oligochaetes also possess from two to five pairs of large, muscular circumoesophageal vessles, called ring vessles or lateral hearts. They carry blood from the dorsal to the ventral region. These vessels are conspicuously contractile and function as accessory organs for blood propulsion. These vessles are often equipped with flap valves to ensure a one way blood flow. The number of such lateral hearts varies. Five are present in Lumbricus, surroudning the oesophagus and only one pair in Tubifex and this pair is circumintestinal. Most oligochaetes have haemoglobin dissolved in the plasma. Memebrs of some families (e.g. Naididae) lack blood pigments. Various phagocytic amoebocytes are also present in the circulatory fluid of most ot these worms. Class Hirudinea : Among the euhirudineans (majority of leeches), the rhynchobdellids marine fish and turtle leeches and freshwater leeches with eversible probocis) have etain the blood-vascular system of oligochaetes, but the coelomic sinuses act as a supplimentary circulatory system. In the arhynchobdellids (leeches with a non-eversible pharynx, often bearing jaws for sucking blood or ingesting prey), the ancestral circulatory system has disappeared, and the coelomic sinuses and 9
212 NSOU CC - ZO - 03 11 : 10 :

NSOU CC - ZO - 03 213 fluid have become the sole internal transport system, now termed the haemocoelomic system (Fig). Because the haemocoelomic system evolved from the original coelom and not the blood-vascular system, all of its vessels and channels are lined by an endothelium, the peritonium. Much of this peritonium, especially in the capillaries, is specialized into large nutrient storage cells, the chloragogen tissue in rhynchobdellids and the botryoidal tissue in the arhynchobdellids. The haemocoelomic fluid is propelled by the muscular contractions of the lateral longitudinal channels. Respiratory pigment (extracellular haemoglobin) is found only in the arhynchobdellid leaches and is responsible for about one half of the oxygen transport (Ruppert and Barness, 1994). 6.6 Reproduction in Annelida Reproduction in Polychaetes : Polychaetes reproduce both sexually and asexually. Asexual reproduction is seen in some polychaetes (cirratulids, syllids, sabellid fan worms and spionids). It takes place by budding or division of the body into two parts or a numbr of fragments. Most of the polychaetes reproduces only sexually and the great majority of polychaetes are dioecious and hermaphroditism is known in serpulids, certain freshwater nereids and isolated cases in other families. Polychaete gonads are usually distinct organs but, depending on speices, vary in position and number. In general they remain associated with septa, blood vessels and lining of the coelom. Formation of gametes may occur throughout the body or only in particular regions of the trunk. The gametes generally mature within the coelom and are released to the outside by mechanisms such as gonoducts, coelomoducts, nephridia, or simple rupture of the parent bodywall. Many species release eggs and 12 :

214 NSOU CC - ZO - 03 Fig. 13 : An epitokous nereid, Neneis irrorata. Note the dimorphic condition of the antgerior and pasterior parapodia. (Brusca and Brusca, 2002) Fig. 14: The epitokous palola viridis. Brusca and Brusca, 2002)

NSOU CC - ZO - 03 215 sperm into the water, where external fertilization is followed by fully indirect development with a planktotrophic larval stage. In some other forms fertilization is internal, followed by brooding or by the production of floating or attached egg capsules. In most instances the embryos are released as free- swimming larvae. Some species brood their embryos on the body surface. Many of the free swimming polychaetes have evolved methods that ensure relatively high rate of fertilization. One of these methods is the fascinating phenomenon of epitoky, characteristic of many benthic syllids, nereids, and eunicids. This phenomenon involves the production of a sexually reproductive worm called an epitokous individual. Epitokous froms may arise from non reproductive (atokous) animals by a transformation of an individual worm as in most nereids and eunicids, or by the asexual production of new eiptokous individuals, as in most syllids. In some forms, the whole body may transform into a sexual individual called a heteronereid or epitoke (Brusca and Brusca, 2003) In others, only the posterior body segments (again called the epitoke) become swollen and filled with gametes, and their associated parapodia become enlarged. The gamete-bearing segments of the epitokes are the most strikingly modified, and the body of the worm appears to be divided into two markedly different regions. The gamete bearing epitokes are capable of swimming from the bottom upwords into the water column, where the gametes are released. Epitoky is controlled by neurosecretory activity, and the upward migration of the epitokes is precisely timed to synchronize spawning within a population. The reproductive swarming of epitokes is linked with lunar periodicity. This activity not only ensures successful fertilization but establishes 15 :

216 NSOU CC - ZO - 03 the developing embryos in a planktonic habitat suitable for the larvae. Perhaps the most famous of the epitokas worms are the palola worms (Palola viridis) of the South Seas. Many polychaetes shed their eggs freely into the sea water where they become planktonic. Some, however, retain the eggs within the tubes or burrows and some of them brood their eggs. A few species, such as Nereis limnicola, brood their eggs within the coelom. The polychaete egg contains a variable amount of yolk, depending on the species, and the cleavage is spiral and holoblastic. After gastrulation the embryo rapidly develops into a top-shaped trochophore larva (Fig. 16), which transforms into juvenile worm through metamorphosis. Reproduction in Oligochaeta : The reproductive system of oligochaetes differs from that of polychaetes in a number of striking respects. Oligochaetes are all hermaphrodites and usually possess distinct and complex reproductive systems, including parmanent gonads. Furthermore, various parts of the reproductiove appartus are restricted to particular segments, usually in the anterior portion of the worm. The arrangement of the reproductive system facilitaties mutual cross- fertilization followed by encapsulation and deposition of the zygotes. The male system inclues one or two pairs of testes located in one or two specific body sgements. In most aquatic groups there is usually one ovarian segment followed by one testicular segment. In terrestrial families, two male segments may be present. Sperms are released from the testes into the coelomic spaces, where they mature or are picked up by storage sacs or spical coelomic pouches, called seminal vesicles derived from pouches of septal peritonium. There may be single seminal vesicle or as many as three pairs in some earthworms. When mature, the sperm are released from the seminal vesicles, picked up by ciliated seminal (sperm) funnels, and carried by sperm ducts to paired gonopores. The female reproductive system consists of a single pair of ovaries located posterior to the male system (Fig. 17). Ova are released into the abjacent coelomic space and sometimes stored until mature in shallow pouches in the septal wall called 16 : NSOU CC - ZO - 03 217 Ex Fig. 18 : Segments 9—15 of Lumbricus (cemposite lateral view) (Brusca and Brusca, 2002). 17 : 218 NSOU CC - ZO - 03 the ovisacs. Next to each ovisac is a ciliated funnel that carries the mature ova to an oviduct and eventually to the female gonopore. Most oligochaetes also posssess one or two or more pairs of blind sacs called spermathecae (seminal recaptacle) that open to the outside via separate pores. A characteristic reproductive structure of oligochaetes is clitellum (Latin for saddle) which is a unique region of glandular tissue. This structure is a principal antomical feature unifying the Oligochaeta and the Hirudinoidea as the clitellate annelids. The clitellum has the appearance of a thick sleeve and consisting of certain adjucent segments in which the epidermis is greatly swollen with unicellular glands that form the girble, partially or almost completely encircling the body from the dorsal side downward (Fig. 19, 20) The exact positrion of the clitellum and the number of segments involved are consistent within any particular species. There are 2 cliteller segments in many aquatic forms, 6 or 7 in Lumbricus, 3 in Pheretima and as many as 60 in certain Glossoscolecidae. In freshwater forms the clitellum is located around the position of the gonopore but in most earthworms it is posterior to the gonopores. The degree of development of the clitellum varies from group to group. In aquatic species the clitellum may be only one cell thick, whereas in many earthworms it forms a thick girdle. The development of the clitellum also varies from season to season. It generally coincides with sexual maturity, but there are some worms in Fig. 20 : The clitellum epithelium (section) showing the three types of secretory cells. (Brusca and Brusca, 2002) Fig. 19 : External structures associated with reproduction of lumbricus (ventral view). (Brusca and Brusca, 2002)

NSOU CC - ZO - 03 219 which the clitellum becomes conspicuous only during breeding season. The glands of the clitellum produce mucous for copulation, secrete the wall of the cocoon and secrete the albumin in which the eggs are deposited within the cocoon. Though hermaphrodite, the oligochaetes practice cross fertilization. Reciprocal copulation enables the worms to pass on sperm of one worm to the other. The sperm thus recieved remain stored in the spermatheca. A few days after copulation, a cocoon is secreted for the deposition of eggs. When completely formed the cocoon slips forward over the anterior end as the worm pulls backward. Both eggs and sperms are discharged into the cocoon and fertilization is external within the cocoon. The open ends of the cocoon contract and seal as they pass off the antrior end of the body. The closed cocoons are deposited in benthic debris by aquatic oligochaetes. Terrestrial forms deposit their cocoons in the soil at various depths depending on the moisture content of the substratum. The shape and size of the cocoons are often species-specific. The eggs are telolecithal, cleavage is holoblastic and unequal. In both terrestrial and aquatic groups development is direct, with no trace of larval stage and all the development takes place within the cocoon. Asexual reproduction is very common among many species of aquatic oligochaetes, particularly the aeolosomatids and the naidids. In fact, there are many asexually reproducing naidids in which sexual individuals are rare or have never been observed. Some oligochaetes reproduce asexually in the summer and sexually in the fall. Asexual reproduction always involves a transverse division of the parent worm into two or more new individuals. Regeneration commonly precedes the separation of the daughter individuals. Reproduction in Hirudinea : Unlike many other annelids, leeches do not reproduce asexully, nor can they regenrate lost parts. Like oligochaetes, all leeches ae hermaphrodites, but they are protandric, not simultaneous hermaphrodites (male reproductive organs develop first). The reproductive system is similar to that of Fig. 21 : Pheretima transfers sperm directly from the male pare, through a penis, into the mate's spermatheca. (Brusca and Brusca, 2002)
220 NSOU CC - ZO - 03 oligchaetes. There are, however, no separate seminal receptacles (spermathecae), and there is internal fertilization. They also undergo direct development. Fig. 22 : Eisenia uses indirect sperm transfer. As in Ljumbricus, the sperm leave the male pares and travel along paired seminal grooves to the spermathecal openings of the mate. (Brusca and Brusca, 2002) The male reproductive system includes a varialble number of paired testes, usually from 5 to 10 pairs in leeches, arranged serially beginning in segment XI or XII. There is a pair of lingitudinal sperm ducts (vas deferens) that lead to a copulatory apparatus and a single gonopore located midventrally on segment X. The copulatory apparatus of leeches is often complex and varies in structure among species. Each sperm duct is coiled distally and enlarges as an ejaculatory duct. The two ducts join at a common glandular, muscular atrium. In arhynchobdellids, the atrium is modified as an eversible intromittent organ, the penis. The rhynchobdellids lack a penis and the atrium functions as a chamber in which spermatophores are produced. Fig. 23 : An earthworm forming and relearsing a cocoon. As the cocoon slides over the worm, it receives ova and sperm. (Brusca and Brusca, 2002).
NSOU CC - ZO - 03 221 Fig. : 24 (A, B) Reproductive Systems of two leches. (A) Hirudo (Anhynohobdelle). (B) Pisciola (suborder Rhynchobdellae). (Brusca and Brusca, 2002). Fig. : 25 Copulating leeches. The arrangement is much like that in obligochaetes. (Brusca and Brusca, 2002) Fig. 26 : Erpobdella with cocoon. (Brusca and Brusca, 2002)
222 NSOU CC - ZO - 03 There is a single pair of ovaries in leeches, which may extend through several segments. Oviducts extend anteriorly from the ovaries and unite as a common vagina, which leads to the female gonopore on the midventral surface of segment XI, just behind the male pore. In some leeches, and oviducal gland surrounds a portion of the oviduct and vagina and apparently functions in egg-laying activity. Copulation and sperm transfer differ markedly between the rhynchobdellans and arhynchobdollans, in part due to the differences in the male copulatory structures. Cocoon formation in leeches is similar to that of oligochaetes, with the clitellum producing a cocoon wall and albumin. As the cocoon slides anteriorly over the female gonopore, it recives the zygotes or young embryos rather than separae eggs and sperm. The cocoons are deposited in damp soil by terrestrial species and even by a few aquatic forms that migrate to land for this process (e.g Hirudo). Most aquatic forms deposit their cocoons by attaching them to the bottom or to algae; a few attach them to their hosts (e.g. some piscicolids). A few freshwater leeches display some degree of parental care for their cocoons. The embryogeny of leeches is similar to that described for oligochaetes. Except for a few species, the amount of yolk is relatively small and development time quite short. 6.7 Questions a) What is the difference between Seta and Parapodia? b) What is permanent clitelleum? c) Distinguish between Oligochaeta and Hirudinea. d) How many types of nephridia are found in earth worm? e) What do you mean by haemocoelomic system? f) Why blood of earthworm is red? g) Write the important external features of Leech. h) Why host blood is not clotted during the feeding of Leech i) What is nephrostome j) What is Peristomium and Prstomium?

NSOU CC - ZO - 03 223 Unit – 7 ?? Phylum : Arthropoda Structure 7.0 Objective 7.1 Introduction 7.2 General Characters 7.2.1 General characters of Crustacea 7.2.2 General characters of Arachnida 7.3 Crustacean larvae 7.4 Bionomics and affinities of Peripatus 7.5 Taxonomic position of onychophora 7.6 Questions 7.0 Objective From this chapter learner will learn the detail story about the biggest of Phylum of the Animal Kingdom. This chapter also deals with the diversity among arthropodan animal and how they are well adapted in different ecosystem of the world. 7.0 Introduction Arthropods are a vast assemblage of animals. At least 75% of all animal species described to date belong to the phylum Arthropoda. No other phylum of animals can rival the arthropods in success and it is due to the tremendous adaptive diversity that has enabled them to survive in virtually every habitat, (from snow covered mountain peaks to the depth of the ocean). Their success as terrestrial animal is probably due to the evolution of water conserving excretory sysems and gaseons- exchange organs and the development of a desiccation resistant impermeable epicuticle. Many members of this phylum are closely related with different aspects of human life like food, health, etc. and thus have great economic importance. 7.2 General Characters 1. Arthropods are triploblastic, bilaterally symmetrical, coelomate and metamerically segmented animals. 2. Presence of paired externally joined appendages usually in each segment (G. arthos = joint; podos = feet). Appendages are variously modified. Anterior segments are specialized to form a distinct head.
224 NSOU CC - ZO - 03 3. Body is covered with a thick chitinous cuticle forming the exoskeleton. The exoskeleton sheds at interval (moulting or ecdysis). 4. Musculature is not continous but comprises of sepearte striped muscles. 5. The body cavity is a haemocoel. True coelom is represented by spaces within the gonads and excretory organs. 6. Circulatory system open type with a drosal tubular heart, having paired lateral ostia. 7. Respiration by general body surface, gills, trachae, book gills or book lungs. Haemocyanin is the usual respiratory pigment. 8. Excretory organs are green-glands, coxal-glands or Malpighian tubules. 9. Central nervous system includes a large bilobed dorsally placed brain and a double ventral nerve cord with one fused ganglion in each segment. 10. Sensory organs comprise of simple or compound eyes (each eye is made up of several visual units or omatidia), chemoreceptors, tactile receptors, balancing and auditory organs. 11. Cilia are entrely absent from all parts of the body. 12. Sexes are usually separate (dioecious or gonochoristic); some hermaphrodite. Sexual dimorphism is seen in many. Fig. 1 : In the animal world, the Phylum Arthropoda includes the largest number of species. All of them possess metameric segmentation, hard chitinous exoskeleton and jointed legs. Number shown against each group denotes the approximate number of species.
NSOU CC - ZO - 03 225 13. Fertilization usually internal. Oviparous or ovoviviparous. 14. Development is usually indirect involving one or more larval forms. 15. Parental care is well marked in some species. Insects, Spiders, Scropions, Centipedes, Crabs, Prawns, Lobsters, Shrimps, and Barnacles are all arthropods. Crustacea (L. crusta = a hard shell) The crustancenas belong to subphylum Crustacea Phylum Arthropoda. 7.2.1 General Characteristics of Crustacea 1. Body is divisible into head, throax and abdomen. Head is fused with thorax in many to form cephalothorax which is covered dorsally by carapace. 2. They are unique among arthropods in having two pairs of antennae (first pair of antennae is called antennules). 3. Other cephalic appendages are a pair of mandibles and two pairs of maxillae. 4. Throax usually with eight pairs and abdomen usually with six paris of appendages. Appendages undergro various modifications. Last segment of abdomen is telson. 5. Throacic and abdominal appendages are typically biramous, and become adapted for different functions. 6. Head bears a pair of compound eyes (in some located on movable jointed stalk) and a small median dorsal naupliar eye (a characteristic feature of the naupliar larva of crustaceans and therefore referred to as the naupliar eye). 7. Respiration by means of gills or by general body surface. Gills are typically associated with the appendages but the location, number and form vary greatly. 2 :

226 NSOU CC - ZO - 03 8. Excretory organs are a pair of blind sacs in the haemocoel of the head and they open onto the bases of the second pair of antennae (antenal glands or green glands) or the second pair of maxillae (maxillary glands). 9. Brain formed by the fusion of first four embryonic ganglia and is connected to the ventral nerve cord by oesophageal connectives. Sense organs, other than eyes include statocysts, sensory hairs and proprioceptors. 10. Most crustaceans are dioecious Copulation and egg brooding are very common. Eggs are mostly centrolechithal and cleavage is superficial. Development through various larval forms like Nauplius, Cypris, Megalopa, Zoea, etc. The earliest hatching stage is a naupliar larva bearing a single median eye and three pairs of body appendages. Crustanceans are one of the most popular invertebrate groups, even among non biologists, for they include some the world's most delicious food items, such as lobsters, crabs and shrimps. There are more than 67000 descirbed living species of crustacea (Brusca and Brusca, 2003). They exhibit an incredible diversity of form, habit and size. The smallest known crustaceans are less than 100 μm in length and live on the antennules of copepods (a group of crustacea). The largest are Japanese spider crabs (Macrocheira kaempferi), with leg span of 4 metres and giant Tasmanian crabs (Pseudocarcinus gigas) with carapace width of 46 cm. The heaviest crustancans are probably American lobsters (Homarus americanus), which attained weights in excess of 20 kilograms. Crustancens are found at all depths in every marine, brackish and freshwater environment on Earth.A few have become successful on land, themost notable being sowbugs and pillbugs (the terrestrial isopods). Crustaceans occupy an important position in aquatic food chains. Examples : Palaemon (prawns), Cancer (crabs), Squilla, Penaeus, Macrobrachium, Eupagurus (hermit crab), Daphnia, Artemia (brine shrimp), Triops, Cypris, Cyclops, Argulus (fish louse), Lepas (goose barnacle), Balanus (rock-barnacle or acorn barnacle), Sacculina.

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228 NSOU CC - ZO - 03 Arachnids (G. arachne = spider) : The arachnids belong to Class Arachnida under subphylum Chelicerata of phylum Arthropoda. 7.2.2 General Characteristics of Arachnida 1. The body is divisible into cephalothorax or prosoma and abdomen or opisthosoma. Prosoma unsegmented, usually covered dorsally by a solid carapace. 2. Prosoma or cephalothorax with one pair of chelicerae, one pair of pedipalpi and four pairs of legs. 3. Antenna and true jaws are absent. 4. In some arachnids (ticks and mites), the prosoma and opisthosoma have fused together and the entire dorsal surface is coverd by a single carepace. 5. The brain is an anterior ganglionic mass lying above the oesophagus. Eyes usually simple. Compound eyes either absent or degenerated. For most arachnids the sensory hairs are the primary sense organs. 6. Abodmen generally without appendages but modified appendges in some. Some arachnids (the spiders) bear upto 4 pairs of small abdominal appendages called spinnerets. 7. Large arachnids (scorpions, some spiders) possess book lung as respiratory organs; small forms (psuedoscorpions, some spiders, mites) possess tracheae. In some arachnid species, both book lungs and tracheae and book lungs are present. 8. The heart is highly developed in large species with book lungs and the blood contains haemocyanin. 3 A : 3 B :

NSOU CC - ZO - 03 229 9. Excretory organs are coxal glands or Malpighian tubules or both. 10. Sexes separate. Single or paired gonads lie in the abdomen. Fertilization is internal. 11. Eggs yolky and centrolecithal. Development direct, not accompaned by metamorphosis. 12. Arachnids are carnivorous and mostly terrestrial. About 98% of the living chelicerates (Subphylum Chelicerata) belong to class Arachnida. Although the earliest members of the class Arachnida were undoubtedly marine, the more than 70000 living arachnid species so far described are primarily terrestrial. Those speices that are aquatic (some mites) represent a secondary return to freshwater or the sea. This class includes many familiar but generally unpopular organisms, including spiders, mites, ticks and scorpions. Nearly half of all arachnid species are spiders and most of the remaining species, about 9000, are mites 4 5 :

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230 NSOU CC - ZO - 03 and ticks. Scropions, the most primitive arachnids have long, segmented abdomens. The highly specialized mites have lost all external evidence of metamerism and the cephalothorax and abdomen are broadly joined together. Arachnids are largely predatory chelicerates and other arthropods are their principal prey. Spiders are major insect eater and used to control insect populations. Ticks and mites are mostly parasites. Some are blood sucking ectoparasites on vertebrates. Mites and ticks have economic and medical importance despite their small physical size. Examples : Buthus (scorpion), Palamnaeus (scorpion), Chelifer (pseudoscorpion), Aranea (spider), Lycosa (spider), Latrodectus (black widow spider), Sarcoptes (mites), Ixodes (ticks), Dermacentor (ticks), Chorioptes (mites). 7.3 Crustacean Larvae : Larva is a developmental stage in the life cycle of many invertebrates as well as some vertebrates. It differs from the adult both in its structure and its habit. Larvae are usually free living i.e.lead an indepedent life and subsqueutnly transform into adults. In creustacea the development is usually indirect through metamorphosis of larval stages. In some crustaceans e.g. Palaemon, Argulus, the larva does not come out of the egg. Transformation occures internally and young, resembling the adult, is hatched out. Within the clsss crustacea, variety of larval forms are seen and in many groups one type of larva transforms into another type and finally becomes the adult. Different types of crustacean larvae : 1. Nauplias larva : The earliest and basic type of crustacean larva is a nauplias which is found in all major groups of crustacea. FIGURE 6 : Ticks. (a) Hard tick, Dermacentor andersoni (male left, female right). (b) Soft tick; Omithodoros moubata (dorsal aspect left, ventral aspect right).
NSOU CC - ZO - 03 231 Characteristics of Nauplias larva– 1. Nauplias is a very small transparent free swimming larva. 2. The body is oval in shape,

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the anterior part of the body is wider than the posterior end and

there is no trace of external segmentation. 3. A median frontal eye is present at the anteiror end. It

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is characteristic of nauplius and often referred to as the nauplius eye. The

median eye may persist or degenerate in adult. 4. The body is with three pairs of appendages. 5. The anterior first pair of appendages are uniramous and placed in front of the mouth. They develop into the antennule of the adult. 6. The remaining two pairs of appendages are biramous and are present in the trunk region and act as locomotor organs. The second pair transforms into antennae and the third pair becomes the mandibles of the adult. 7. In between the trunk appendages lies the mouth which is enclosed by a prominent labrum. 8. Alimentary canal is straight and simple and terminates at the posteriormost end of the body through anus. 9. In the anterior part there is a pair of lateral projection known as lateral horn or frontolateral horn. In allmost all crustaceans the nauplius is the first larval stage of development but its appearance varies in different forms or groups. In cladocera, nauplius stage appears inside the egg. In ostracoda nauplius, a pair of bivalved shells and uniramous appendages are present. In the cirripedia, a number of spines are present in nauplius. Alimentary canal is absent in Sacculina nauplius. In Isopoda, the nauplius is maggot-like. In some forms the nauplius larva develops straight away into adult, but in many other crustaceans it gives rise to other intermediate larval forms like metanauplius, protozoea, zoea, cypris, mysis, megalopa, phyllosoma, alima, etc. 2. Metanauplius Larva : The nauplius larva of Copepoda metamorphosed by a series of ecdysis and form metanauplius larval stage. 1. It

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is the second larval stage which develops from the nauplius larva. 2.

The body has an anterior oval cophalothorax and an abdomen terminating in a pair of caudal forks.

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232 NSOU CC - ZO - 03 3. Besiedes the three pairs of nauplius appendages, it also bears the rudiments of four pairs of appendages which are two pairs of maxillae and two pairs of maxillipedes of the adult. Some decapods, stomatopods (mantis shrimps) and some notostracans (e.g., Apus) begin their life history with the free swimming metanauplias larva. 3. Cypris Larva : In some Cirripedia (Lepus, Sacculina) the nauplius larva after several moults develops into cypris stage. 1. The body and the appendages are enclosed within bivalved carapace with adductor muscle to close it. 2. In addition to medium eye, a pair of compound eyes are present. 3. The antennule is large and four jointed and modified for attachment to the substratum with cement gland. The second antenna is absent. 4. Six pairs of biramous thoracic appendages are present for swimming. 5. The tip of the abdomen bears a caudal furca. 6. The larva contains a mass of germ cellls. 4. Protozoea Larva : In case of marine prawns (Penaeus) and some other decapods, the eraliest nauplius by growth and moulting develops into a protozoea larva. 1. Body is divisible into a braod

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segmented cephalothroax covered with a small carapace and a slender abdomen which is unsegmented. 2.

First antenna (antennule) is four jointed, and uniramous, second antenna is biramous with three-jointed endopodite and four jointed exopodite. 3. Mandibles are small and masticatory in function. 4. Two anterior pairs of maxillipeds are biramous. 5. It still lacks compound eyes, but impressions are visible. 6.

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Three pairs of thoracic limbs make their appearance as buds. 7.

Abdomen ends in a forked telson. 8. The seven pairs of appendages become well developed and capable of movements. 5. Zoea Larva : Zoea is the second important larva of the Crustacea after the nauplias larva. In Penaeus, protozoea develops into zoea. It is also

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the common larva of decapods and hence it has variations in its features in different

NSOU CC - ZO - 03 233 species. 1. The larval body is divisible into a broad cephalothroax and an segmented abdomen. 2.

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The cephalothorax is covered by a helmet-like carapace which bears two long spines,

a median rostral one (protrudes into a rostrum in front) and a median dorsal one. 3. Compound eyes are prominent and stalked. 4. The larva bears antennules, antennae, mandibles, maxillae and two pairs of well-developed maxillipeds. 5. Thoracic appendages appear as rudiaments. 6. Abdomen is six-segmented and curved, without appendages and has a forked telson at the tip. 6. Mysis larva

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or Schizopod Larva : In shrimps and some lobsters zoea transforms into mysis

that resembles adult Mysis in general features. 1. Elongated transparent body, differentiated into

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cephalothorax and six segmented abdomen including a telson. 2. Carapace is produced in front into a pointed rostrum. 3. Six pairs biramous thoracic appendages for locomotion. 4.

Presence of a pair of stalked compound eyes on the head. 5. The endopodites of the thoracic appendages are long but the exopodites are reduced. In some decapods (e.g., in Penaeus), the egg hatches as nauplius, it passes by successive moults through zoea stage, protozoea stage and mysis stage which changes into an adult. In some lobsters, (e.g. Homarus) both nauplius and zoea are passed within the egg, and it hatches as a mysis larva which changes into an adult. 7. Megalopa Larva : In true crabs (brachyuran decapods), zoea metamorphoses into megalopa larva. It looks, to some extent, the adult crab. 1. It has a broad unsegmented crab-like cephalothorax and a straight abdomen. Cephalothorax is covered by a broad carapace. The carapace is produced into a median spine anteriorly. 2. Thorax is with five pairs of walking legs. 3. First thoracic appendage is chelate. 4. Large stalked eyes are distinctly visible.
234 NSOU CC - ZO - 03 5. Abdomen bears biramous pleopods. Megalopa larva transforms into adult through moulting. 8. Phyllosoma Larva : In the rock-lobster (Palinurus), the newly hatched larva is called phyllosoma larva or glass crab. It is a modified mysis stage. 1. The body is more or less mysis like. 2. It is remarkably large, flattened, leaf-like delicate and glassy. 3. A narrow constriction demarcates the head from thorax. 4. A pair of compound eyes with long stalks. 5. Thorax bears six pair of appendages–first thoracic or maxillipedes are rudimentary (Palinurus) or absent (Scyllarus), second appendages are uniramous, remaining four pairs are long birammous legs. 6. Abdomen is short, segmented but limbless. The larva undergoes several moultings and transforms into adult. 9. Alima Larva : In some malacostraca like Squilla, the egg directly hatches out in a young stage, called alima larva. It is modified form of zoea. 1. The body is divisible into cephalothorax and abdomen. The cephalothorax is covered by a short and broad carapace. 2. The body is slender, having a glass-like transparency. 3. In addition to all cephalic appendages, only first two thoracic appendages are found. 4. Abdomen has six segments with four or five pairs of pleopods. 5.

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The alima larva differs from zoea larva in the armature of the telson and a very large raptorial second maxillipedes. 10.

Kentrogen Larva : 1. Body is sac-like and elongated. 2. Undifferentiated mass of cells is present inside the body. 3. It has a chitinous tube called dart. 4. Presence of root like processes. 5. All crustacean characteristics lost due to parasitism. Kentrogen larva is seen in the parasitic form like Sacculina (Cirripedia). Sequences of larval appearance in crustacea : In Branchiopoda, Cladocera, Ostracoda and Copepoda only nauplius larva appears. But in Cirripedia, nauplius stage is followed by cypris stage which transforms into an adults. In the Sacculina, after cypris another stage called
NSOU CC - ZO - 03 235 Fig. 7A : Some larval forms of Crustacea. Fig. 7B : More larval forms of Crustacea.

236 NSOU CC - ZO - 03 Kentrogen stage, appears. In Euphausia, nauplius metamorphoses into protozoea and calyptopis before passing into the adult. In Penaeus, larvae pass through nauplius, protozoea, zoea and mysis stages, before becoming and adult. In the crabs, after certain transformations within the egg, the larva is hatched as zoea which changes into megalopa stage and then becomes an adult. In Palinurus, the larva hatches out in a modified mysis stage which is called phyllosoma larva. 7.4 Bionomics and Affinities of Peripatus (Onychophora) Peripatus belongs to the phylum Onychophora. Previously onychophora was treated as a class and it was placed as an appendix to the phylum Arthropoda, but recently it has been given the status of a separate phylum. Peripatus is a small caterpillar-like animal and it is very important from zoological point of view because the animal displays some characteristics of annelids and some characteristics of arthropods along with some specialized features of its own. As the onychophorans have many similarities with both annelids and arthropods, they have been described as a missing link between the two groups by some zoologists but some of their special adaptations and peculier features do not confirm the "missing link" status of Onychophora by the modern zoologists. The onychophorans have been divided into two families–Family Peripatopsidae and Family Peripatidae by Meglitsch and Schram (1991). Commonly studied genus is Peripatus. Geographical distribution. Peripatus exhibits discontinuous distribution with its species scattered in most of the warmer part of the world–Africa, Australia, New Zealand, Central America, Mexico, West Indies, Malaya Archipelago, India and other localities. More specifically, the members of family Peripatidae are distributed to the equitorial West Africa, West Indies, Mexico to the Rio de Janeiro, North East India and Southern part of South East Asia, while the members of family Peripatopsidae are distributed in Chilie, South Africa, Australia, New Zealand, Tashmania, New Britain and new Guinea. No species have been found north of the Tropic of Cancer.
NSOU CC - ZO - 03 237 Habit and habitat : Peripatus is a terrestrial animal, living in moist or humid places, in crevices of rocks, under stones, logs and bark and other dark and damp places where it is protected both from loss of water and from the predators. It is nocturnal in nature and predaceous and carnivorous in feeding habit (feeding on insects, other small arthropods and worms). External Morpholgy : The body of Peripatus is caterpillar like (Fig 11). It is soft elongated, more or less cylindrical, measruing between 1.5 cm to 15 cm in length. The external segmentation is indistinct and marked only by the presence of paired appendages. Numerous superficial lines or annuli mark the body but such annuli do not correspond to segmentation. Head is not clearly differentiated. The body covering is thin cuticle which is soft and has velvety texture and thrown into a number of fine transverse rideges or wrinkles bearing numerous small conical papillae or tubercles armed with chitinous spines. The colouration usually varies from dark grey to brown but red, blue and green colourations are also marked. The anterior end bears a pair of simple eyes, a pair of annulated antennae and 10:
238 NSOU CC - ZO - 03 Fig. 11 : Peripatus. Internal structure.
NSOU CC - ZO - 03 239 a ventral mouth, which is flanked by a pair of mandible, each with two claw- like blades and a pair of short conical oral papillae. The body has 14-43 pairs of short, unjointed and fleshy stumpy legs, that are hollow evagination of the body bearing terminal pads, pairs of claws and muscles. The anus lies at the posterior end of the body, slightly towards the verntral side behind the last pair of legs. The genital opeing or gonopore is located just in front of the anus in between last pair of legs. A nephridiopore lies on the inner base of each leg. Anatomical Features : 1. The body wall is dermomuscular, consisting of cuticle, epidermis, dermis, and striped circular and longitudinal muscles. 2. True coelon is reduced to the small cavities of excretory and reproductive organs. 3. The body cavity is a haemocoel and well developed, forming the hydrostatic skeleton. 4. A pair of slime glands are located, one on either side of the body cavity. These open on the tip of oral papillae and secrete or discharge an adhesive slime for entangling the prey, during food capture. The slime also helps in defence. 5. Digestve system includes alimentary canal and a pair of large salivary glands (which are modified metanephridia). Alimentary canal is a stright tube comprises of mouth, a tongue, buccal cavity with jaws, muscular pharynx, short eesophagus, long midgut or stomach-intesitine, rectum and anus (Fig.). 6. Peripatus is adapted to air breathing and the respiratory organs are simple unbranched or rarely branched tracheae. They communicate with the exterior by numerous stigma (spiracles) situalted over the surface of the body and are placed in the depressions between papillae or ridges of the integument. 7. Circularoty system open, consists of a dorsal tubular and contractile heart which runs entire length of the body and is enclosed in a pericardial sinus. Blood is colourless and contains phagocytic amoebocytes. 8. Excretory organs are paired segmental sac-like nephridia with a ciliated funnel and nephrostome. The nephridiopore is located on the inner base of each leg.

240 NSOU CC - ZO - 03 9. The nervous sysem consists of a bilobed brain and a pair of widely separated ventral nerve cords connected together by transverse commissures. Ganglia on the cords are indistinct. 10. Sense organs include a pair of eyes near the base of the antennae (which also act as sense organs), taste spines in and around buccal cavity and tactile spines on the surface tubercles. 11. Sexes separate (Gonochoristic), males are usually smaller than females. Reproductive organs are paird. 12. Fertilization is internal and development is direct. Most species of Peripatus are viviparous, eggs develop in uterus of female (females broad their eggs internally and give birth to young ones). Affinites of Peripatus : Peripatus, a small caterpillar-like animal, is very important from zoological point of view becaue the animal exhibits some characteristics of annelids and some characteristics of arthropods along with some specialized (unique) features of its own. Because it shares the characters of two different phyla, Peripatus is considered by some zoologists as conecting link between the two phyla. An account of its affinities (similarities) with three other large phyla, Annelida, Arthropoda and Mollusca is given below : A. Affinities with Phylum Annelida : 1. Body is vermiform (worm like) with truncated extremities. 2. Absence of a true head. 3. Segmentation in both is homonymous. 4. Body wall dermo-muscular, consisting of a thin, flexible and permeable cuticle and underlying circular and longitudinal muscles. 5. Presence of paired nephridia which are segmentally arranged. 6. Structure of eye is similar to that of some polychaetes in having large chitinous lens and well developed retina. 7. Like the parapodia of annelids (Polychaeta), the hollow unjointed stumpy legs are the extensions of the body wall. 8. Simple, straight alimentary canal with terminal mouth and anus. 9. Presence of cilia in the excretory and reproductive ducts as in annelids.

NSOU CC - ZO - 03 241 10. Locomotion slow by contraction and expansion of body muscles as in annelids. 11. The slime and coxal glands correspond with the similar glands of polychaetes and oligochaetes. B. Affinities with Phylum Arthropoda : 1. Presence of antennae. 2. Jaws are modified appendages. 3. Locomotion by definite legs, having definite musculature and provided with claws. 4. Cuticle has a thin deposition of chitin like that of arthropods and it is moulted periodically. 5. Body cavity is a haemocoel. True coelom is reduced to the small cavities of exeretory and repriductive organs. 6. Dorsal tubular heart with lateral ostia. Heart and circulatory system are distinctly arthropodan. 7. Respiration by tracheae. 8. Brain is large and resembles the brain of typical arthropods. 9. Excretory organs closely resemble the green gland of crustaceans. 10. General structure of the reproductive organs and pattern of development are similar to arthropods. C. Affinities with Phylum Mollusca : 1. Slug-like appearance. 2. Ladder-like nervous system resembling that of polyplacophora (Chiton) and lower prosobranchia. 3. Antennae tentacle-like. According to many zoologists these resemblances are only superficial. D. Peculiar Onychophoran Characteristics (Its own characters) : 1. Peripatus possesses certain characteristics of its own by which they differ from other phyla. These are : 1. Body shows no or indistinct segmentation. 2. Texture of skin is different from other phyla. Cuticle is rough and velvety, permeable and with numerous processess. 3. Antennae are not homologous to that of arthropods.

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242 NSOU CC - ZO - 03 4. Three segmented head of Peripatus exhibits a condition mid-way between that of Annelida and Arthropoda. 5. Restriction of jaws to a single pair. Jaw is modified second appendage and movement of jaws is antero-posterior. 6. Presence of non-jointed legs with claws. 7. Irregular distribution of spiracles or tracheal openings. Tracheae are not branched. 8. Two ventral nerve cords are widely separated and without distinct ganglia. 9. The structure of eye is less complicated. 10. Disposition of reproductive organs is different. 7.5 Taxonomic position of Onychophora The characters of Peripatus have made it most interesting from the point of view of evolution. It is the oldest terrestrial group which probably originated from some marine ancestors. With the peculiar nature and some annelidan characters it appears that Peripatus probably originated from some marine polychaetes which gave up the marine habit and has become modified for locomotion on land without jointed appendages. As discussed earlier Peripatus exhibits both annelidan and arthropodan characteristics. Therefore, they were regarded by some zoologists to be an intermediate stage or connecting link between Annelida and Arthropoda. According to some Peripatus appears to be more closley allied to arthropods than to annelids and perhaps arose as an offshoot from near the base of arthropod line. Based on such phylogenetic considerations, Manton (1970) and other contemporary zoologists have included them within Phylum Arthropoda as a subphylum or class. Marshall and Williams (1972) placed all the members of onychophora in a separate subphylum Onychophora under phylum Arthropoda. But absence of jointed chitinous exoskeleton and jointed appendages and presence of annelidan characters in onychophora do not support the inclusion of Onychophora within Arthropoda. At the same time Peripatus shows marked differences from all other classes of Arthropoda. In fact onychophorans are neither worms nor arthropods. At present it is believed that onychophoras are not an evolutionary link between Annelida and Arthropoda but an ancient independent group of segmented animals contemporary to Arthropoda and as such has been placed under separate phylum Onychophora. Additional information : ? Onychophora is undoubtedly very ancient group because a mid-cambrian
NSOU CC - ZO - 03 243 (about 520 million years ago) fossil, Aysheaia, closely resembles the modern onychophorans. Aysheaia was more closer to the annelids than the arthropods. ? Kaestner (1967) has stated that the Onychophora probably represents an early lateral branch of evolutionary line terminating in the arthropods. ? A cladistic analysis places the Onychophora in an intermediate position between the Polychaeta and the Tardigrade–Arthropoda clade (Brusca and Brusca, 2003). ? Onychphora represnt a sister group to the Arthropoda on the basis of morphological, palaeongtological and molecular data (Anderson, 1998). ? "Both morphological and molecular evidence argue that arthropods had a single origin, and that onychophorans are an early offshoot from an ancestor that eventually gave rise to both tardigrades and arthropods" (Pechenik, 2000). ? "Although onychophorans reflect an annelidan ancestry, their origins are obscure. Their development is somewhat similar to that of clitellate annelids (oligochaetes/leeches), and recent studies on ultrastructure of onchophoran sperm have also revealed striking similarities to the sperm of clitellates. Some zoologists postlate that clitellates and onychophorans are a monophylatic group and the sister group of the myriapod insect assemblage." (Ruppert and Barnes, 1994). 7.6 Questions a) Write short notes on— i) Haemocoèl ii) Living forsil iii) Connecting link iv) Book gill v) Cephalothorax vi) Epipodite b) How many legs are present in insects? c) Why crustaceans are also known as decapoda? d) What do you mean by social insects?
244 NSOU CC - ZO - 03 Unit – 8 ??Phylum : Echinodermata Structures 8.0 Objective 8.1 Introduction 8.2 General characteristics 8.3 Classification 8.4 Water Vascular System 8.5 Questions 8.0 Objective This chapter deals with those animals which are considered to be the ancester of chor- date animals. You also learn why all the animals belong to this phylum lives in ocean only. Not only that these animals are considered to be the first deutostomian animal. 8.1 Introduction Members of the Phylum Echinodermata are among the most familiar marine invertebrates, some being the most beautiful of all sea-creatures. The phylum contains some 6000 known species and constitute the only major group of deuterostome invertebrates. Echinoderms are exclusively marine and are largely bottom dwellers. All are relatively large animals, most being at least several centimeters in diameter. The most striking characteristic of the group is their pentamerous radial symmetry–that is,

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the body can usually be divided into five parts arranged around a central axis. Another unique feature of the phylum is the presence of of bilateral symmetry in the larval phase. The radial symmetry in adult is regarded as a secondary acquisition (

derived from a bilateral ancestor), and the echinoderms are not closely related to the other radiate phyla. 8.2 General Characteristics 1.

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The echinoderms are exclusively marine, free living non-colonial and mostly bottm-dwellers. 2. They are triploblastic,

unsegmented, enterocoelous coelomate animals. 3. Adults exhibit radial symmetry, usually pentamerous i.e. the body can
NSOU CC - ZO - 03 245 usually be divided into five parts arranged around a central axis, but their larvae are bilaterally symmetrical. 4. Adults generally do not have anterior and posterior ends. Instead body is distinguishable into oral (bearing the mouth) and aboral (not bearing the mouth) surfaces, without any differentatiated head. 5. Most echinoderms possess a well developed internal skeleton composed of calcareous ossicles. Commonly the

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skeleton bears projecting spines or tubercles that give the body surface a warty or spiny

appearnace, hence the name echinoderm, meaning "spiny skin" (Gr. echinos = hedgehog; derma = skin). 6. The oral surface of the body is marked by five equidistant radiating grooves, called ambulacra, originating from the mouth, with intervening interabmulacra. 7. Coelom spacious, developed as outgrowths of the archenteron (enterocoelous type). 8. Digestive tract is mostly a coiled tube with the anus placed on the aboral surface. 9. A characteristic coelomic Water Vascular Sysem (WVS) or ambulactal system is present. It performs many functions such as feeding, locomation and respiration, etc. 10. Presence of tubular contractile tube feet or podia used as locomotory organ and or feeding organ. 11. The blood vascular system also called haemal or blood (lacunar system) is present. It is well developed in Echinoids and Holothuroids. 12. Nervous systems simple, consisting of a circum-oral ring and radial nerve along each ambulacrum. 13. No definite respiratory and excretory system in most cases. Respiration is done through body wall, podia, respiratory tree and papulae. 14. Specialized sense organs are poorly developed. 15. Sexes are usually separate (gonochoristic). Reproductive tracts are very simple. Fertilization is usually external in sea water. 16. Eggs are typically homolecithal, cleavage radial and indeterminate, development through bilaterally symmetrial larvae which undergo metamorphosis into radially symmetrial adults. 8.3 Classification The scheme of classification presented here is based on the the classification plan
246 NSOU CC - ZO - 03 outlined by Ruppert and Barnes (1994) in their book "Invertebrate Zoology", 6th Edition. According to them phylum Echinodermata is divided into four subphyla– Subphylum Homalozoa (Extinct) Subphylum Crinozoa –– Class Crinoidea Subphylum Asterozoa –– Class Asteriodea, Class Ophiuroidea and Class Concentricycloidea Subphylum Echinozoa –– Class Echinoidea and Class Holothuroidea All members of Subphylum Homalozoa are extinct. Subphylum Crinozoa includes only one class – Class Crinoidea. Subphylum Asterozoa includes three classes–Class Asteroidae, Class Ophiuroidea and Class Concentricycloidea. Subphylum Echinozoa includes two classes—Class Echinoidea and Class Holothuroidea. Classification with Characters : Subphylum Homalozoa (Extinct) : Paleozoic echinoderms lacking any evidence of radial symmetry. Example : Enoploura Subphylum Crinozoa : 1. Radially symmetrical echinoderms with a globoid or cup-shaped theca and 5-10 brachioles or arms. 2. Mostly attached, with oral surface directed upward. This subphylum contains the fossil eocrinoids (class Eocrinoidea), cystoids (Class Cystoidea) and the fossil and living crinoids. Only the characters of class Crinoidea are described here Class Crinoidea (Cambrian–Recent) [G. crinon = lily; eidos = form] About 700 speices. 1. Stalked and free moving echinoderms having the oral side of the body directed upward. Arms well developed, movable, branched and bearing pinnules.

NSOU CC - ZO - 03 247 2. Body exhibits strong pentamerous symmetry. 3. Mouth is centrally placed and anus is generally excentrically placed on the oral surface of the body. 4. The ambulacral grooves radiates from the mouth and extend along the arms and pinnules upto their tips. 5. The theca (protective covering or case) on the aboral side is differentiated into a non-porous cup-like Calyx. 6. Madreporite, spines and pedicllariae are absent. 7. Sexes separate, gonads are located in the arms or pinnules. 8. Barrel-shaped free-swimming larva, called doliolaria larva with five ciliated bands. This class includes both extinct and living forms Examples : Antedon (feather stars), Neocrinus (long stalked sea lilies), Cenocrinus (long stalked sea lilies), Holopus (very short stalked sea lilies. Sub-phylum Asterozoa : 1. Radially symmetrical, free moving (unattached) echinoderms. 2. Body composed of a flattened central disc and radially arranged arms. 3. Oral surface directed downward. On the oral surface in the ambulacral groove, tube feet are present. 4. Anus and madreporite aboral. The subphylum includes three classes – class Asteroidea, Class Ophiuroidea and Class Concentricycloidea. Class Asteroidea (Cambrian – Recent) [G. aster = star; eidos = form] About 1800 spices. 1. Body star shaped, arms not sharply set off from the central disc. 2. Ambulacral grooves are open and a large coelomic cavity is present in relatively wide arms. 3. Each ambulacral groove contains two to four rows of tube feet or podia. Tube feets with or without suckers. 4. Oral and aboral surfaces are distinct. Oral surface directed downward and aboral surface upward. 5. Madreporite and anus are present on the aboral surface.

248 NSOU CC - ZO - 03 6. Pedicellariae are present. 7. Larval forms are bipinnaria and/or brachiolaria. The members of this class are generally called sea stars : Examples : Asterias, Astropecten, Heliaster, Ctenodiscus. Class Ophiuroidea (Carboniferous to Recent) [G. ophis = snake; oura = tail; oidos = form] About 2100 species : 1. Body pentamerous and star-shaped. 2. Arms sharply set off from the central disc. Arms are elongated and flexible. 3. Ambulacral grooves absent, tube feet without suckers. 4. No spacious prolongations of the coelom into the arms. Arms largely filled with vertical ossicles. Fig. 1 : Some important echinoderms. A. Heliaster. B. Ctenodiscus. C. Arbacia. D. Zoroaster. E. Solaster. F. Diadema. G. Clypeaster.

NSOU CC - ZO - 03 249 5. Mouth and madreporite are situated on the oral surface of the body. Anus is lacking. 6. Pedicellariae absent. 7. Larva is Ophiopluteus. The members are commonly termed the brittle stars or serpent stars. Examples : Ophiura (brittle stars), Ophiothrix (brittle stars), Ophiocoma (brittle stars). Fig. 2 : Some important Echinoderms (contd.). A Laganum. B. Pelagothuria. C. Porcellanaster. D. Thyone. E. Echinocardium. F. Gorgonocephalus.

250 NSOU CC - ZO - 03 Class Concentricycloidea (L. concentric rings) 1. Minute (maximum 1 cm diameter) deep water echinoderms with disc- shaped body. 2. Body covered aborally with plate-like ossicles. 3. Two concentric water rings on the outer edge of the disc. Marginal spines are located around the periphery. 4. Coelom spacious. 5. Water vascular system has two ring canals with the tube feet arising from the outer one. 6. Ambulacral system absent. 7. No larval form. The members are called sea daisies and are known by a single genus and two species that were discovered in 1983 and 1984 from the coast of NewZealand and described in 1986 by Baker et al. Examples : Xyloplx medusiformis and X. turnerae. Subphylum Echinozoa [G. echinos = a hedge hog; eidos = form]. 1. Radially symmetrical globoid or discoid echinoderms without arms or brachioles (small arm-like processes). 2. Mostly unattached. 3. Madreporite and anus remain on the aboral side. 4. Hydrocoel forms a ring around the mouth. The subphyklum comprises two classes– Class Echinoidea and Class Holothuroidea. Class Echinoidea (Ordovician – Recent) [G. echinos = a hedge hog; eidos = form] About 900 species : 1. Body may be globular, heart-shaped, oval or disc shaped. 2. Body orally and aborally flattened and without arms. 3. Body is enclosed in a skeleton in the form of a continuous shell or test (corona) of closely fitted clacareous plates.

NSOU CC - ZO - 03 251 4. Movable spines are mounted on the test. The name Echinoidea means "like a hedge hog". It is called so because it contains movable spines (like the hedge hog) that covers the body. 5. Although the ambulacral grooves are absent, the body surface is divided into alternate ambulacral and interambulacral areas. 6. The ambulacral areas extend from the oral to the aboral sides of the body. 7. Ambulacral plates have pores for the passage of tube-feet. 8. Tube feets are highly extensible, provided wth suckers and locomotory in function. 9. Mouth and anus are surrounded by membraneous peristome and periproct respectively. 10. Mouth is generally provided with an elaborate chewing appartus or Aristotle's lantern with teeth. 11. Larva is echinoplutens. The sea urchnins, heart urchins, cake urchins are included in this class. Examples : Echinus (sea urchins), Abracia (sea urchins), Dendraster (sand dollar), Clypeaster (sea biscuit), Echinocardium (heart urchins). Class Holothuroidea (Devonian – Recent) [G. holothurion = a water polyp; edio = form] About 1200 species : 1. Body elongated / cylindrical along the oral / aboral axis. 2. Body exhibits somewhat bilateral symmetry. 3. Mouth and anus located at the opposite extremities of the body. 4. Skin soft, thin and leathery, without spines and pedicellariae. 5. Oral or buccal podia form a circle of tentacles around the mouth. 6. Arms are absent. 7. Alimentary canal long and coiled and cloaca usually with respiratory trees. 8. Skeleton reduced to microscopic ossicles. 9. Tube-feet locomotory in function and restricated to five ambulacral areas. 10. Larva is auricularia.

252 NSOU CC - ZO - 03 The membrs of this class are known as sea cucumbers. Some move on bottom, others live beneath stones or in crevices. Examples : Cucumaria, Holothuria, Thyone, Molpadia. 8.4 Ambulacral System or Water Vascular System (WVS) : The ambulacral system or water vascular sysem (WVS) is unique to the echinoderms. It is consideredd as the major unifying characteristic of the phylum Echinodermata. The system consists of a series of fluid-filled canals derived primarily from 1 of 3 pairs of coelomic compartments (the left hydrocoel) that form during embryonic development (Pechenik, 2000). The canals are lined with a ciliated epithelium (as they are derived from coelom). The ambulacral system exhibits radial symmetry from the beginning and it is equally developed in all echinoderms. This system lies just above the haemal system. It is primarily locomotory in function and also subserves the function of tactile and respiratory organs in some forms. The excretory role of this system, as suggested by some workers, is not yet fully ascertained. General plan of ambulacral or water vascular system : The water vascular system in different classes of Echinodermata has almost the same structural organization. It comprises of a few canals together with some appendages attached to these canals. The typical arrangement of the water vascular system is exhibited by Asterias. It consists of madreporite,

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stone canal, ring canal, radial canal, Tiedeman's bodies, lateral canals and tube feet.

The internal canals of the water vascular system connect to the outside through the button-shaped madreporite on the aboral surface covered with ciliated epithelium of the body surface. The bottom of each furrow contains many pores that open into pore cansls passing downward through the madreporite. Acutally pore canals join to form a common canal to open into an cup like depression called ampulla beneath the madriporite. The pore canals eventually lead into a vertical stone canal that descends to the oral side of the disc (Fig.). The stone canal is so named because of the calcareous deposits in its walls. On reaching the oral side of the disc, the stone canal joins a circular canal, the ring canal, just to the inner side of the ossicles that ring or surround the mouth (peristominal ring).

NSOU CC - ZO - 03 253 The inner side of the ring canal (water ring) gives rise to four or more, usually five pairs of greatly folded pouches called Tiedemann's bodies (Fig.). Each pair of these pouches has an interradial position. Also attached interradially to the inner side of the ring canal in many asteroids (although not in Asterias) are one to five elongated, muscular bladder like sacs which are suspended in the coelom. These sacs are known as polian vesicles. Both Tiedemann's bodies and polium vesicles are accessory fluid-storage structures. In addtiion to storing fluid, the Tiedemann's bodies also serve to filter fluid from the water vascular system into the main body cavity (the perivisceral coelom), helping to maintain body turgor. Some zoologists are of the opinion that Tiedemann's bodes produce certain coelomocytes or

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phagocytic amoebocytes which are released into the water vascular system.

Fig. 3 : A. Water vascular system n Asterias. Note that in Asterias the polian vesicles are absent. B. Enlarged view of the madreporite of Asterias. C. Diagrammatic view of the vertical section through the madreporite in Asterias. D. Diagrammatic sectional view of a tube-foot and its nerve supply in Asterias.
254 NSOU CC - ZO - 03 From the outer margin of ring canal, a long, ciliated radial canal extends into each arm (Fig). The radial canals run up to the tip of the arms and each ends at the lumen of the tentacle tentacle. From either side of each radial canal, lateral canals are given off atternately along its entire length. The lateral canals pass between the ambulacral ossicles on each side of the ambulacral groove (Fig.). Each lateral canal is provided with a valve and terminates in a bulb and a tubefoot or podium. The bulb or ampulla, is a mall, muscular sac that bulges into the aboral side of the perivisceral coelom.The ampulla opens directly into a canal that passes downward between the ambulacral ossicles and leads into the tube foot or podium. Ambulacral ossicles are calcarious ossicles supporting the ampullae and tube feet.

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The tube feet are short, tubular external projections of the body wall located in the ambulacral groove.

Commonly, the tip of each tube foot or podium is flattened, 4 :
NSOU CC - ZO - 03 255 forming a sucker. Like the body wall, the podium is covered on the outside with a ciliated epithelium and internally with peritonium. Between these two layers lie connective tissue and longitudinal muscle fibers. Tube foot or podium often lacks circular muscles and so it can not extend itself. Fluid is pumped into the tube foot hydralically. An one-way valve at the juncture of the ampulla and radial canal ensures that fluid flows from ampulla to tube foot, rather than to the radial canal, when the ampulla contracts. The tube feet or podia are arranged in two rows when the lateral canals are all of the same length or in four rows where they are alternately long and short. The entire water vascular system is filled with fluid that is similar to sea water except that it contains coelomocytes, a little protein and a relatively high concentration of potassium ions. The system operates during locomotion as a hydraulic system. When the muscular ampulla contracts, the valve in the latgeral canal closes, and water is forced into the podium, which elongates. When the podium comes in contact with the substratum, the sucker adheres. Adhesion is largely chemical, the podium secretes a substance that bonds with surface films. Another secretion breaks the bonds and brings about release. This has been designated as duogland adhesion system. [one or more gland cells on each tube foot apparently secrete an adhesive that binds that tube foot to a substrate; adjacent gland cells then apparently frelease another chemical that somehow breaks those bonds.] 5
256 NSOU CC - ZO - 03 When attachment is prolonged, or a large force is generated, adhesion by suction probably also takes place. After the sucker adheres to the substratum, the longtudinal muscles of the podium contract, shortening the podium and forcing fluid back into the ampulla. During movement each podium or tube foot per forms a short of stempping motion. The podium swings forward, grips the substratum, and then moves backward. backword. In a particular section of an arm most of the tube feet are performing the same step, and the animal moves forward. The action of the podia is highly coordinated. During progression one or two arms act as leading arms, and the podia in all arms move in the same direction, but not necessarily in unison. A single echinoderm may possess more than 2000 tube feet. 8.5 Questions a) What is madriporite? b) What do you mean by stone canal? c) How many parts are present in tube feet? d) What are the name of larval stages in Echinoderm animal? e) What do you mean by ambulacral system? f) Is blood vascular system is present in Echinodermata? g) Write the important characters of phylum Echinodermata.

NSOU CC - ZO - 03 257 Unit–9 ?? Phylum : Mollusca Structure 9.0 Objective 9.1 Introduction 9.2 General characteristics 9.3 Classification 9.4 Torsion in gastropoda 9.4.2 Adaptive significance of torsion 9.4.3 Detorsion 9.5 Larval stages in Mollusca 9.6 Questions 9.1 Objective This unit deals with those animals which are externally covered with a shell or conch. From this unit you will learn that how beautifully patterned conchs are present in these animals. The study of the shells of these animals is a separate science which is known as Choncology. 9.0 Introduction Members of the phylum Mollusca are among the most conspicuous and familiar invertebrate animals and include such forms as calms, oysters, snails, slugs, mussels, squids, octopus, etc. In abundance of spieces molluscs constitute the second largest invertebrate phylum after the arthropods. Over 50,000 living species have been described (Ruppert and Barnes, 1994). In addition, some 35000 fossil spieces are known because the plylum has had a long geological history. Mollucs are found in in the abyssal depths of the ocean and above high tide line, and are common in freshwater everywhere. A few of them are terrestrial.

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The biggest of all invertebrates (giant squid) and probably the most intelligent invertebrate (Octopus) are the

molluscs. Molluscan shells including pearls always been economically important and some molluscs are important food items, and thus are also economically important. 9.2 General Characteristics 1. Triploblastic, coelomate, unsegmented (except Monoplacophora) and bilaterally symmetrical animal.

258 NSOU CC - ZO - 03 2. Soft body (L.mollis = soft) covered by a thick muscular fold or sheet of skin, the mantle or pallium which forms a cavity, the mantle cavity. It encloses the visceral mass and secretes the shell. Presence of mantle is the unique feature of all molluscs. 3. Exoskeleton, in the form of calcareous shell, is present in most, in some forms shell absent and in some shell is internal. 4. Presence of ventral muscular foot which helps in locomotion and may be secondarily modified in some forms. 5. Cephalization well marked in class Gastropoda and class Cephalopoda but in other classes the head is small or poorly differentiated. Figure 1 A, B : (a) The eye of a cephalopod; (b) the brain of an octopus in dorsal

NSOU CC - ZO - 03 259 6. Head carries mouth, eyes and tentacles (eyes and tentacles absent in Pelecypoda and Scaphopoda). 7. Many molluscs possess a toothed, chitinous, tongue like ribbon, the rudula which assists in feeding (rasping organ). 8. Coelom is reduced, confined to the lumen of pericardial cavity, gonads and kidney. Body cavity is haemocoel. 9. Respiration is done

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by one or many ctenidia or gills enclosed in the mantle cavity.

Respiratory pigment is usually haemocyanin. 10. Circulatory system is of open type with dorsal heart and few bloood vessels. However, cephalopods shows some tendency towards a closed system. 11. A chemoseceptor of tactile receptor organ, called the Osphradium, generally located adjuscent to the Ctenidium. Other sense organs are eyes, tentacles, and statocysts in most forms. 12. Excretion is by one or two pairs of kidenys (metanephridia)

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communicating the coelom with mantle cavity by nephridiopore. 13. Nervous system

consist of paired ganglia, connectives, commissiures and nerves. Figure (cont.). 1C : (c) the brain of an octopus in lateral view.

260 NSOU CC - ZO - 03 14. Sexes usually separate (gonochoristic or dioecious) but a few are hermaphrodite. 15. Fertilization is either external or internal. Development direct or through free larval forms (veliger larvae, trochophore larvae). Direct development mainly in Gastropoda and Cephalopoda. 16. Cleavage generally spiral and determinate. 9.3 Classification : Phylum Mollusca has been classified differently by different authors depending upon the characters of foot, mantle, shell, respiratory organs, nervous system, etc. The classificatory scheme followed here is based on as outlined by E.E.Ruppert and R.D. Barnes (1994) in their book "Invertebrate Zoology", 6th Edition. Phylum Mollusca is divided into following seven classes: (1) Class Aplacophora; (2) Class Polyplacophora; (3) Class Monoplacophora; (4) Class Gastropoda; (5) Class Bivalvia; (6) Class Schaphopoda; (7) Class Cephalopoda. Classification with Characters (upto Classes) : Class Aplacophora (G. a = without, plakos = a sheet of wood) : 1. Primitive worm like marine molluscs with no shell. 2. Elongated bilaterally symmetrical body covered by cuticle. 3. Foot absent or reduced to a ventral ridge. 4. Mantle thick with calcareous spiculaes or scales. 5. Head is poorly developed, without eyes or sensory tentacles. 6. Digestive tube straight, radula may be present or not. 7. Gills are either absent or reduced to a pair and located in posterior mantle cavity. 8. Nervous system primitive with distinct brain and nerve cords. 9. No separate excretory organs, vascular system rudimentary. 10. Most aplacophorans are hermaphrodites. Development direct or through
NSOU CC - ZO - 03 261 trocophroe larva. Examples : Chaetoderma, solenogasters such as Neomenia, Proneomenia. Class Polyplacophora [G. poly = many; placos = a sheet of wood] (meaning bearer of many plates) 1. Body oval or elliptical (somewhat elongated) and dorsoventrally flattened (convex dorsally and flattened ventrally). Bilaterally symmetrical. 2. Dorsal side is covered by eight transverse and overlapping shell plates held together by a surrounding fleshy thick girdle. 3. A broad muscular creeping foot is present on the ventral surface. 4. Head inconspicuous, eyes and tentacles asbent. 5. Gills 6

88%	MATCHING BLOCK 91/94	SA	BZO 1.1 B.Sc BZO Block 2,3,and 4 11.04.22-87- ... (D136039508)

to 8 pairs, persent in the pallial groove on the lateral sides of foot. 6.

Alimentary canal coiled with well developeed radula bearing many teeth. 7. A pair of shaped kidneys present. 8. Sexes separate, development through a free swimming trochophore larva in most, but veliger larva is absent. They are called the armadillos of the sea. Examples : Chiton, Lepidochiton, Chaetopleura, Lepidopleurus. Class Monoplacophora (G. mono = single; plakos = a sheet of wood) : 1. Body bilaterally symmetrical and metamerically segmented but the segmentation is internal. 2. Dorsal side is covered by a single piece of shield-like shell (hence the name Monoplacophora). 3. Foot ventral with a flat creeping sole and with 8 pairs of pedal retractor muscles. 4. Mouth antero-median and anus postero-median. 5. Head is without eyes and tentacles. 6. Mantle covers the dorsal surface of body. 7. Radula well developed. 8. 5 to 6 pairs of gills (monopectinate ctenidia) are serially arranged in pallial groove on either side of the foot. 9. Six pairs of nephridia and two pairs of gonads.
262 NSOU CC - ZO - 03 10. Sexes separate, fertilization external. 11. Development indirect. Monoplacophorans

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are regarded as primitve molluscs and are believed to be ancestral to the gastropods (snails) and cephalopods (

squids and octopods). This group was thought to have become extinct in the Devonian but only a few living species represent the class. Examples : Neopilina galatheae, Vema, Micropilina. Class Gastropoda (G. gastros = stomach; podos = foot) 1. A muscular and broad foot is present below the digestive system and visceral mass. 2. Visceral mass is twisted at 180º in an anticlockwise direction (torsion), relative to the head and foot. 3. Shell single, spirally twisted. Shell reduced or absent in some. 4. Head well differentiated with one or two pairs of tentacles and eyes. 5. Mantle cavity contains a single pair of bipectinate ctenidia. In some ctenidia absent and mantle cavity functions as pulmonary sac or lung. 6. Buccal cavity with an odontophore and a redula bearing rows of chitinous teeth. 7. Anus is usually situated anteriorly close to mouth. 8. A chemo-receptive sense organ, called osphradium is present in the mantle cavity. 9. Nervous system contains distinct paired cerebral buccal pleural, pedal, parietal and visceral ganglia. 10. On the upper surface of the foot in some forms there may be an operculum which closes the shell aperture. 11. Sexes separate (dioecious) in most forms while some are monoecious (hermaphroditic). 12. Development includes trochophore and veligar larval stages. Gastropods are mostly marine, some freshwater, some terrestrial. The class Gastropoda is the largest class of Mollusca.
NSOU CC - ZO - 03 263 Examples : Pila (apple snail), Patella (limpet), Aplysia (sea hares), Doris, Planorbis, Lymnaea, Achatina (garden snail), Limx (grey slug). Class Bivalvia (Pelecypoda or Lamellibranchiata) This class includes such common molluscs as clams, oysters and mussles. (L. bi = two; valvae = folding doors; G. pelekys = a hatchet; podos = foot). 1. Bivalves are laterally compressed and possess a shell composed of two valves, hinged together dorsally, that completely enclose the body. 2. The foot, like the remainder of the body, is laterally compressed, usually hatchet or plough-share shaped, hence the name Pelecypoda, meaning "hatchet foot". Foot is antero-ventral, commonly used for crawling or burrowing purposes. 3. There is no cephalization i.e. head, tentacles and eyes are absent. Fig. 2 : Some members of Phylum Mollusca (not drawn up to scale), A. Pecten (scallop), B. Octopus. C. Loligo (squid). D. Limax (slug). E. Helix (Roman snail). F. Mytilus (sea-mussel).
264 NSOU CC - ZO - 03 4. Mouth is provided with two pairs of labial palps, most are ciliary feeders or filter feeders radula absent. 5. Mantle consists of paired leaf-like right and left lobes which secrete the shell. Posterior-edges of mantle often fused to form inhalent and exhalent siphons. 6. Gills or ctenidia are paired, well developmed and plate-like, hence the name lamellibranchiata. They are often specialized to assist in feeding (food collection). 7. Nervous system consists of four

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pairs of ganglia cerebral, pleural, pedal and visceral. Cerebral and pleural of each side usually fused into a cerebropleural ganglian. 8. Sense organs are statocyst and

osphradium. 9. Mostly unisexual, some bisexual. Fertilization external. 10. Development indirect through trochophore and veliger larvae. Exampls: Nucula, Mytilus (sea mussel), Pinctada (pearl oyster), Ostrea (edible oyster) Unio (fresh water mussel), Lamellidens, Solen (razor clam). Class Scaphopoda (Tusk Shells) [G. skaphe = a boat; podos = foot] 1. Tusk-shaped tubular or conical shell, open at both ends. Anterior part of the shell is much wider than the posterior end. 2. The elongated body completely enclosed by the mantle. 3. From the wider anterior opeing of the shell protrude the narrow trilobbed (wedge-shaped) burrowing foot and buccal region. 4. Mouth surrounded by adhesive knobbed tentacles, called captacuca used both for feeding and as sense organs. 5. Buccal mass possess a radula. 6. Head reduced, lacks eyes. 7. Heart rudimentory, gills absent. 8. Gonad unpaired and kidneys paired.
NSOU CC - ZO - 03 265 9. Sexes separate, fertilization external. 10. Eggs planktonic, both trochophore and veliger larval stage in life cycle. Scaphopods are exclusively marine, widely distributed in all seas. The animals remain buried on sandy or mudy sea bed with their anterior end downward, and posterior end, (through which ventilating current enters and leaves), near the surface of the substratum (see bed) Fig. 3 : Bivalve mollusc. Cross section of a generalized Lamellibranch (after Ruppert, et al., 2004) Examples : Dentalium, Cadulus, Antalis. Class Cephalopoda (G. kephale = head; podos = foot) 1. Head well developed and projects into a circle of large, prehensive tentacles or arms modified from foot (homologous to the anterior of the foot of other molluscs). Hence the name cephalopoda. 2. Body bilaterally symmetrical. 3. Shell usually internal either reduced or absent and covered by the mantle in most species. An external shell occurs only in Nautilus.

266 NSOU CC - ZO - 03 4. Head bears large eyes and mouth. Mouth with horny or calcareous beak- like jaws and radula. 5. Tentacles or arms bear suckers, except Nautilus. 6. A funnel or siphon is present which expels water from the mantle cavity, helps in jet propulsion during swimming. Most cephalopods possess an ink gland (except Nautilus) associated with rectum. 7. Gills or ctenidia are bi-pectinate and are either one or two pairs. 8. Circulatory system closed, heart with two or four auricles. 9. Excretory system comprieses one or two pairs of nephridia. 10. Nervous system is highly developed and complex. There is a great cephalization. All of the typical molluscan ganglia are concentrated and more or less fused to form a brain that encircles the oesophagus and in encased in a cartilaginous cranium. 11. Sexes separate, external sexual dimorphism in some species. Gonad single. One of the arms of the male modifies as an spoon like intromittent organ, called hectocotylus, for transferring spermatophores to the female. 12. Cleavage meroblastic, development direct i.e. metamorphosis or larval form absent. This class includes cuttle fishes, squids, nautiluses, octopuses, all of which are exclusively marine. Examples : Sepia (cuttle fish), Loligo (squied), Nautilus, Octopus (Devil fish), Architeuthis (giant squid, it is the largest animal not only in cephalopodes but also among the invertebrates. It may attains 20 metres in total length). 9.4.1 Torsion in Gastropoda All the living molluscs, except the Gastropods, retain ancestral bilateral symmetry of the body with mantle cavity lying posteriorly or laterally. Gastropods, on the other hand, possess an asymmetrical body with mantle cavity lying anteriorly and the shell and visceral mass coiled spirally and directed posteriorly. This anterior positon of the mantle cavity in gastropods is due to torsion or twisting of he visceral mass during development. This unique process of torsion is a characterisic feature of all living gastropods. Torsion is the rotation of the visceral mass (containing organs of the body) and
NSOU CC - ZO - 03 267 its overlying mantle and shell as much as 180º with respect to the head and foot (Fig.). The twisting is always in a counterclockwise dierection (viewing the animal from above) and it is completely different from the phenomenon of coiling (Brusca and Brusca, 2002). Torsion takes place during developement of all gastropods, usually during the late veliger larval stage. During torison, the mantle cavity and the anus are moved from a posterior to a more anterior position, somewhat above and behind the head. Visceral structures and incipient organs that were on the right side of the larval animal end up on the left side of the adult. The gut is twisted into a U-shape, and when the longitudinal nerve cords connecting the pleural to the visceral ganglia develop, they are crossed rather like a figure eight. Most veligers have nephridia, which reverse sides, but the adult gills and gonads are not fully developed when torsion occurs. (Brusca and Brusca, 2002). "The original mechanism by which torsion was brought about was probably the Fig. 4 : Diagrammatic representation of torsion in Gastropod. A. Hypothotical ancustral stage with symmetrical arrangement of structures. B. Displacement of the mantle cavity to the right side. C. Showing 90' torsion. D. Showing complete torsion. 268 NSOU CC - ZO - 03 contraction of larval retractor muscles, the entire rotation being completed in a few minutes. In most of the gastropods in which torsion has been carefully studied, larval retractor muscles account for 90º of the rotation, differential growth for the rest. Even in the very early veliger larva, the mesodermal bands develop asymmetrically. The right band is distinctly larger than the left and can be distinguished as five large mesodermal cells. As these cells elongate to form muscle cells, they gradually, displace he visceral hump to the left, emphasising the asymmetry. These cells converge on to the right side in the posterior region of larval shell and are inserted into the anterior end of the body as larval retractor muscles. There are no related muscle cells on the left side. As soon as the larval muscle cells have any contractile power, the process of torsion commences (Fig.). If the muscle contraction accounts for only 90º of rotation, the process usually lasts for a few hours. At the end of this first stage, the mantle cavity which originally lay ventrally and posteriorly now lies on the right side and the foot projects on the left." [The above descripiton of torsion is according to Parker and Haswell (1972), Textbook of Zoology, Volume-1, Invertebrates, 7th edition] Stage two of torsion is usually longer in duration and is the result of differential Fig. 5A: Figures showing the torsion of a free-swimming larva in a primitive gastropod (Patella sp.) (after Pechenlk) Fig. 5 B, C : Diagrammatic representation of torsion in veliger larva of a prosobranch. B. Pre-torsional stage. C. Post-torsional stage (after Parker and Haswell).

NSOU CC - ZO - 03 269 growth. It is difficult to give a generalized account on torsion in gastropods, however, Thomson (1958) distinguished five possible ways in which torsion can be brought about. These are : 1. 180º rotation of visceral hump is achieved by muscle contraction alone. This was probably the original mechanism and is known only for Acmaea. 2. 180º rotation achieved in two stages, an initial 90º movement (rotation) by larval retractor muscle contraction followed by a slower rotation of remaining 90º by differential growth process. This is probably the commonest mechanism of present-day forms, e.g. Haliotis, (Prosobranchia) Patella (Prosobranchia). 3. In some gastropods 180º rotation is achieved by differential growth process alone. e.g. Vivipara (prosobranchia) 4. Torsion achieved by differential growth processes, the change in the position of the anus being halted at a site appropriate to the adult stage, e.g. Aplysia (opisthobranchia). 5. Torsion no longer recognisable as movement of the visceropallium, the organs being in the post-torsional postion from their first appearance, e.g. Adalaria (opisthobranchia). Whatever the mechanism involved, the post-torsional larva now has its mantle cavity placed anteriorly and whatever organs are developed will be affected in some way, particularly in their spatial relationship with each other. 9.4.2 Adaptive significance of torsion The adaptive significance of torsion is speculative, however three advantages are plausible. First, without torsion withdrawl into the shell would proceed with the foot entering first and the more vulnerable head entering last. After torsion, the mantle cavity became anterior, so that the sensitive part like head could withdraw first followed by foot, thus avoiding the attack of potential predators. A second advantage of torsion concerns an anterior opening of the mantle cavity that allows clean water from in front of the animal to enter the mantle cavity, rather than water contaminated with silt stirred up by the snail's crawling. The twist in the mantle's sensory organs around the head region is a thrid advantage of torsion because it makes the snail more senstitive to stimuli coming from the direction in which it moves.

270 NSOU CC - ZO - 03 It should be mentioned here that placing the mantle cavity in front (with the anus and nephridia empty dorsal to the head) created a potential fouling problem relative to the situation in the ancestral molluscs with the mantle cavity in the rear. This fouling occurs because the water now passes directly into the cavity from the front, goes over the ctenidia, pickes up the wastes from the anus and nephridia and essentially exists on top of the animal's head, where it may be deposited. However, a number of evolutionary adaptations (many of the major evolutionary trends) seem to circumvent this fouling problem : In most primitive gastropods the problem is solved by having slits or holes in the shell over the mantle cavity so that water with wastes exists farther back on the shell. More advanced gastropods have solved the problem by extending the anal and nephridial openings to the far edge of the mantle cavity and developing a siphon to channel an oblique water flow through the mantle cavity. In this the water enters on one side and exits on the other side, away from the head region. Finally, in one group, opisthobranchia, the animals have undergone detorsion and the whole mantle cavity is displaced back toward the rear or is lost. 9.4.3 Detorision : Detorsion means the reversion of the changes that had occured during torsion. Acquisition of secondary symmetry observed in some opisthobranch gastropods is regarded as the result of detorsion. As a result of detorsion the pallial complex shifts towards the posterior part along the right side. The ctenidia are pointed backwards and the auricles come behind the ventricle. The visceral loop becomes untwisted and symmetrical. In this way a secondary external symmetry is established again. Detorsion is always associated with the loss of shell and liberation of gills (ctenidia) from their enclosing case, the gills becoming exposed and subjected to external current. The organs lost in torsion are never replaced. With the result, the opisthobranches continue to have unpaired ctenidium, auricle and kidney. This indicates towards their evolution from the prosobranch gastropods. Different gradations of detorsions are encountered in different members of opisthobranchs. Detorsion is incomple or partial in primitive opisthobranchs like Acteon and Bulla but complete in advanced forms such as Aplysia. Complete detorsion is accompanied by reduction or loss of the shell. In some nudibranchs (e.g. Doris, Aeoldia) the shell and mantle cavity are absent and the body becomes secondarily bilaterally symmetrical.

NSOU CC - ZO - 03 271 9.5 Larval Stages in Mollusca Developent in molluscs may be direct, mixed or indirect. In fact, excepting the cephalopods development is usually indirect. In msot forms, during indirect development, the free-swimming trochophore larva that develops, is remarkably similar to that seen in annelids. Like the annelid larva, the molluscan trochophore bears an apical sensory plate with a tuft of cilia and a girdle of ciliated cells–the prototroch–just anterior to the mouth (Fig.). In some free-spawning molluscs (e.g. Chitons), the trochophore is the only larval stage, and it metamorphoses directly into the juvenile. But in many groups (gastropods and bivalves), the trochophore stage is followed by a uniquely molluscan larval stage called a veliger. The veliger may posssess a foot, shell, operculum and other adult-like structures. The most characteristic feature of the veliger larva is the swimming and feeding organ or velum, which consists of two large ciliated lobes developed from the trochophore's prototroch. In some species the velum is subdivided into four, five, or even six separate lobes. Veligers feed by capturing particulate food between opposed prototrochal and metatrochal bands of cilia on the edge of the velum. Some veligers apparently are non-feeding. Eventually eyes and tentacles appear, and the veliger transforms into a juvenile, settles to the bottom and asumes an adult existence. Some bivalves have long-lived planktotrophic veligers, whereas others have short-lived lecithotrophic veligers. The formers have larval life of two or three months and the short-lived ones have larval life not more than a week. Many widely distributed species have very long larval life that allow dispersal over great distances. A few birvalves have mixed development and brood the developing embryos in the suprabranchial cavity throughout the trochophore period; then the embryos are released as veliger larvae. Some marine and fresh water clams have direct development, i.e. no larval form. Development of a free-swimming trochophore, succeeded by a veliger larva, is typical of marine bivalves. The veliger is bilaterally symmetrical and eventually becomes enclosed within the two valves charcterisitc of bivalve. In the fresh water mussels (Unionacea and Mutelacea) the eggs or embryos are brooded between the gill lamellae, where they develop through the veliger stage. The veligers of these groups are often highly modified for a parasitic life on fishes, thereby facilitating disparsal (the fish disperse the rather sedentary freshwater bivalves). Various names have been given to these specielized parasitic veligers. In
272 NSOU CC - ZO - 03 the Unionacea they are caleld glochidia (Fig.). They attach to the skin or gills of the host by sticky mucuous, hooks or other attachment devices. Most glochidia lack a gut and absorb nutrients from the host by means of special phagocytic mantle cells. The host tissue often forms a cyst around the glochidium. Eventually the larva matures, breaks out of the cyst, drops to the bottom and assumes its audlt life. Among the gastropods, only the primitive archaeogastropods that rely on external fertilization have retained a free-swimming trochophore larva. All other gastropods suppress the trochophore or pass through it quickly before hatching. In many groups embryos hatch as veligers (e.g. opisthobranchs). Some of these gastropods have feeding (planktotrophic) veligers that may have brief of extended (to several months) free-swimming larval life. Others have short-lived, yolk-laden non-feeding (lecithotropic) veligers that remain planktonic only for short periods. Planktotrophic veligers feed by use of the velar cilia, whose beating drives the animal forward and draws minute planktonic food particles, into contact with the shorter cilia of a food groove. Once in the food groove, the particles are trapped in mucus and carried along ciliary tracts to the mouth. Almost all pulmonates and many advanced marine prosobranchs (e.g. Fig. 6 : External features of a

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trochophore larva. B. Internal organization of a trochophore larva. C. An advanced trochophore larva showing the additional ciliated segments at the posterior end.

NSOU CC - ZO - 03 273 neogastropods) have direct development, and the veliger stage is passed in the egg case, or capsule. Upon hatching, tiny snails crawl out of the capsule into their adult habitat. It is usually during the veliger stage that gastropods undergo torsion when the shell and visceral mass twist 180 degrees in relation to the head and foot. Cephalopods produce large, yolky, telolecithatl eggs. Development is always direct, the larval stages being lost entirly or passed within an egg case. Scaphopod development is very similar to that of the marine bivalves. There is a free-swimming trochophore larva, succeeded by a bilaterally symmetrical veliger larva. Charcters of a typical trochophore larva : 1. Body is transparent, oval or pear-shaped with broad anterior and narrow posterior end. 2. It is bounded externally by a thin ectodermal epithelium which is thickened at two ends and also along the equatorial ring. 3. The thickned anterior end forms sensory apical plate which bears a tuft of cilia. 4. A pair of cerebral ganglia and pigmented larval eyes are present on the apical plate. 5. There is a curved gut with a mouth, ectodermal oesophagus, endodermal sac like stomach and an ectodermal hind gut opeing by anus. It feeds on microorganisms. Fig. 7 : Structure of a veliger larva of Nassarius reticulatus (after Parker and Haswell).
274 NSOU CC - ZO - 03 6. At the equatorial region a preoral band of large cilia, called pre-oral ciliary band or prototroch, develops around the body just in front of the mouth. 7. A similar band of cilia may occurs at the posterior end. This is post-oral band or metatroch. 8. Close to anus another ciliated band, called telotroch is present. 9. A spacious blastocoel, between the gut and ectodermal epithelium, is present. 10. A pair of protonephridia and larval mesodermal cells are found in the blastocoel. Characters of veliger larva : 1. It is modified trochophore larva. 2. Presence of ciliated organ, curved gut and larval nephridia. 3. The prototroch of trochophore expands to form a ciliated disc called velum. Fig. 8 : A glochidium.
NSOU CC - ZO - 03 275 In some gastropods velum is produced into ciliated lobes. 4. Presence of bilobed mantle and shell. 5. Foot is ventral between the mouth and anus. Characters of glochidium larva : 1. Microscopic form (ranges from 0.1 to 0.4 mm). 2. Body is enclosed in a triangular bivalved shell with its valves united dorsally and free ventrally. The free ends bear curved hook and spines. 3. The two valves are connected together by a single large adductor muscle. 4. Mantle lobes are two, bearing brush-like sensory hairs. 5. A long filamentous byssus (provisional byssus) arises from the byssus gland near the adductor muscles. 6. Glochidium leads an ectoparasitic life, attaches to fish skin and gill. 9.6 Questions a) What do you mean by hecto utylised arm? b) What is malacology? c) What is Choncology? d) What type of Symmetry is found in molluscan animal? e) What is the excretory organ in mollusca? f) How many larval stages are found in mollusca? g) What is the name of respiratory organ in mollusca?
276 NSOU CC - ZO - 03 Notes

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1/94	**SUBMITTED TEXT**	23 WORDS	**52%**	**MATCHING TEXT**	23 WORDS

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SA BZO - 21 - Ariel (1).doc (D113089369)

2/94	SUBMITTED TEXT	16 WORDS	71%	MATCHING TEXT	16 WORDS

The term taxonomy is derived from the Greek words taxis meaning arrangement, and nomos meaning law.

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3/94	SUBMITTED TEXT	33 WORDS	72%	MATCHING TEXT	33 WORDS

the scientific study of the kinds and diversity of organims and of any and all relationships among them." The other simple defintion by Mayr (1969) is "systematics is the science of diversity of organisms".

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4/94	SUBMITTED TEXT	11 WORDS	90%	MATCHING TEXT	11 WORDS

not only morphology and anatomy, but also genetics, behavioural aspects and

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5/94	SUBMITTED TEXT	18 WORDS	84%	MATCHING TEXT	18 WORDS

Classification can be defined as "the ordering of animals into groups or sets on the basis of their relationships" (

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6/94	SUBMITTED TEXT	29 WORDS	40%	MATCHING TEXT	29 WORDS

which the first two cover the status of recommendations and the third part of the Appendices is the constitution of the commission. The glossary contains the terms used in the codes

SA BZO 1.1 B.Sc BZO Block 2,3,and 4 11.04.22-87-326.pdf (D136039508)

7/94	SUBMITTED TEXT	31 WORDS	57%	MATCHING TEXT	31 WORDS

The scientific name of fig tree is Ficus carica or F. indica but the scientific name of the fig shell is Ficus ficus or Ficus gracilis. 2. The scientific names of a species

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8/94	SUBMITTED TEXT	14 WORDS	89%	MATCHING TEXT	14 WORDS

it is binomial), while the scientific name of Indian lion is Panthera leo persica (

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9/94	SUBMITTED TEXT	18 WORDS	96%	MATCHING TEXT	18 WORDS

is trinomial). 3. The first part of a scientific name is generic (L. Genus = race) and is

SA BZO 1.1 B.Sc BZO Block 2,3,and 4 11.04.22-87-326.pdf (D136039508)

10/94	SUBMITTED TEXT	26 WORDS	68%	MATCHING TEXT	26 WORDS

a Latin noun, A latinized Greek or a Latinized vernacular word. 4. The second part of a name is species (L. species = particular kind) name and

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11/94	SUBMITTED TEXT	13 WORDS	84%	MATCHING TEXT	13 WORDS

be a single word or group of words. The first alphabet or letter

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12/94	SUBMITTED TEXT	18 WORDS	61%	MATCHING TEXT	18 WORDS

used continuously in literature (atleast by 10 authors in 25 publications) becomes the accepted official name.
Remark: The disadvantage of

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13/94	SUBMITTED TEXT	12 WORDS	100%	MATCHING TEXT	12 WORDS

Each species is given a name, that serves as a unique

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14/94	SUBMITTED TEXT	13 WORDS	78%	MATCHING TEXT	13 WORDS

the field of molecular taxonomy and population genetics with improved analytical power and precision. [

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15/94	SUBMITTED TEXT	21 WORDS	54%	MATCHING TEXT	21 WORDS

explained the molecular basis of solation and gelation. They propsed that the forces generated by the folding and unfolding of protein molecules

SA MZON - 11.doc (D113527188)

16/94	SUBMITTED TEXT	22 WORDS	76%	MATCHING TEXT	22 WORDS

In otherwords, the sol state of protoplams is due to the folding of protein molecules and gel state is due to their unfolding.

SA MZON - 11.doc (D113527188)

17/94	SUBMITTED TEXT	37 WORDS	53%	MATCHING TEXT	37 WORDS

It has been shown that there is a definite correlation between the stages of nuclear division and external morphological changes (Fig. 18). During prophase the animal become round, studded with fine pseudopodia and in reflected light a well-defined hyaline area

SA MZO 1.1 Block 2-.docx.pdf (D129310881)

18/94	SUBMITTED TEXT	11 WORDS	100%	MATCHING TEXT	11 WORDS

plasma membrane which is continuous with the membrane surrounding the cilia.

SA protozoa.pdf (D108707900)

19/94	SUBMITTED TEXT	24 WORDS	72%	MATCHING TEXT	24 WORDS

the ciliature may also be diveded into body ciliature which occures over the general body surface and the oral ciliature, which is associated with the

SA protozoa.pdf (D108707900)

20/94	SUBMITTED TEXT	17 WORDS	91%	MATCHING TEXT	17 WORDS

membrane which runs transversely along the right wall and marks the junction of the vestibule and buccal cavity.

SA protozoa.pdf (D108707900)

21/94	SUBMITTED TEXT	13 WORDS	100%	MATCHING TEXT	13 WORDS

at the anterior end and the other at the posterior end of the body (

SA MZO - 11.doc (D113091521)

22/94	SUBMITTED TEXT	13 WORDS	100%	MATCHING TEXT	13 WORDS

Infection of fresh human host takes place by swallowing the infective cysts with

SA BZO - EDITED COPY.doc (D113089085)

23/94	SUBMITTED TEXT	37 WORDS	78%	MATCHING TEXT	37 WORDS

Houseflies generally carry the cysts from the faeces to the foods. Cockroaches have also been found to transport cysts. Food-handers are also responsible (sometimes) for the contamination of food through touch by dirty fingers carrying the cysts under the nails.

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24/94	SUBMITTED TEXT	15 WORDS	70%	MATCHING TEXT	15 WORDS

the small intestine of the host excystment occurs, as the cyst wall is digested by

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25/94	SUBMITTED TEXT	14 WORDS	90%	MATCHING TEXT	14 WORDS

vertical planes passing through the central axis (Fig. 54), like the spokes of a wheel. The

SA MZON - 11.doc (D113527188)

26/94	SUBMITTED TEXT	23 WORDS	97%	MATCHING TEXT	23 WORDS

The animals with radial symmetry do not have anterior and posterior sides or dorsal and ventral surfaces. They have a mouth bearing oral side

SA MZON - 11.doc (D113527188)

27/94	SUBMITTED TEXT	34 WORDS	70%	MATCHING TEXT	34 WORDS

many jelly fishes possessing four radial canals and the body can be divided into four equal parts (hence tetramerous). Pentamerous radial symmetry. Most echinoderms possess pentamerous radial symmetry where the body can be divided into five roughly equal parts.

SA MZON - 11.doc (D113527188)

28/94	SUBMITTED TEXT	20 WORDS	92%	MATCHING TEXT	20 WORDS

the sea anemones and true coral polyps belonging to the subclass Hexacorallia (class Anthozoa). The mesenteries and tentacles are arranged in

SA MZON - 11.doc (D113527188)

29/94	SUBMITTED TEXT	25 WORDS	67%	MATCHING TEXT	25 WORDS

A longitudinal plane that passes along the axis of the body to separate the animal in right and left halves, is called the mid sagittal plane.

SA MZON - 11.doc (D113527188)

30/94	SUBMITTED TEXT	13 WORDS	100%	MATCHING TEXT	13 WORDS

incurrent pores or ostia which extend from the external surface to the spongecoel.

SA BZO - EDITED COPY.doc (D113089085)

31/94	SUBMITTED TEXT	16 WORDS	70%	MATCHING TEXT	16 WORDS

is formed by out pushing of the body wall at regular intervals into finger-like projections, called

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32/94	SUBMITTED TEXT	15 WORDS	96%	MATCHING TEXT	15 WORDS

incurrent canals which open to the exterior between blind outer ends of the radial canals.

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33/94	SUBMITTED TEXT	15 WORDS	78%	MATCHING TEXT	15 WORDS

The wall between incurrent canal and radial canal is pierced by numerous minute pores, called prosopyles (

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34/94	SUBMITTED TEXT	27 WORDS	78%	MATCHING TEXT	27 WORDS

with a single osculum at the summit. The basal wall is termed hyposphere which is devoid of flagellated chambers. The upper wall with many small, oval flagellated chambers,

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35/94	SUBMITTED TEXT	15 WORDS	84%	MATCHING TEXT	15 WORDS

brings the food and oxygen and takes away the CO_2 , nitrogenous wastes and

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36/94	SUBMITTED TEXT	20 WORDS	67%	MATCHING TEXT	20 WORDS

carries the sperms from one sponge to another for fertilization of the ova. 3.5 Spicules in sponges The skeleton of sponges

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37/94	SUBMITTED TEXT	16 WORDS	87%	MATCHING TEXT	16 WORDS

both asexual and sexual modes. Asexual reproduction by budding and sexual reproduction by the formation of

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38/94	SUBMITTED TEXT	14 WORDS	96%	MATCHING TEXT	14 WORDS

metagenesis in which the asexual polypoid, sessile generation alternates with sexual medusoid, free swimming generation,

SA BZO 1.1 B.Sc BZO Block 2,3,and 4 11.04.22-87-326.pdf (D136039508)

39/94	SUBMITTED TEXT	13 WORDS	76%	MATCHING TEXT	13 WORDS

a tubular body with a mouth opening surruounded by tentacles at one end

SA BZO - EDITED COPY.doc (D113089085)

40/94	SUBMITTED TEXT	12 WORDS	78%	MATCHING TEXT	12 WORDS

varies from moderately elongated flattened shape to long flat ribbon-like and leaf-like.

SA BZO - EDITED COPY.doc (D113089085)

41/94	SUBMITTED TEXT	12 WORDS	100%	MATCHING TEXT	12 WORDS

The anterior end of the body is broader than the posterior end.

SA BZO - 21 - Ariel (1).doc (D113089369)

42/94	SUBMITTED TEXT	10 WORDS	100%	MATCHING TEXT	10 WORDS

contains a complete set of male and female reproductive organs.

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43/94	SUBMITTED TEXT	15 WORDS	83%	MATCHING TEXT	15 WORDS

together with all the membranes surrounding it is known as onchosphere. The onchosphere loses the

SA MZON - 11.doc (D113527188)

44/94	SUBMITTED TEXT	17 WORDS	91%	MATCHING TEXT	17 WORDS

Hooks merely anchor the hexacanth to the intestinal wall, while secretion of penetration glands dissolves the intestinal tissues.

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45/94	SUBMITTED TEXT	30 WORDS	51%	MATCHING TEXT	30 WORDS

juvenile possesses an alimentary canal, a nerve ring and a larval exeretory system. This juvenile resembles very much with Rhabditis (a soil nematode), hence it is also termed rhabditiform larva or

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46/94	SUBMITTED TEXT	10 WORDS	100%	MATCHING TEXT	10 WORDS

and becomes the second stage juvenile or second stage rhabditoid.

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47/94	SUBMITTED TEXT	15 WORDS	90%	MATCHING TEXT	15 WORDS

Males and females can be differentiated by size and shape of their tail tips. The

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48/94	SUBMITTED TEXT	18 WORDS	100%	MATCHING TEXT	18 WORDS

Adult males and females are most often coiled together and are difficult to separate. Females are ovoviviparous and

SA BZO 1.1 B.Sc BZO Block 2,3,and 4 11.04.22-87-326.pdf (D136039508)

49/94	SUBMITTED TEXT	12 WORDS	95%	MATCHING TEXT	12 WORDS

the larvae creep out of the labium to the human skin).

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50/94	SUBMITTED TEXT	18 WORDS	100%	MATCHING TEXT	18 WORDS

Adaptation may be defined as the fitness of an organism to live in its specific habitat or environment.

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51/94	SUBMITTED TEXT	14 WORDS	100%	MATCHING TEXT	14 WORDS

places in the host's body where sufficient food is available without effort. They need

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52/94	SUBMITTED TEXT	23 WORDS	79%	MATCHING TEXT	23 WORDS

of the host, the alimantary canal and digestive glands are partly or wholly lost. In the adult trematodes there is an incomplete gut, in

SA BZO - EDITED COPY.doc (D113089085)

53/94	SUBMITTED TEXT	10 WORDS	100%	MATCHING TEXT	10 WORDS

sense organs are absent but are generally provided with tangoreceptors (

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54/94	SUBMITTED TEXT	10 WORDS	100%	MATCHING TEXT	10 WORDS

organs on the lips (amphids) and on the tail (phasmids).

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55/94	SUBMITTED TEXT	20 WORDS	77%	MATCHING TEXT	20 WORDS

Absence of complicated sensory structures can also be correlated to sedentary life in a sheltered habitat, espcically endoparasites. 4. Circulatory system

SA BZO - EDITED COPY.doc (D113089085)

56/94	SUBMITTED TEXT	19 WORDS	92%	MATCHING TEXT	19 WORDS

system : Circulatory system is absent because circulatory system is primarily meant for transporation of nutrients that is not required

SA BZO - EDITED COPY.doc (D113089085)

57/94	SUBMITTED TEXT	26 WORDS	92%	MATCHING TEXT	26 WORDS

is semipermeable and allows the fluids to enter the body. It becomes thin, serving partly or wholly for food absorption in parasites living in rich nutritious environments,

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58/94	SUBMITTED TEXT	22 WORDS	100%	MATCHING TEXT	22 WORDS

the cuticle becomes thick, impregnated with impermeable chitin-like substances and enzyme resistant, so that it is not digestible by the host’s digestive juices

SA BZO - EDITED COPY.doc (D113089085)

59/94	SUBMITTED TEXT	18 WORDS	76%	MATCHING TEXT	18 WORDS

suitable mechanisms for attachment with their hosts. Helminths are variously modified for adhesion to the body of their hosts.

SA BZO - EDITED COPY.doc (D113089085)

60/94	SUBMITTED TEXT	12 WORDS	83%	MATCHING TEXT	12 WORDS

In tapeworms, the scolex bears either four sucking cups or large suckers (

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61/94	SUBMITTED TEXT	16 WORDS	82%	MATCHING TEXT	16 WORDS

In some cestodes and nametodes, hook or hook-like structures also develop in or near the cephalic

SA BZO - EDITED COPY.doc (D113089085)

62/94	SUBMITTED TEXT	11 WORDS	100%	MATCHING TEXT	11 WORDS

has a conical process at the anterior end called apical papillae.

SA BZO - EDITED COPY.doc (D113089085)

63/94	SUBMITTED TEXT	24 WORDS	65%	MATCHING TEXT	24 WORDS

a pair of penetration gland at the anterior end. These glands secrete histolytic enzymes that help in dissolving the host’s tissue to penetrate into it.

SA BZO - EDITED COPY.doc (D113089085)

64/94	SUBMITTED TEXT	35 WORDS	74%	MATCHING TEXT	35 WORDS

The intestinal parasites live in an environment completely devoid of free oxygen, NSOU CC - ZO - 03 199 the respiration is thus of anaerobic type, consisting of extracting energy from the food

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65/94	SUBMITTED TEXT	25 WORDS	89%	MATCHING TEXT	25 WORDS

Each parapodium basically consists of two lobes (biramous) a dorsal notopodium and a ventral neuropodium, and each lobe bears a bundle of bristles or setae supported internally by

SA MZON - 11.doc (D113527188)

66/94	SUBMITTED TEXT	10 WORDS	95%	MATCHING TEXT	10 WORDS

Associated with parapodium are dorsal and ventral sets of oblique muscles,

SA MZON - 11.doc (D113527188)

67/94	SUBMITTED TEXT	34 WORDS	83%	MATCHING TEXT	34 WORDS

During movement, two parapodia of a segement always remain in opposite phases of motion and thus cause a sort of paddling activity through water. The bristiles and acicula are protruded and withdrawn through the action of the

SA MZON - 11.doc (D113527188)

68/94	SUBMITTED TEXT	31 WORDS	85%	MATCHING TEXT	31 WORDS

polychaetes in accordance with the different functions they perform. Creeping and swimming forms have well developed parapodia; the burrowing forms and tube dwellers have feebly developed parapodia especially in the posterior part of their body.

SA MZON - 11.doc (D113527188)

69/94	SUBMITTED TEXT	23 WORDS	68%	MATCHING TEXT	23 WORDS

Setae : Setae are the main locomotor structures in oligochaetes, but they are also present in polychaetes. Setae are implanted directly in the

SA MZON - 11.doc (D113527188)

70/94	SUBMITTED TEXT	21 WORDS	100%	MATCHING TEXT	21 WORDS

muscles. Like parapodia, setae may also show variations in form reflecting their functional significance. Burrowing forms have short, simple and blunt setae,

SA MZON - 11.doc (D113527188)

71/94	SUBMITTED TEXT	19 WORDS	84%	MATCHING TEXT	19 WORDS

at the posterior end (posterior suckers) of the body. They are formed by the fusion of several body segments.

SA MZO - 11.doc (D113091521)

72/94	SUBMITTED TEXT	13 WORDS	76%	MATCHING TEXT	13 WORDS

the anterior part of the body is wider than the posterior end and

SA BZO - 21 - Ariel (1).doc (D113089369)

73/94	SUBMITTED TEXT	13 WORDS	88%	MATCHING TEXT	13 WORDS

is characteristic of nauplius and often referred to as the nauplius eye. The

SA MZON - 11.doc (D113527188)

74/94	SUBMITTED TEXT	12 WORDS	95%	MATCHING TEXT	12 WORDS

is the second larval stage which develops from the nauplius larva. 2.

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75/94	SUBMITTED TEXT	14 WORDS	89%	MATCHING TEXT	14 WORDS

segmented cephalothroax covered with a small carapace and a slender abdomen which is unsegmented. 2.

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76/94	SUBMITTED TEXT	11 WORDS	100%	MATCHING TEXT	11 WORDS

Three pairs of thoracic limbs make their appearance as buds. 7.

SA MZON - 11.doc (D113527188)

77/94	SUBMITTED TEXT	15 WORDS	100%	MATCHING TEXT	15 WORDS

the common larva of decapods and hence it has variations in its features in different

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78/94	SUBMITTED TEXT	13 WORDS	82%	MATCHING TEXT	13 WORDS

The cephalothorax is covered by a helmet-like carapace which bears two long spines,

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79/94	SUBMITTED TEXT	13 WORDS	100%	MATCHING TEXT	13 WORDS

or Schizopod Larva : In shrimps and some lobsters zoea transforms into mysis

SA MZON - 11.doc (D113527188)

80/94	SUBMITTED TEXT	24 WORDS	60%	MATCHING TEXT	24 WORDS

cephalothorax and six segmented abdomen including a telson. 2. Carapace is produced in front into a pointed rostrum. 3. Six pairs biramous thoracic appendages for locomotion. 4.

SA MZON - 11.doc (D113527188)

81/94	SUBMITTED TEXT	20 WORDS	82%	MATCHING TEXT	20 WORDS

The alima larva differs from zoea larva in the armature of the telson and a very large raptorial second maxillipedes. 10.

SA BZO - 21 - Ariel (1).doc (D113089369)

82/94	SUBMITTED TEXT	40 WORDS	27%	MATCHING TEXT	40 WORDS

the body can usually be divided into five parts arranged around a central axis. Another unique feature of the phylum is the presence of of bilateral symmetry in the larval phase. The radial symmetry in adult is regarded as a secondary acquisition (

SA MZON - 11.doc (D113527188)

83/94	SUBMITTED TEXT	14 WORDS	62%	MATCHING TEXT	14 WORDS

The echinoderms are exclusively marine, free living non-colonial and mostly bottm-dwellers. 2. They are triploblastic,

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84/94	SUBMITTED TEXT	15 WORDS	100%	MATCHING TEXT	15 WORDS

skeleton bears projecting spines or tubercles that give the body surface a warty or spiny

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85/94	SUBMITTED TEXT	12 WORDS	78%	MATCHING TEXT	12 WORDS

stone canal, ring canal, radial canal, Tiedeman's bodies, lateral canals and tube feet.

SA Lab Book.pdf (D151540213)

86/94	SUBMITTED TEXT	10 WORDS	100%	MATCHING TEXT	10 WORDS

phagocytic amoebocytes which are released into the water vascular system.

SA BZO - 21 - Ariel (1).doc (D113089369)

87/94	SUBMITTED TEXT	17 WORDS	97%	MATCHING TEXT	17 WORDS

The tube feet are short, tubular external projections of the body wall located in the ambulacral groove.

SA MZON - 11.doc (D113527188)

88/94	SUBMITTED TEXT	15 WORDS	78%	MATCHING TEXT	15 WORDS

The biggest of all invertebrates (giant squid) and probably the most intelligent invertebrate (Octopus) are the

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89/94	SUBMITTED TEXT	12 WORDS	83%	MATCHING TEXT	12 WORDS

by one or many ctenidia or gills enclosed in the mantle cavity.

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90/94	SUBMITTED TEXT	10 WORDS	100%	MATCHING TEXT	10 WORDS

communicating the coelom with mantle cavity by nephridiopore. 13. Nervous system

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91/94	SUBMITTED TEXT	15 WORDS	88%	MATCHING TEXT	15 WORDS

to 8 pairs, persent in the pallial groove on the lateral sides of foot. 6.

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92/94	SUBMITTED TEXT	17 WORDS	73%	MATCHING TEXT	17 WORDS

are regarded as primitve molluscs and are believed to be ancestral to the gastropods (snails) and cephalopods (

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93/94	SUBMITTED TEXT	24 WORDS	82%	MATCHING TEXT	24 WORDS

pairs of ganglia cerebral, pleural, pedal and visceral. Cerebral and pleural of each side usually fused into a cerebropleural ganglian. 8. Sense organs are statocyst and

SA BZO - 21 - Ariel (1).doc (D113089369)

94/94	SUBMITTED TEXT	23 WORDS	54%	MATCHING TEXT	23 WORDS
trochophore larva. B. Internal organization of a trochophore larva. C. An advanced trochophore larva showing the additional ciliated segments at the posterior end.					

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PREFACE In a bid to standardise higher education in the country, the University Grants Commission (UGC) has introduced Choice Based Credit System (CBCS) based on five types of courses: core, generic discipline specific elective, and ability/ skill enhancement for graduate students of all programmes at Elective/ Honours level. This brings in the semester pattern, which finds efficacy in tandem with credit system, credit transfer, comprehensive and continuous assessments and a graded pattern of evaluation. The objective is to offer learners ample flexibility to choose from a wide gamut of courses, as also to provide them lateral mobility between various educational institutions in the country where they can carry acquired credits. I am happy to note that the University has been recently accredited by National Assessment and Accreditation Council of India (NAAC) with grade "A". UGC (Open and Distance Learning programmes and Online Programmes) Regulations, 2020 have mandated compliance with CBCS for all the HEIs in this mode. Welcoming this paradigm shift in higher education, Netaji Subhas Open University (NSOU) has resolved to adopt CBCS from the academic session 2021-22 at the Under Graduate Degree Programme level. The present syllabus, framed in the spirit of syllabi recommended by UGC, lays due stress on all aspects envisaged in the curricular framework of the apex body on higher education. It will be imparted to learners over the six semesters of the Programme. Self Learning Materials (SLMs) are the mainstay of Student Support Services (SSS) of an Open University. From a logistic point of view, NSOU has embarked upon CBCS presently with SLMs in English. Eventually, these will be translated into Bengali too, for the benefit of learners. As always, we have requisitioned the services of the best academics in each domain for the preparation of new SLMs, and I am sure they will be of commendable academic support. We look forward to proactive feedback from all stake-holders who will participate in the teaching-learning of these study materials. It has been a very challenging task well executed, and 1 congratulate all concerned in the preparation of these SLMs. I wish the venture a grand success. Professor (Dr.) Subha Sankar Sarkar Vice-Chancellor

Printed in accordance with the regulations of the Distance Education Bureau of the University Grants Commission. First Print : August, 2021 Netaji Subhas Open University Under Graduate Degree Programme Choice Based Credit System (CBCS) Subject: Honours in Zoology (HZO) Course: Diversity of Chordates Course Code: CC-ZO-04

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Unit 1 Protochordata Structure 1.1 Objectives 1.2 Introduction 1.3 General characteristics of hemichordata, urochordata and cephalochordata 1.3.1 Hemichordata 1.3.2 Urochordata 1.3.3 Cephalochordata 1.4 Study of larval forms in protochordates 1.4.1 Introduction 1.4.2 Tornaria larva 1.4.3 Tadpole larva 1.5 Retrogressive metamorphosis in urochordata 1.6 Summary 1.7 Questions 1.8 Suggested readings 1.1 Objectives After studying this unit, learners would be able to understand the following— the characteristics of chordates. the general characteristics of hemichordata, urochordata and cephalochordate. the larval forms in protochordates. an idea about tornaria and tadpole larva. the retrogressive metamorphosis in ascidia. 1.2 Introduction The phylum chordata comprised of a varied group of diverse animals ranging from 7

NSOU CC-ZO-04 8 ascidian to man. The most important features of phylum chordate are presence of: (i) notochord; (ii) dorsal tubular nerve cord; (iii) pharyngeal gill slits and post and tail. The hemichordate, urochordata and cephalochordate were considered as the invertebrate members of the phylum chordata, thus, separated as "invertebrate chordates" (Hyman, 1959). The protochordates are a connecting link between the vertebrates and other deuterostomes (animals where the anus develops from the blastopore and the mouth is formed a new). However, the phylogenetic status of hemichordate is a subject of great controversy. According to recent classification urochordata, cephalochordata and vertebrata belong to a cephalochordates and vertebrates are more closely related with other. But the chordate nature of urochordates and cephalochordates is well established though their relationships with the vertebrates and with each other are difficult to ascertain. 1.3 General characteristics of hemichordata, urochordata and cephalochordata 1.3.1 Hemichordata The phylum hemichordata represents a group of lowest invertebrate chordate having profound phylogenetic significance. This group forms a sort of structural bridge between the nonchordates and chordates. Hemichordata was previously known as enteropneusta due to the presence of gill slits in Balanoglossus clavigerus (Gegenbaur, 1870). Bateson (1885) suggested the name hemichordata in place of enteropneusta. Example: Balanoglossus General Characteristics: (i) They are solitary or colonial, soft and fragile animals. (ii) Body divisible into three regions: proboscis (protosome); collar (mesosome); trunk (metasome). (iii) The representatives are vermiform, unsegmented, bilaterally symmetrical and triploblastic. (iv) Appendages are absent; in few forms the collar may bear arms with tentacles. (v) Buccal diverticula is present.

NSOU CC-ZO-04 9 (vi) Alimentary canal is complete. This is either a "straight" or 'U'- shaped tube. (vii) Mostly marine in habitat and feed on micro-organisms and debris by ciliary mode of mechanisms. (viii) One to several pairs of gill-slits present. (ix) Circulatory system is open type with a central sinus heart vesicle, dorsal and ventral vessels, sinuses and lateral vessels. (x) Excretion is performed by glomerulus, present in proboscis and connected with blood vessels. (xi) Nervous system is primitive, comprising mainly of an intra epidermal nerve plexus. (xii) Mode of reproduction is sexual but a few forms exhibit asexual reproduction. (xiii) Development is direct (without larval stage) or indirect (with a tornaria larva). 1.3.2 Urochordata The members of the phylum urochordata exhibit a high degree of diversity in form, habit and habitat. The urochordates are also known as tunicates (L. tunica; an undergarment) or Ascidian (Gr. Askos; a leather bag). Example: Ascidia General characteristics: (i) Exclusively marine, solitary or colonial, fixed or pelagic. (ii) Body varies considerably in size, form and colour. (iii) Unsegmented body is covered by a test or tunic. (iv) They have two pores related to the atrial and branchial siphons. (v) Coelom is absent; the atrial cavity receives gonoducts, anus and gill-slits. (vi) In larva, notochord is present but absent in adult. Fig-1 : External Structures of Balanoglossus

NSOU CC-ZO-04 10 (vii) Alimentary canal is complete, presence of spacious pharynx. (viii) Respiration by gill slits and test. (ix) Circulatory system closed type. Heart is tube like and central in position. (x) Excretion is performed by nephrocytes, neural gland and pyloric glands. (xi) In adult the nervous system is represented by single dorsal ganglion. (xii) Usually bisexual. Fertilization is external. Asexual reproduction by budding. (xiii) Development indirect, through tadpole larva. Metamorphosis is retrogressive. Fig-2 : Anatomical organisation of adult Ascidia 1.3.3 Cephalochordata The cephalochordate is an important group of animals for phylogenetic analysis and

NSOU CC-ZO-04 11 comparative anatomy of the chordates in general. Despite their great variety all these types show certain common features, often referred to as the typical chordate characters. It is better to regard these not as a list of isolated "characters" but as the signs of a certain pattern of organization that is characteristics of the group. Example: Branchiostoma (Amphioxus) General characteristics: (i) Marine animal, commonly found in the sandy shores of the sea. (ii) Sedentary animal, although it can swim actively in water. (iii) Small lancet-shaped body is divisible into the body proper and definite post-anal tail. (iv) The oral hood bears more than twenty stiff buccal or oral cirri or tentacles. (v) The mouth is kept hidden within the oral hoods. (vi) Presence of wheel organ. (vii) The anus is situated of the left side of the ventral fin. (viii) The atrium opens to the exterior through a round atriopore locatedclosed to the anterior end of the ventral fin. (ix) On the lateral sides of the body there are numerous gill-slits which remain partly covered by the lateral folds of the body. (x) The body is provided with a dorsal fin, which joined to a somewhat caudal fin present round the tail. (xi) A ventral fin runs along the mid ventral line lying between caudal fin and atriopore. Fig.3 : A diagrammatic view of Branchiostoma (Amphioxus)

NSOU CC-ZO-04 12 1.4 Study of larval forms in protochordates 1.4.1 Introduction Protochordates are an informal category of animals (i.e., not a proper taxonomic group), named mainly for convenience to describe invertebrate animals that are closely related to vertebrates. This group is composed of the Phylum Hemichordata and the Subphyla Urochordata and Cephalochordata. Tornaria larva is the larva of Hemichordata (Balanoglossus) and tadpole larva is the larval form of Urochordata (Ascidia). 1.4.2 Tornaria larva Balanoglossus reproduces normally by sexual process. A sexual reproduction occurs very rarely. The development is indirect, i.e., the development is followed by the metamorphosis of a well developed larval form, the tornaria larva. This larva was first discovered by Johannes Muller (1850), who gave the name tornaria due to its habit of rotating in circle. General characteristics of tornaria larva are: (i) Oval in shape and bilaterally symmetrical body. (ii) Size varies from 1 to 3 mm. (iii) The mouth is present on the ventral side near the equatorial plane of the body. (iv) Anterior to the mouth there is a prolonged preoral lobe. (v) There are three distinct ciliated bands on the body. (vi) The preoral and postoral ciliated bands unite for a short distance at the apical plate. (vii) One ciliate ring is present around the anus, which is called circumanal ciliated band or telotroch. (viii) The cilia in the band are long, powerful and act as the chief locomotor organ. (ix) The anus is located medially on the posterior end of the body. (x) The digestive tract is distinguishable into oesophagus, stomach and intestine. (xi) Possess one pair of gill slits. (xii) It undergoes morphological changes to become an adult.
NSOU CC-ZO-04 13 Fig.-4 : (A) A full drown Tornaria larva; (B-C) Stages of subsequent metamorphosis of tornaria larva 1.4.3 Tadpole larva The larval form present in the life history of Ascidia is called tadpole larva. The general characteristics of tadpole larva is as follows— (i) Highly motile and does not take food from the outside. (ii) The body is more or less oval in outline. (iii) Body divisible into head and tail region. e
NSOU CC-ZO-04 14 (iv) The whole body is covered by tunic. (v) The head is elliptical and has three adhesive papillae or chain warts. (vi) The tail is laterally compressed and pointed terminally. (vii) The tail is provided with caudal fin. (viii) The dorsal and ventral fins are continuous along the tail and are marked with striae. (ix) The central nervous system is situated dorsal to the notochord. (x) A single median eye is present. (xi) An otocyst, the organ of balance is situated in the ventral side. (xii) The notochord is restricted only in the tail region. (xiii) Segmental muscle bands are present in the tail region. (xiv) The mouth is present and the alimentary canal is rudimentary. (xv) Well developed pharynx is sac like. (xvi) A fully developed endostyle and two pairs of gill slits are present. (xvii) Non functional heart with epicardia lies beneath the endostyle. (xviii) The paired atrial sacs are present. (xix) Just after hatching the tadpole larva becomes positively phototactic and negatively geotactic. Fig.5 : Ascidia sp.—A free swimming tadpole larva
NSOU CC-ZO-04 15 1.5 Retrogressive metamorphosis in urochordata The subphylum urochordata constitutes an unique group of animals under the phylum Chordata. In urochorates, the notochord is confined to the tail region in the adult stage, thus named as urochordata. This subphylum is sub-divided into three classes: (i) Ascidiacea; (ii) Thaliacea; and (iii) Larvacea or Appendicularia. The unique example of this group is Ascidia. Ascidia is a hermaphroditic animal, known for its indirect development; i.e., the development is accompanied by metamorphosis. Metamorphosis in most animals, is a progressive process. But, in Ascidia the developmental events are largely retrogressive. In Ascidia, a highly developed tadpole larva, in course of ontogenic development transforms into a sessile and degenerated adult. The metamorphosis in Ascidia shows a peculiar scheme of retrogression of a complex and well organized larval form to a simpler degenerated adult amply speak for the retrogressive metamorphosis in Ascidia. In Ascidian metamorphosis, two sets of changes occur: (i) the disappearance of notochord, nerve chord and muscle bands; (ii) formation of stigmata, specialization of pharynx, over development of atrium etc. The essence of retrogressive metamorphosis in Ascidia is therefore; (i) the differential growth and disappearance of histologically differentiated larval tissues; and (ii) the formation of the adult structures from the residual larval tissue. A. Pre-larval stages: (i) The egg are small and almost yolkless. (ii) The segmentation is holoblastic and nearly equal at the initiation. (iii) Gastrulation occurred by invagination. (iv) The gastrula after about three days transformed into free swimming tadpole larva. (v) The tadpole larva has all the characteristics of chordate organization. B. Larval stages: (i) The tadpole larva is very active and do not take food from outside. (ii) The body is more or less oval in outline. (iii) Body divisible into two regions; i.e., head and tail. (iv) The whole body is covered by tunic.

NSOU CC-ZO-04 16 (v) The tail is laterally compressed and pointed terminally and provided with caudal fin. (vi) The dorsal and ventral fins are continuous along the tail and marked with striae. (vii) The central nervous system is situated dorsal to the notochord. (viii) The notochord is restricted in the tail region. (ix) A single median eye is present. (x) An otocyst, the organ of balance is situated in the ventral side. (xi) The mouth and the alimentary canal is rudimentary. (xii) The pharynx is sac like and is well developed. (xiii) A fully developed endostyle and two pairs of gill slits present. (xiv) Non functional heart with epicardia lies beneath the endostyle. C. Metamorphosis and emergence of the adult: The free swimming tadpole larva after a short period of free existence fixes itself to sea weeds or stones by adhesive papillae and immediately falls a victim of first degeneration and undergoes progressive and retrogressive changes during its development. I. Progressive changes: (i) The branchial chamber becomes enlarged and the number of stigmata are enhanced; (ii) The post pharyngeal portion of the gut gets divided into different parts; (iii) The atrium becomes more extensive; (iv) The development of velum is observed; (v) The gonads and gonoducts appear from the mesoderm. II. Retrogressive changes: (i) The length of the tail becomes greatly diminished. (ii) The nerve chord becomes restricted to the trunk region and is ultimately reduced to a solid nerve ganglion; (iii) The notochord becomes coiled, disorganized and finally disappeared; (iv) The trunk becomes broadened; (v) The number of the striae are diminished and become restricted to certain regions;

NSOU CC-ZO-04 17 (vi) The muscle band also become degenerated; (vii) The tail is further shortened; (viii) Shifting of the mouth is caused by the rapid growth of the region between the adhesive papillae; (ix) The tail becomes more shortened and partially withdrawn into the test. Fig. 6 : Metamorphosis of Ascidia sp. - free tailed larva into a fixed ascidian A : Progressive changes; B : Retrogrossive changes C : Adult Ascidia

NSOU CC-ZO-04 18 1.6 Summary Urchordata, Cephalochordata and Vertebrata belong to a cephalochordates and vertebrates are more closely related with other. Tornaria larva is the larva of Hemichordata and tadpole larva is the larval form of Urochordata. Retrogressive metamorphosis is an unique feature of Ascidia. Metamorphosis of tadpole larva occur through both the progressive and retrogressive changes. 1.7 Questions (i) Write the unique characteristics of chordotes. (ii) Write the general characteristics of hemiehordata, urochordata and cephalochordate. (iii) Draw the structure of tornaria larva and discuss its importance. (iv) What is meant by retrogressive metamorphosis? (v) Write a brief note on retrogressive metamorphosis in ascidia with suitable diagram. 1.8 Suggested readings 1) The life of vertebrates by J. Z. Young; Year: 1981. Published in India by Oxford University Press, New Delhi. 2) Study material Post Graduate Zoology (Paper: 1). Structure and function of chordates and non-chordates, Year: 2010. Pub: Registrar, Netaji Subhas Open University. 3) Learning protochordata through latest portfolio of theory and practice. Edited by P.K. Verma and Nandita Pande (Editor-in-Chief: Brian Jenkins); Year: 2002; Pub: Dominant Publisher and Distributors, New Delhi-110002 4) Biology of Animals (Volume-II) by Arup Kumar Sinha, Simananda Adhikari and Banku Behari Ganguly; Year 1991; Pub: New Central Book Agency 5) Elyman, L (1959). The invertebrates: smaller coelomate groups. McGraw Hill, New York.
NSOU CC-ZO-04 19 Unit 2 Origin of chordata Structure 2.1 Objectives 2.2 Introduction 2.3 Echinoderm theory of origin of chordates 2.4 Views of different scientists on the origin of chordates 2.5 Summary 2.6 Questions 2.7 Suggested readings 2.1 Objectives After studying this unit, learners would be able to understand the following— the salient features of chordates. different theories relating with the origin of chordates. different views about the origin of chordates. the Gastang's theory of origin of chordates. 2.2 Introduction The phylum chordata is known to have the unique features such as for the presence of notochord, dorso-tubular nerve cord and pharyngeal gill slits. It was and is still a genuine paradox to the systematic position as to what evolutionary changes in the general organization of animal body led to the emergence of chordates. Since later part of the nineteenth century various conflicting views have been proposed to explain the origin of chordates. The views tracing the origin of chordates from a number of invertebrate phyla have been discarded, yet among the major invertebrate phyla the annelid and arachnid theories claiming possible source of its ancestry. The echinoderm theory having an utmost relevance with and holding key to chordate ancestry. 19

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NSOU CC-ZO-04 20 2.3 Echinoderm theory of origin of chordates Among the major phyla of non-chordates, the echinoderms are the most striking evidence of chordate ancestry. Larval forms usually represent past ancestral forms. Larval evidence strongly suggests that the protochordates evolved as small, bilaterally symmetrieal animals possessing many of the features of larval echinoderms, or the hemichordates but lacking specializations of either the fully formed chordates (or vertebrates) or the echinoderms. With the assumption of redial symmetry and sessile mode, these form give rise to echinoderms, but some of them retained the original bilateral symmetry and by developing gill slits, better musculature and notochord give rise to the chordates. Evidence based biochemical analysis provides strong relationship between the echinoderms and the chordates. The similarity of blood serum, muscle chemistry and the presence of phosphocreatinine and phosphoarginin as suppliers of energy to muscles in both echinoderms and chordates claimed much more closer relationship between the two groups. These two components are not present together in other invertebrate phyla. 2.4 Views of different scientists on the origin of chordates Based on the research supports, the view of the Echinoderm theory of origin of chordates is more pertinant. The following are the views of the scientists. 1) The theory given by Johannes Muller (1860) is

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based on the comparative studies of larval stages of echinoderms and hemichordates.

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Tornaria larva of hemichordates resembles echinoderm larvae of bipinnaria, auricularia, dipleurula and doliolaria, which all possess ciliary bands and apical tuft of cilia

may insight a clue about the origin of chordate. 2) Garstang's neotenous larva theory (1894) proposed that the ancestry of chordates and of the vertebrates is to be traced during the larval stages of the invertebrates rather than in their adults. He advocated that "if the ciliated bands of the auricularia larva of the sea-cucumber were to become accentuated and rise up as ridges leaving a groove between them, and if these ridges were to fuse, converting a groove into a tube, a structure would be produced which has all the relations of a nervous system". Garstang's
NSOU CC-ZO-04 21 theory further asserts that if the larval forms of such animals persisted and become sexually mature, they would provide exactly the necessary material for the evolution of the chordates. 3) Some authors advocated that the similarity between the larval forms was the result due to similar ecological factors. H. B. Fell (1965) concludes that the similarity of the free swimming larvae of some echinoderms and Balanoglossus provides no concrete evidence of common ancestry. Gregory (1951) states that Balanoglossus may not be a chordate at all and that its bag like ciliated swimming larva is merely a parallel adaptation for securing suitable location for their sessile adults. 4) N. J. Berrill (1955) suggests the following larval sequence for the ancestry of chordates: Echinoderm → auricularia → hemichordate-tornaria→ protochordate- ascidian tadpole → permanently free swimming chordate. This view agrees with Gastang's theory but not in the manner in which Gastang assumes the changes to have taken place. However, Berrill's view places the ascidians is the main line of the origin of chordates, at least as larva. 5) Hyman (1959) and others also believe that the pterobranchs (Hemichordate) may be similar to the common ancestor of both the echinoderms and the hemichordates. 6) Jefferies (1975) opined that the origin of chordates is to be found among the carpoid fossils (subphylum-Homalozoa; phylum- Echinodermata) which have an echinoderm like skeleton of calcite known as "calcichordate theory". In his theory, Jefferies argued that two of the carpoid orders, the "Cornutai" and "Mitrata" should be placed in a separate subphylum "calcichordata" which had echinoderm affinities are actually more closely related to the early chordates. Jefferies states that a cephalodiscus like hemichordate gave rise to two lines of evolution, one by losing the gill slits and elaborating the tentacles towards the echinoderms and the other by losing the tentacles and elaborating the left gill slits toward the early chordates whose earliest representatives was the carpoid comuta. 7) Barrington (1979) states the "The view that larval biology contains the key to chordate ancestry is highly speculative, although it dose not lack biological plausibility. It is not the only way of looking at the problem".

NSOU CC-ZO-04 22 8) Young (1981) states that the Bateson (1886)-Gastang (1894) theory of the origin of chordates is correct. The chordates are related to the sessile lophophore feeders which in course of time acquired the pharyngeal gill slits and their larva to have muscles, a notochord and a nerve tube. Then by paedomorphosis the sessile stage disappeared and the chordates began the course of evolution. 9) Pouch, Heiser and McFarland (1990) commented about the phylogenetic affinities of chordates and invertebrates remain uncertain. Although the weight of evidence favours deuterostomes as the group from which chordates arose, no living adult or larval deuterostomes can yet be identified as their closest living relatives. Although genomic approaches to chordate phylogenies suggested to the traditional euchordata view : vertebrates and cephalochordates as sister groups to the exchision of basal tunicates and placed vertebrates and tunicates as sister groups. This theory has received support from alfactores hypothesis (Dunn et al, 2008) In the foregoing views of different scientists it may say that Bateson (1886)-Gastang (1894) theory of the origin of chordates is correct (Young, 1981). Romer (1965, 1970) pointed out that the chordates have arisen from some sort of echinoderm like ancestors. His ancestral prototype is a sessile filter-feeder which acquired pharangeal gill-slits and their larval forms possessed muscles, notochord and nerve tube. Then by paedomorphosis the sessile stage disappeared and the free chordates started their evolution. However, in-spite of this generally agreed proposition, an element of uncertainty still remains due to lack of adequate concrete evidences. Further more, Garstang's dipleurula theory were more accepted. 2.5 Summary Phylum chordata is known to have the unique features like notochord, dorso- tubular nerve cord and pharyngeal gill slits. Evidence based biochemical analysis provides strong relationship between the echinoderm and the chordate. Romer (1965, 1970) pointed out that the chordates have arisen from some sort of echinoderm like ancestors.

NSOU CC-ZO-04 23 2.6 Questions i) What do you mean by chordate? ii) Write about the echinoderm theory of origin of chordates. iii) Discuss in brief about the views of different scientists for the origin of chordates. 2.7 Suggested readings 1) The life of vertebrates by J. Z. Young; Year: 1981. Published in India by Oxford University Press, New Delhi 2) Study material Post Graduate Zoology (Paper: 1). Structure and function of chordates and non-chordates, Year: 2010. Pub: Registrar, Netaji Subhas Open University 3) Learning protochordata through latest portfolio of theory and practice. Edited by P.K. Verma and Nandita Pande (Editor-in-Chief: Brian Jenkins); Year: 2002; Pub: Dominant Publisher and Distributors, New Delhi-110002 4) Biology of Animals (Volume-II) by Arup Kumar Sinha, Simananda Adhikari and Banku Behari Ganguly; Year 1991; Pub: New Central Book Agency 5) Text Book of Zoology Vertebrates (volume-2) 7th Edition by T. Jeffery Parkar and Williama Haswell (Edited by Marshall & Williams) Year: 1995. Pub: AITBS Publishers & Distributors, New Delhi-110051

NSOU CC-ZO-04 24 Unit 3 Agnatha Structure 3.1 Objectives 3.2 Introduction 3.3 General characteristics of cyclostomata 3.4 Classification of cyclostomata 3.5 Development of lamprey 3.5.1 Salient features of ammocoetes larva 3.6 Summary 3.7 Questions 3.8 Suggested readings 3.1 Objectives After studying this unit, learners would be able to understand the following— the salient features of agnathans. the general characteristics of cyclostomata. the classification of cyclostomata. the salient features of ammocoetes larva. 3.2 Introduction The class cyclostomata (cyclos = round and stoma = mouth) are the modified and degenerate off shoot of the primitive vertebrate stalk. Cyclostomata is a group of agnathans that comprises the living jawless fishes-the lampreys and hagfishes. They are parasitic, usually feeding on fish in their adult stage. Morphologically, they resemble with the eels. They are known to be the only living vertebrates without true jaws, hence called Agnatha. 24

NSOU CC-ZO-04 25 3.3 General characteristics of cyclostomata 1) The mouth is round and suctorial. 2) The paired fins are absent. 3) Median fins with cartilaginous fin rays. 4) No paired appendages. 5) The skin is soft and smooth and devoid of scales. 6) The exoskeleton is absent. The endoskeleton is cartilaginous without bones. 7) The notochord is persistant throughout life. 8) The digestive system is devoid of any stomach. 9) The nostril is single and median. 10) Pharayngeal gill slits with about 5-15 pairs of gills are present. 1l) The heart is two-chambered. 12) The cerebellum is small. 13) Spleen is absent. 14) The lateral line acts as a sense organ. 15) The ninth and tenth cranial nerves are not present. 16) The sexes are separate. Some hagfish species are believed to be hermaphrodite. 17) Excretory system consists of a pair of mesonephric kidney. 18) Development may be direct or indirect through ammocoetes lerva. 3.4 Classification of cyclostomata The subphylum Agnatha is divided into two classes—Cyclostomata and Ostracodermis. The class Cyclostomata is further sub-divided into two orders: 1) Petromyzontia is exlempified by Lampreys; and 2) Myxinoida is represented by Hagfish. Order-l: Petromyzontia (Lamprey)

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NSOU CC-ZO-04 26 Characteristics: 1) Both the larval form and adult are marine and freshwater in habitat. 2) They have a ventral mouth with many horny teeth. 3) The mouth is present in the buccal funnel. 4) The buccal funnel is suctorial and shows horny teeth. 5) The nostril is present dorsally and no connection with the pharynx. 6) Eyes are functional. 7)

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Seven pairs of gill slits are present. 8) Well developed dorsal fin is present. 9) Branchial basket is complete. 10) Brain is well developed. 11)

Pineal eye is well developed. 12) Ear has two semicircular canals. 13) The development is indirect. Example: Petromyzon (Sea-lamprey); Lampetra fluviatilis Fig 3.1: External structures of Petromyzon Order - 2: Myxinoidea Characteristics: 1) They are found exclusively in the marine environment. 2) They have a terminal mouth with few teeth. 3) Buccal funnel is absent.
NSOU CC-ZO-04 27 4) They possess 6-14 pairs of gill slits. 5)

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The nasal sac opens into pharynx through a canal. 6) Eyes are

vestigial and few in number. 7) Dorsal fin is either absent or very small and weak. 8) Branchial basket is poorly developed. Fig 3.2: Structure of the hagfish. (A) Dorsal view of an entire Myxine; (B) Ventral view of anterior end of Myxine. s
NSOU CC-ZO-04 28 9) Brain is of primitive type. 10)

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Pineal eye is reduced. 11) Ear has only one semicircular canal. 12)

The hag-fishes are all marine in habitat. 13) Eggs are large and few in number. Example: Myxine glutinosa (Hag-fish or slime eel); Eptatretus (Bellostoma) 3.5

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Development of lamprey The eggs of lamprey are telolecithal, having a large amount of yolk. Cleavage is holoblastie but unequal resulting in the formation of

blastula. Blastula consists of micro and macromeres. Invagination in blastula gives rise to gastrula.

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Gastrulation occurs by invagination and the blastopore takes up a postero-dorsal position and becomes converted into arms. The development of the central nervous system is peculiar in lampreys. It develops as a solid cord or keel which hollows to form the lumen of the nerve cord. This process is called as thickened keel method. After about twenty-one days a young larval form hatches out as the ammocoetes larva. 3.5.1 Salient features of ammocoetes larva 1) Ammocoetes is a freshwater larva of Petromyzon. 2) Transparent and eel like body. 3) It lives inside U-shaped burrow. At times it comes out of burrow. 4) Colour is muddy brown. 5) Body is divisible into head, trunk and a tail. 6) Suctorial buccal funnel absent. 7) Oral hood surrounds the mouth in the place of the buccal funnel. 8) Trunk has a single dorsal fin. 9) Tail has a caudal fin which is in continuation of the dorsal fin. 10) Teeth are absent but several branched buccal tentacles surrounded the mouth. 11) The alimentary canal includes a mouth, buccal cavity, pharynx, intestine and anus. 12) A velum is present between the buccal cavity and the pharynx.

NSOU CC-ZO-04 29 13) The pharynx has an endostyle, a pair of peripharyngeal bands and a hypopharyngeal groove. 14) Eyes are vestigial and concealed below the skin. 15) Pineal eye is well developed. 16) Trunk has seven pairs of gill-slits just behind the head. 17) Liver, bile duct and gall bladder are present. 18) Protonephric kidney present. 19) It exhibits filter feeding. Fig 3 : Anatomical organisation of Ammocoetes larva of Petromyzon; A.Ventral view B. Lateral view

NSOU CC-ZO-04 30 20) Respiratory current goes into the pharynx through mouth and comes out through gill-slits. 21) Heart with pericardium is present. 3.6 Summary Cyclostomata is a group of agnathans that comprises the living jawless fishes— the lampreys and hagfish. The class cyclostomata is sub-divided into two order—1) Petromyzontia and 2) Myxinoidea Ammocoetes is a freshwater larva of Petromyzon. 3.7 Questions i) Who are called as agnatha? ii) Write the general characteristics of cyclostomata. iii) Write the classification of cyclostomata up to order with its distinctive characteristics and example. iv) Write the salient features of ammocoetes larva 3.8 Suggested readings 1) The life of vertebrates by J. Z. Young; Year: 1981. Published in India by Oxford University Press, New Delhi 2) Learning protochordata through latest portfolio of theory and practice. Edited by P.K. Verma and Nandita Pande (Editor-in-Chief: Brian Jenkins); Year: 2002; Pub: Dominant Publisher and Distributors, New Delhi-110002 3) Biology of Animals (Volume-II) by Arup Kumar Sinha, Simananda Adhikari and Banku Behari Ganguly; Yearl991; Pub: New Central Book Agency 4) Text Book of Zoology Vertebrates (volume-2) 7th Edition by T. Jeffery Parkar and Williama Haswell (Edited by Marshall & Williams) Year: 1995. Pub: AITBS Publishers & Distributors, New Delhi-110051

NSOU CC-ZO-04 31 Unit 4 Pisces Structure 4.1 Objectives 4.2 Introduction 4.3 General characteristics of chondrichthyes 4.4 General characteristics of osteichthyes 4.5 Classification of pisces up to order 4.6 Fish migration 4.6.1 Definition 4.6.2 Types of migratory movements 4.6.3 Pattern of fish migration 4.6.4 Factors affecting fish migration 4.6.5 Different stimuli and fish migration 4.7 Fish osmoregulation 4.7.1 Introduction 4.7.2 Types of osmoregulation 4.7.3 Osmoregulation in freshwater fishes 4.7.4 Osmoregulation in marine water fishes 4.8 Parental care in fishes 4.8.1 Introduction 4.8.2 Prelude of parental care 4.8.3 Biological modification with regard to parental care 4.8.4 Structural modification with regard to parental care 4.8.5 Internal incubation 4.8.6 Viviparity 4.9 Summary 4.10 Questions 4.11 Selected readings 31

NSOU CC-ZO-04 32 4.1 Objectives After studying this unit, learners would be able to understand the following— the characteristics of pisces. the general characteristics of Chondrichthyes. the general characteristics of Osteichthyes. the classification of pisces up to order. fish migration. fish osmoregulation. the parental care of fishes. 4.2 Introduction Fishes are aquatic cold blooded vertebrates which exploit the aquatic habitat and become a "sentinel organism" of the water bodies. Fishes constitute the first group of animals that have developed the biting jaws in the phylogenetic history of vertebrates. Fishes are known for its unique characteristics, like- (i) fins with dermal fin rays; (ii) presence of dermal scale; and (iii) presence of lateral line sense organ. The biology of fishes is so diverse that it is extremely difficult to give a concise account of the group. Living fishes with jaws mostly fall into two well marked classes- (i) the cartilaginous fish (Condrichthyes); and ii) bony fishes (Osteichthyes). These groups arose in the late devonion period. 4.3 General characteristics of chondrichthyes 1) Exclusively marine fishes. 2) Streamlined body provided with cartilaginous endoskeleton. 3) Mouth is located on ventral side. 4) Gill slits are separate and without gill cover (operculum). 5) Pelvic fins bear claspers in males. 6) Skin is tough and provided with minute placoid scales. 7) Predatory animals with powerful jaws and teeth. Example: Shark, Rays, Skates etc.

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NSOU CC-ZO-04 33 4.4 General characteristics of osteichthyes 1. The endoskeleton is cartilaginous in the embryonic stage, but adult are with bony endoskeleton. 2. Caudal fin usually homocercal type. 3. The exoskeleton, if present comprised of cycloid, ctenoid or ganoid scales. 4. The mouth is terminal. Digestive tract leads into an anus. Cloaca is absent in bony fishes. 5. External nares are present lie on the dorsal surface of the snout. 6. Bony fishes have a swim bladder (also called air bladder), arising from the dorsal wall of the oesophagus, used to maintain balance. 7. Four pairs of gills covered by an operculum on each side. 8. Single circuit heart is two chambered (one auricle and one ventricle) and also has sinus venosus and conus arteriosus. Lung fishes have three chambered heart (two auricles and one ventricle). 9. Kidneys are mesonephric. Ammonia is chief nitrogenous waste. 10. Presence of ten pairs of cranial nerves. 11. The brain bears relatively small olfactory lobes and cerebellum. 12. Lateral line system is well developed. 13. They have internal ears which helps the fish keep its balance. 14. Fertilization is generally external. Most forms are oviparous, some are ovoviviparous. 15. Some bony fishes show parental care. Examples: Marine Fishes: Exocoetus, Hippocampus, Echeneis (Sucker fish), Lophius (Angler fish) etc. Fresh Water Fishes: Labeo, Catla, Clarias (Magur), Anguilla, Anabas, Mystus etc. 4.5 Classification of pisces up to order There are difference in the classification scheme of pisces according to different authors. Considering all the views, the following classification is a combined classification based on Romer (1959) and Parker & Haswell (1967). According to

NSOU CC-ZO-04 34 them pieces has been placed in a different "series". The series "pisces" have been classified into three different classes, i.e., placodermi, chondrichthys and osteichthys. The following is a schematic diagram of classification of pisees Seris Class Sub-class Super-order Order Placodermi (all the subclasses are extinct today) Cladoselachi Pleurotremata Elasmobranchi Chondrichthys Selachi Hypotremata Holocephali Crossopterygii Polypteriformes Osteichthys Chondrostei Acipenseriformes Amiiformes Actinopterygii Holostei Semiontiformes Clupeiformes Teleosti Scopeliformes cypriniformes Anguiliformes Beloniformes Syngnathiformies Mastacembeli formes P I S C E S →→→→→→ → → → → → → → → → → →

NSOU CC-ZO-04 35 Ophiocephaliformes Symbranchiformes Perciformes Teleosti Scorpaeniformes Pleuronectiformes Echeneiformes Tetrodoutiformes Lophiiformes Series: Pisces 1. Class: Placodermi (6 subclasses): All the subclasses are extinct today. 2. Class: Chondrichthys 2.1 Subclass: Elasmobranchi Characteristics: (i) Exclusively marine (ii) Body provided with placoid scales (iii) Pelvic fins modified as claspers in males (iv) Heterocercal type of tail (v) Mouth ventral in position (vi) Cloaca present (vii) Spiracle present 2.1.1 Superorder : Cladoselachi (extinct Sharks) (i) Paired fins with a median axis (ii) Vertebra not differentiated (iii) Tail fin variable 2.1.2 Superorder: Selachi (Modern cartilaginous fishes) → → → → → → → → → ↑ →

NSOU CC-ZO-04 36 Characteristics: (i) Paired fins are folded (ii) Tail fin heterocercal (iii) Males with claspers (iv) Five pairs of gill slits (v) Operculum absent (vi) Placoid scales present 2.1.2.1 Order: Pleurotremata (Shaks and Dogfishes) Characteristics: (i) Body cylindrical (ii) Gill slits laterally placed (iii) Pectoral fins small in size (iv) Eyes laterally placed 2.1.2.2 Order: Hypotremata (Skates and Rays) Characteristics: (i) Body dorsoventrally flattened (ii) Gill slits ventrally placed (iii) Pectoral fins large and fused on the lateral margins (iv) Bottom dwellers 2.2 Subclass: Holocephali (Chimaera) Characteristics: (i) Four pairs of gills (ii) Notochord persists (iii) Teeth modified as crushing plates (iv) Mouth with lips (v) Holostylic jaw suspension

NSOU CC-ZO-04 37 (vi) Tail whip-like (vii) Spiracles absent but a single nostril present (viii) Skin naked with scattered placoid scales 3. Class: Osteichthys 3.1 Subclass: Crossopterygii (Latimeria) Characteristics: (i) Internal nares present (ii) Fins lobed except the first dorsal fin (iii) Scales with cosmine layer (iv) Air bladder lung-like (v) Jaw suspension autostylic (vi) Notochord persists and vertebrae unossified 3.2 Subclass: Actinopterygii (Rayfin bony fishes) Characteristics: (i) Fins with fin rays (ii) Tail fin homocercal types (iii) Scales cycloid and ctenoid (iv) Internal nares absent (v) Air bladder present but no lungs (vi) Jaw suspension methystylic 3.2.1 Super order: Chondrostei Characteristics: (i) Skeleton partly cartilaginous (ii) Ganoid scales present (iii) Two internal nostrils present (iv) Air bladder two-lobed and ventral

NSOU CC-ZO-04 38 3.2.1.1 Order: Polypteriformes (Polypterus) 3.2.1.2 Order: Acipenseriformes (Acipenser; Polyodon) 3.2.2 Superorder: Holostei Characteristics: (i) Skeleton partly cartilaginous (ii) Teeth sharp (iii) Ganoid scales on body (iv) Air bladder lung-like (v) Tail fin homocercal (vi) Opisthocoelous vertebrae 3.2.2.1 Order: Amiiformes (Amia calva) 3.2.2.2 Order: Semiontiformes (Lepidosteus) 3.2.3 Super order: Teleostei Characteristics: (i) Bony skeleton (ii) Tail homocercal (iii) Scales cycloid and ctenoid 3.2.3.1 Order: Clupeiformes (Herrings; Salmons, Sardines) 3.2.3.2 Order: Scopeliformes (Bombay duck) 3.2.3.3 Order: Cypriniformes (=Ostariophysi) (Labeo, Catla, Mystus, Clarias, Wallago, Heteropneustes) 3.2.3.4 Order: Anguilliformes (Eels) 3.2.3.5 Order: Beloniformes (Flying fishes) 3.2.3.6 Order: Syngnathiformes (Sea horse and Pipe fish) 3.2.3.7 Order: Mastacembeliformes (Eel-like Mastacembelus) 3.2.3.8 Order: Ophiocephaliformes (Ophiocephalus)
NSOU CC-ZO-04 39 3.2.3.9 Order: Symbranchiformes (Eel-like Amphipnous) 3.2.3.10 Order: Perciformes (Lates; Perea) 3.2.3.11 Order: Scorpaeniformes (Scorpion fish) 3.2.3.12 Order: Pleuronectiformes (Flat fishes) 3.2.3.13 Order: Echeneiformes (Sucker fish) 3.2.3.14 Order: Tetraodontiformes (Tetrodon; Diodon; Ostracion) 3.2.3.15 Order: Lophiiformes (Angler fishes) 4.6 Fish migration 4.6.1 Definition The term migration may be applied to the cycle or periodic travels of an animal if it returns eventually to the original place of departure. Such movements can be constructed with emigrations and involves a change in location not necessarily followed by return journey. Fish exhibit migration due to searching of food, shelter and for breading purpose. 4.6.2 Types of migratory movements According to Thompson (1942) migratory movement was grouped into the following categories: A. Local and seasonal movements: There are merely changes of ground at a particular time of year. The migratory movements are sometime very small often larger but still confined within one geographical area. B. Dispersals: The movements are more extensive only the breeding area is well defined and the movement is ideally an even and outward spread from the centre. C. True migration: True migration is the movement between highly separated and well defined areas. The movement impels migrant to return to the region from which they have migrated. 4.6.3 Pattern of fish migration Several authors have coined specialized terms considering the return of water current and character to designate the pattern of fish migration.
NSOU CC-ZO-04 40 A. Movements in relation to water current: Merk (1915) introduced two terms, denatant and contranatant movements of fishes. Denatant means swimming or drifting or migrating with the current and contranatant means swimming or migrating against the current. The young stages of fish generally drift with the current to the nursery ground, the spawning migration is against the current. Again the adult fishes swim against the current to reach the spawning area. B. Movements in relation to water character: Mayers' (1949) has proposed some terms to designate the fish migration considering the water characteristics. 1. Diadromous: Truly migratory fishes which migrate between the sea and fresh water. This type of migration has following sub-divisions. (a) Anadromous: Diadromous fishes which spend most of their lives in sea and migrate to freshwater for breeding, e.g: Salmon, Sea lamprey, Tenulosa ilisha (Hilsa). (b) Catadromous: Diadromous fishes which spend most of their lives in freashwater and migrate to the sea for breeding, e.g: Eeuropean eel (Anguilla anguilla) eel. (c) Amphedromous: Diadromous fishes where migration from freshwater to the sea or vice-versa, is not for the purpose of breeding but occurs regulatory at some other definite stage of the life cycle, e.g. Fresh water mullet (cestraeus plicatitis). (d) Limnodromous : Many freshwater fishes leave the lakes to spawn in the river. This is called as limnodromous migration. e.g. : white fish (coregonus lavaretus). 2. Potamodromous: True migration of fishes whose migration occur wholely in the fresh water, e.g: Some species of salmon and trout. 3. Ceranodromous: Truly migratory fishes which live and migrate wholely in the sea. e.g: Harring, Cod. 4.6.4 Factors affecting fish migration The following are the factors affecting fish migration. Physical factor : light, temperature, turbidity, depth of water etc. Chemical factor : Salinity, pH value of water etc. Biological factor : Predators, competitors, Shortage of food, hormonal secretion etc.

NSOU CC-ZO-04 41 4.6.5 Different stimuli and fish migration Fish migration is considered to be directed by various stimuli. These stimuli have been discussed below. A. Chemical stimuli: The alfaction play a vital role in finding food and locating areas which could be characterized by chemical clues. Different experiments prove that the threshold of smell of fishes is very much slower than that of test. Parker (1922) has rightly classed the alfactory organ of fishes as a distance receptor. B. Temperature stimuli: Temperature may act as sensory receptor ordinate on the metabolism. In teleost the thermal receptors are scattered by spinal nerves. C. Water current stimuli: So far as migration is concerned, the reaction of fish to water currents is one of the most interesting aspects of their behavior directing the course of their movements. To select the rheotactic response the visual and tactile sense organs are necessary. D. Light stimuli: Fish react phototactically to light. The eye is the main receptor for light. In some fishes, in the pineal area, the dermal photoreception also occurs. Under natural conditions, most fishes often show a vertical migration from deep water by day of shallow water by night and probably the phototactic reactions are efficiently used by fish on migration. E. Electrical stimuli: Regnarl (1932) was the first to suggest that the electro- magnetic force generated by moving water could have some biological significance. Thornton (1932) argued that deep sea fish could defeat the another animals by means of the electric current produced by their own motion. F. Celestrial stimuli: Various evidences like compass reaction suggests that the fishes make are of celestrial clues for orientation during migration. Haster et al (1958) observed it in the White Ban (Roccus chysops). Migration of Sole (Solea vulguris) in Southern North Sea is oriented at right as lightened by Haswell (1960). 4.7 Fish osmoregulation 4.7.1 Introduction The water is essential component of all living cell and it is the universal biological solvent. As the life began in the water medium most of the organism live in water
NSOU CC-ZO-04 42 medium and face the more problem of osmoregulation. Fish, migrate from freshwater to marine water and vice-versa, thus requires osmoregulation. Freshwater fish and seawater fish osmoregulate in different ways. Due to the different nature of the salinity of water in which they live, their process of osmoregulation is different. Osmoregulation is the process by which an organism regulates the water balance in its body and maintains the homeostasis of the body. It includes controlling excess water loss or gain and maintaining the fluid balance and the osmotic concentration, i.e., the concentration of electrolytes. It ensures that the fluids in the body do not get too diluted or concentrated. 4.7.2 Types of osmoregulation There are two major types of osmoregulation— 1. Osmoconformers: Osmoconformersare organisms that keep their internal fluids isotonic to their environment, that is, they maintain an internal salinity similar to their ambient conditions. These organisms try to maintain the osmotic pressure of their body equal to their surrounding environment. Most of the marine invertebrates, hagfish, skates and sharks are osmoconformers. 2. Osmoregulators: These organisms maintain their internal osmolality, which can be extremely different from that of the surrounding environment, through physiological processes. Some fish have evolved osmoregulatory mechanisms to survive in all kinds of aquatic environments. When they live in fresh water, their bodies tend to take up water because the environment is relatively hypotonic. In such hypotonic environments, these fish do not drink much water. Instead, they pairs a lot of very dilute urine, and they achieve electrolyte balance by active transport of salts through the gills. When they move to a hypertonic marine environment, these fish start drinking sea water; they exerete the excess salts through their gills and their urine. 4.7.3 Osmoregulation in freshwater fishes The body fluid of freshwater fishes is generally hyperosmotic to their aqueous medium. Thus, they are posed with two types of osmoregulatory problems- i) because of hyperosmotic body fluid they are subjected to swelling by movement of water into their body owing to osmotic gradient; ii) since the surrounding medium has low salt concentration, they are facing with continual loss of their body salts to the environment. Thus, freshwater fishes must prevent net gain of water and net loss of salts. Net intake of water is prevented
NSOU CC-ZO-04 43 by kidney as it produces a dilute, more copious urine (Fig. 1). Fig. 1 Osmoregulatory inflow and outflow of salts and water in a fresh water fish. HpU : hypotonic urine; S : salt W : water, W + S : water and salt. On the other way, the useful salts are largely retained by re-absorption into the blood in the tubules of kidney, and a dilute urine is excreted. Although some salts are also removed along with urine which creates torrential (loss of some biologically; important salts such as KC1, NaCl which are replaced in various parts. As for example, NaCl actively transported in the gills against a concentration gradient in excess of 100 times. In these fishes the salt loss and water uptake are reduced by the integument considerable with low permeability or impermeability to both water and salt also by not drinking the water (Fig. 2). Fig:2 Exchange of water and salt in some fishes. (a) marine elasmohranch does not drink water and has isotonic urine; (b) marine teleost drinks water and has isotonic urine; (c) freshwater teleost drinks no water and has strongly hypotonic urine; AS(G) : absorbed salt with gill; HrNaCl (RG) : hypertonic NaCl

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NSOU CC-ZO-04 44 from rectal gland; SS(G) : secretes salts from gill; W : water. 4.7.4 Osmoregulation in marine water fishes In marine fishes, the concentration of body fluid and marine water is almost similar. Therefore, they do not require much energy for maintenance of osmolarity of their body fluid. As for example is hagfish, Myxine whose plasma is iso-osmotic to the environment. Hagfish maintains the concentration of Ca ++ , Mg ++ and SO 4 ++ significantly lower and Na + and Cl + higher in comparison to sea water. Modern bony fishes (marine teleost) have the body fluid hypotonic to sea water, so they have tendency to lose water to the surroundings particularly through gills via epithelium. The lost volume of water is replaced by drinking salt water (Fig.3). About 70- 80% sea water containing NaCl and КС1 enters the blood stream by absorption across the intestinal epithelium. However, most of the divalent cations like Ca ++ , Mg ++ and SO 4 ++ left in the gut are finally excreted out. Excess salts absorbed along with sea water is ultimately received from the blood with the help of gills by the active transport of Na + Cl – sometimes К + and eliminated into the sea water. However, divalent ions are secreted into the kidney (Fig. 3). Fig. 3: Osmotic regulation in marine bony fishes. HpU : hypotonic urine; SW : sea water; W + S + NH 3 : water, salt and ammonia; W : water. Thus, urine is iso-osmotic to the blood but rich in those salts, particularly Mg2 ++ , Ca ++ and SO 4 – – which are not secreted by the gills. Combined osmotic action of gills and kidney in marine teleost resulted in the net retention of water that is hypotonic both to the ingested water and urine. By using similar mechanism some teleost species such as the salmon maintain more or less constant plasma osmolarity in-spite of being migratory between marine and freshwater environment.
NSOU CC-ZO-04 45 4.8 Parental care in fishes 4.8.1 Introduction Parental care is an adaptation to protect the offspring for continuity of race. However, all fishes do not exhibit parental care. Those fishes are highly fecund, fertilized eggs or youngs and leave to the mercy of nature after egg laying. But there are many fishes where definitive parental care has been evolved. These fishes, in general, are less fecund and lay small number of eggs. Therefore, various devices have been adopted to ensure proper development of the eggs into adults. One or both the sexes may participate in the process. 4.8.2 Prelude of parental care Aims of reproduction is the perpetuation of the race in the living organisms and is assumed by- A. Producing large number of offspring, without paying any attention, few will survive in many teleosts. B. Some fishes produce fewer offspring, therefore the parental care is very strong. 4.8.3 Biological modification with regard to parental care Parental care normally include some changes in the parental activity and also involve some structural modification. A. Eggs laid down in protected place: Protection of developing youngs is found in some fishes. The protection is normally accomplished in the following ways- 1. Embryos in shelled cases: The provision of the hard and impermeable egg shell and good supply of yolk is common in several elasmobranchii eggs. Example: Scyllium sp. 2. Cocoon: Protection affords by cover or cocoon within which several eggs remain enclosed. Example: Lung fishes. B. Eggs laid down in unprotected place: Here care is given by parents. 1. Selection of site: The fish select the site for laying their eggs according to their habitat, which they feels to protect their affsprings from different hazardous environment. NSOU CC-ZO-04 46 (a) Tenulosa, Salmon (anadromous fish) select fresh water for spawning. (b) Freshwater eels (Anguilla) have catadromous habit, descending into the ocean to bring the eggs to salt water habit for development. 2. Deposition of eggs: Remarkable protection is given by many fishes in depositing the eggs in suitable places to ensure safety of the offspring. For example, Rhodens deposit its eggs into the mantle cavity of the pond muzzle by means of a seasonally developed ovipositor. Eggs may be entangled in hollow ropes, so that they are not scattered. Example: Pearch. 3. Nest building: Construction of nest for reception of the fertilized eggs varies from small hole to a beautiful and elongated structure. (a) Flighting fish (Betta splendens) builds any nests prepared by blowing bubbles of air and sticky mucus are also encountered in many fishes. The bubbles of air and mucus adhere to form a floating mass of foam.

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The eggs are collected by the male and he throws them in such a way that the eggs can adhere to the lower surface of the foamy nest. (b) Some fishes digged up muddy floor and filled up with small stones for deposition of their eggs. Example: Salmon. (c) The male of many cichlids fishes prepare shallow basin like nest with a layer of fine sand for laying eggs by the females. Example : Oreochromis sp. (d) North American cyprinids construct elaborate nests composed of large lips of stone pebbles. (e) African asteoglossid (Heterostis) make nest by cleaning a space among the aquatic vegetation. Nest measuring about space 1 feet in length and 2 feet in depth and wall made up of grass, thickening much where they deposit their eggs. (f) In labyrinth fishes they makes a nest by bubbles of air and sticky mucous. The male keep the eggs inside the nest. C. Care regarded by carrying the eggs/youngs: Some fishes rendered highest degree of protection by carrying eggs/youngs with them. They do not build nests. 1) Mouth cavity as shelters: (a) In cichlids, the female carry their eggs in their mouth cavity. Even after hatching, they try to uses the mouth cavity as shelter at the time of danger

NSOU CC-ZO-04 47 (found in tilapia). In a catfish Arius, the male carry the eggs as well as young fry in the mouth cavity. (b) In South American cichlids, the females in addition to care for the eggs, the parent allow newly hatched larvae to feed on the mucous covering of their body. 2) Formation of pouch: (a) In Brazilian catfish, male develops an enlarged lower lip in the form of a pouch. The eggs are incubated in the pouch. (b) Indopacific catfishes, Kurtus exihibited by male. Males provided by a bony hook like projection from their forehead during breeding season. This is for the attachment of garland formed by eggs attached with each other. 3) Coiling round eggs: In Pholis, the eggs are rolled into a rounded ball and one of the parents possibly male, guards the egg ball by coiling round it. 4.8.4 Structural modification with regard to parental care (a) In many male Perciformes, the forehead provided with a bony cephalic hook being supported by a special processes of skull on extension, the egg has become attached to these hook. (b) In Platystacus, the carrying of eggs is of advanced type. The skin at the lower surface of the body of the female become soft and spongy during spawning season. Immediately after the fertilization of the egg, the female presses her body against the egg in such a way that each egg becomes lodged in a small integumentary depression. Each egg is attached inside the cup by an inconspicuous stalk. The eggs remain in this position till hatching. (c) The male of the pipe fish and sea horse (Hippocampus) developed a simple groove lined with soft skin and a special pouch closed by flaps of skin respectively. The eggs are transferred into the brood pouch by the female and development takes place within the brood pouch. 4.8.5 Internal incubation (a) In some bony fishes, development takes place within the vascular and follicles of the ovary.

NSOU CC-ZO-04 48 (b) In some cases fertilization takes place with the follicle buds, further development occurs in the cavity of the ovary after the egg leaves the tissue. Example: Embiotoced fishes. (c) Super foetation, i.e., developing more than one group simultaneously into the same ovary in some cyprinoderm fishes. 4.8.6 Viviparity The sprinids in Central Europe, take remarkable precaution for safety of their offspring oviduct is drawn out from the body and from ovipositor and females lay eggs inside the ovipositor.The retention of the embryos within the body of the parent until the end of the embryonic life. Most of the fishes, who have well defined structure meant for nutrition all and respiratory exchanges between the parent and the developing youngs. The nutrition is drawn by forming yolk sac placenta in most of the cases. The highest degree of parental care found in viviparous fishes. 4.9 Summary Fish are aquatic cold blooded vertebrates which exploit the aquatic habitat. Migration may be applied to the cycle or periodic travels of an animal if it returns eventually to the original place of departure. Fish migration is considered to be directed by various stimuli. Osmoregulation is the process by which an organism regulates the water balance in its body and maintains the homeostasis of the body. Parental care is an adaptation to protect the offspring for continuity of race. Fish exhibits parental care. 4.10 Questions i) Write the general characteristics of chondrichthyes. ii) Write the general characteristics of osteichthyes. iii) Classify pisces up to order with distinctive characters and examples. iv) Write a short note on fish migration. v) What is fish osmoregulation?

NSOU CC-ZO-04 49 vi) Write on the parental care in fishes. 4.11 Suggested readings 1) The life of vertebrates by J. Z. Young; Year: 1981. Published in India by Oxford University Press, New Delhi 2) Study material Post Graduate Zoology (Paper: 1). Structure and function of chordates and non-chordates, Year: 2010. Pub: Registrar, Netaji Subhas Open University 3) Learning protochordata through latest portfolio of theory and practice. Edited by P.K. Verma and Nandita Pande (Editor-in-Chief: Brian Jenkins); Year: 2002; Pub: Dominant Publisher and Distributors, New Delhi-110002 4) Biology of Animals (Volume-II) by Arup Kumar Sinha, Simananda Adhikari and Banku Behari Ganguly; Year l991; Pub: New Central Book Agency 5) Text Book of Zoology Vertebrates (volume-2) 7th Edition by T. Jeffery Parkar and Williama Haswell (Edited by Marshall & Williams) Year: 1995. Pub: AITBS Publishers & Distributors, New Delhi-110051

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NSOU CC-ZO-04 50 Unit 5 Amphibia Structure 5.1 Objectives 5.2 Introduction 5.3 General characteristics and classification up to order 5.3.1 General characteristics of class amphibia 5.3.2 Schematic diagram of classification of living amphibians 5.4 Parental care in amphibians 5.4.1 Introduction 5.4.2 Types of parental care 5.5 Metamorphosis in amphibians 5.5.1 Definition 5.5.2 Types of amphibian metamorphosis 5.5.3 Metamorphic changes of amphibians 5.5.4 Structure of metamorphosis 5.5.5 Hormonal control for metamorphosis 5.5.6 Metamorphosis of toad 5.6 Summary 5.7 Questions 5.8 Selected readings 5.1 Objectives After studying this unit, learners would be able to understand following— the characteristics of amphibian. the classification of amphibian. the parental care in amphibians. 50
NSOU CC-ZO-04 51 the metamorphosis in amphibians. the hormonal control for metamorphosis. 5.2 Introduction Amphibia, the first land vertebrates to become adapted to life on land. They are known for pentadactyle limb, presence of middle ear. This group arose in the Devonion period and was completed by the reptiles in course of time. This class falls into three main divisions— (i) anura which includes the frog and toad; (ii) urodela includes; newts and salamanders and (iii) apoda that includes superficially worm Gymnophiona. In the present chapter the general characteristics, classification, parental care and metarporphosis in amphibians will be discussed. The study of amphibians is called Ichthyophis, while the study of both reptiles and amphibians is called herpedology. 5.3 General characteristics and classification up to order 5.3.1 General characteristics of class amphibia 1. Cold blooded vertebrates. 2. Amphibious in nature, viz., live both land as well as in water. 3.

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Body is divisible into head and trunk. Tail may be present in some amphibians. 4. The skin is smooth or rough having glands

which keep the animals moist. 5. Usually without scales, if

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present, they are hidden beneath the skin (e.g., Caecilians). 6. Paired fins are absent. Unpaired fins may be present. Two pairs of limbs are

used for locomotion except Caecilions. 7. The

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gills are present at least in the larval stage; some adult forms also carry external gills in addition to lungs (e.g., Necturus, Proteus). 8. Skull is dicondylic, i.e., with two occipital condyles for articulation with

vertebral column. 9. The respiratory organs are lungs, bucco-pharyngeal cavity, skin and gills. 10. The heart is three chambered, having two auricles and one ventricle. Presence of sinus venosus and truncus arteriosus. 11. Kidneys are mesonephric. Larvae and

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tailed amphibians (e.g., salamander) are ammonotelic. Frogs and toads are ureotelic. NSOU CC-ZO-04 52 12. Alimentary canal, urinary and reproductive tracts open into a common chamber called cloaca which opens outside through cloacal aperture. 13.

Ear consists of internal and middle ear. Tympanum (outer membrane) covers the middle ear. 14.

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The eyes have eyelids. Nictitating membrane is well developed. 15. Ten pairs of cranial nerves			

are present. 16. Lateral line system is found during their development. 17. Fertilization

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is external. However, in Salamander and lehthyophis (blind worm) fertilization is internal. 18. Development is			

mostly indirect. 5.3.2 Schematic diagram of classification of living amphibians The following classification is based on Young (1981). * marked subclass and orders are extinct now, thus not been included. Class Subclass Order A M P H I B I A *Labyrinthodontia (folded teeth) *Lepospondyli (Scale vertebrae) Anura (no tail) Urodela (with tail) Apoda (no limb) [[[*Temnospondyli (divided vertebrae) *Ichthyostegalia (fish vertebrae) *Anthracosauria (coal lizards) Lissamphibia (smooth amphibia)

NSOU CC-ZO-04 53 Sub-class: Lissamphibia (smooth amphibia) General characteristics: 1. Found throughout the tropical and temperate areas of the world. 2. Possess a broad skull, the orbits enlarged into cheek and temporal regions. 3. Teeth are fang-like, i.e., pedicellate. 4. Vertebrae are monospondylics (i.e., wanting separate intercentra). 5. In the ear, auricular operculum and columella are present. 6. Scale-less smooth skin possess numerous glands. 7. Respiration through skin. Order-1: Anura (Sometimes referred to as Salientia) General characteristics: 1. These animals are short, four-legged, stout bodied and tailless. 2. They possess well developed eyelids and distinct tympanum. 3. Large eyes are situated well ahead of the head. 4. Wide mouth, may or may not possesses tongue. 5. The posterior limbs are longer than the anterior limbs. 6. Frontal and parietal bones of the skull are joined to form a single bone called frontoparietal. 7. Mandible is devoid of teeth. 8. There are five to nine pre-sacral vertebrae in the vertebral column. 9. The post-sacral vertebrae are fused to form a rod-like structure, called urostyle. 10. Vertebrae always possess zygapophyses and transverse processes except the atlas. 11. The tibia and fibula are fused at least proximaily and distally. 12. Generally fertilization is external. Tadpole larva metamorphoses to adult. Examples: Duttafrinus melanostictus (common Indian toad), Hyla annectans Rana tigrina (Indian Bull frog), Rhacophorus malabaricus, Bufo melanostictus.

NSOU CC-ZO-04 54 Order-2: Urodela (also known as Caudata) (Gk. Oura = tail; delos = visible) General characteristics: 1. These animals are lizard-like in appearance, with distinct head and a well- developed tail. 2. There are two pairs of weak limbs in the body. 3. In aquatic forms a lateral line system is present. 4. Small eyes are without lids. In cave-dwellers, eyes are lost. 5. Usually four pairs of aortic arches are present. 6. The columella in the middle ear is absent. 7. Kidney is opisthonephric type. 8. In the skull, cartilagenous elements are only found in occipital region. 9. The vomer and palatine are fused to form vomero-palatine. 10. Vertebrae may be amphicoelous or opisthocoelous, with ribs. 11. Simple pectoral girdle is composed of cartilage. 12. There is an Y-shaped bone epipubis attached to the pubis. 13. Fertilization is generally internal. Examples: Tylototriton (Only Indian genus), Ambystoma, Triton, Necturus, Salamandra, Triturus. Order-3: Apoda (Also known as Gymnophiona or Caecilia) General characteristics: 1. These are worm-like, limbless burrowing creatures. 2. Body smooth, slimy and externally segmented by a series of annular grooves within which small, granular dermal scales are embedded. 3. Lidless eyes are reduced and covered by the skin or by the maxillary bones. 4. A peculiar conical flap-like, protrusible sensory tentacl is present in between nostril and eye. 5. Both the tympanum and tympanic cavity are absent.

NSOU CC-ZO-04 55 6. Tongue is fused with the floor of the mouth cavity. 7. Tail, if present, is short and conical. 8. Skull is solid and compact. Maxilla and palatine fused to form maxillopalatine. 9. Teeth are present on the premaxilla, maxillopalatine, vomer and dentaries. 10. Vertebrae are amphicoelous and with persistent notochord. 11. Pectoral and pelvic girdles are absent. There is no sternum. 12. Intestine is straight. 13. Only right lung is well developed. 14. Only pulmonary and systemic arches are present. 15. Fertilization may be external or internal. 16. The eggs are large and yolky. Examples: Ichthyophis (India), Uraeotyphlus malabaricus (South India), Gegenophis (South India). 5.4 Parental care in amphibians 5.4.1 Introduction Parental care is mostly a modification in the parents to take care of the off-springs so that with a meager number of eggs continuation of race can be maintained. In amphibia, the reproductive mechanism had undergone extensive modifications perpetuation of race can be maintained either the process of overproduction of eggs or by caring of a small number of eggs. Rearing or care of the offsprings is an acheivement in the trend of evolution. However, the phenomenon of parental care is quite well developed in amphibians where extreme modifications in structure and behaviour are observed. 5.4.2 Types of parental care There are various ways by which the parental care is manifested in amphibians. 1. Selection of site: In certain frogs and toads care of the eggs has been taken by selection of suitable site. Example: In Rhacophorus schlegli, the eggs are laid in a hole on muddy bank of
NSOU CC-ZO-04 56 river or pond and covered by foamy mucus to prevent desiccation. The eggs are washed out into the water of the river or pond or by rain and development starts. In Triton and Leptodactylus the eggs are laid under the surface of the leafs near the vicinity of water. 2. Frothing of water: Rhacophorus maculates (both male and female) just after laying eggs the surrounding water is made frothy by the wriggling movement of hindlimbs, so that the eggs are prevented from desiccation and also can escape the sight of enemies. 3. Formation of nests: The parents take care of the laying eggs in the nests formed by them. For example: Hyla faber, dig a hole in the mud for the developing eggs and the surplus mud nest. Phyllomedusa, the leaf nest is formed by folding the margin of the leaves. Triton constructed shoot nest by fixing the shoots of the trees in which the eggs are deposited and the youngs are developed. The whole nest remains covered by a gelatinous secretion. 4. Carrying eggs over the body: Hyla goeldii female carry the eggs in the broad pouch that are placed on their back. The young come out as full- fledged frog with tail. Likewise, the female Cryptobatrachus carry the eggs on the back. Desmognathus female carry eggs and live in underground hole. 5. Carrying larvae from one place to another: In Arthroleptis,

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the tadpole larvae are attached to the males and are carried from one pond to other.

However, at the time of danger they are kept inside the buccal cavity. 6. Placement of eggs in safest part: In Ichthyophis, the body remains coiled round the egg mass to guard them until hatching. In Rhinoderma darwini, the eggs are swallowed by the males and are placed inside the inflated vocal sac. The eggs may remain there until hatching or even up to the completion of metamorphosis. 7. Viviparity: In Salamandra atra the eggs are placed inside the uterine cavity where entire tadpolehood is completed. The larva remain attached with the uterine wall by membrane which functions physiologically in the manner of a primitive placenta.
NSOU CC-ZO-04 57 Fig-1. Parental care in amphibians : A. Mud nests of Hyla; B. Ichthyopis coiling round the eggs; C. Cryptobatrachus evansi, where the brood pouches are opened to show developing eggs. D. Desmoguathus fuscus with eggs; E 1 : Pipa pipa; E 2 : Pseudoplacenatation in Pipa dersigera; F : Gastrotheca; G. Alytes 5.5 Metamorphosis in amphibians 5.5.1 Definition Metamorphosis may be defined as "a rapid differentiation of adult characters after a relatively prolonged period of slow or arrested differentiation in a larva". According

NSOU CC-ZO-04 58 to Duellman and Trueb (1986), metamorphosis can be defined as "a radical transformation from larval life to the adult stage involving structural, physiological, biochemical and behavioural changes." 5.5.2 Types of amphibian metamorphosis There are two types of metamorphosis—Progressive and Retrogrossive. Progressive metamorphosis: During metamorphosis if the animal progresses in the evolutionary grades, the metamorphosis is considered as a progressive metamorphosis; e.g., in most anurans of amphibia. Retrogressive metamorphosis: When metamorphosis takes place in lower direction, i.e., by metamorphosis the animal retrogresses or shows indication of degeneration in the scale of evolution, called retrogressive metamorphosis. It is found in neotenic forms like salamanders. 5.5.3 Metamorphic changes of amphibians Metamorphic changes in amphibians takes place in the following three stages : Premetamorphic stage: The stage is characterized by the considerable growth and development of larval structures but metamorphosis does not occur. Prometamorphosis: The stage is characterized by the continuous growth specially the development of limbs and initiation of metamorphic changes. Metamorphic climax: The stage is characterized by the radical changes in the features of the larva, and climax is considered by the loss of most larval features. 5.5.4 Structure of metamorphic tadpole larva Structure of a freshly hatched tadpole larva 1) A freshly hatched tadpole larva has a limbless body. 2) The body is divided into an ovoid head, a short trunk and a slender tail. 3) Anus is situated ventrally at the root of the tail. 4) An adhesive sucker is present on the ventral side of the head by which the tadpole larva attaches itself to the aquatic weeds. 5) The mouth is absent.

NSOU CC-ZO-04 59 6) The yolk material provides the nutrition. 7) The respiratory organs are in the forms of three pairs of highly vascular and branched feathery external gills. 8) After a few days the mouth is formed near the sucker. 9) A pair of horny jaws surrounds the mouth. 10) The tail becomes more elongated and develops a dorsal and a ventral fin. 11) V-shaped myotomes develop on both the sides of the tail. 12) At this time free-swimming tadpole larva ingests aquatic weeds, as a result of which the alimentary canal becomes extremely elongated. 13) To accommodate such a long alimentary canal inside the cavity of the short trunk, it becomes spirally coiled like the spring of a watch. Structure of an advanced tadpole larva 1) In the advanced stage, the pharynx of the tadpole larva becomes perforated by gill- slits. 2) External gills disappear and the internal gills are formed between the gill slits. 3) The gills and the gill-slits are covered by the operculum (or gill-cover). 4) The tadpole larva has three pairs of external gills at the start which are subsequently replaced by three pairs of internal gills. 5) In the larval stages, the arterial arches also show modifications in terms of both external and internal gills. 6) The operculum fuses with the trunk on all sides except a small opening, called spiracle on the left side. 7) Water enters into the pharynx through the mouth and goes out through the spiracle. 8) During this transit of water the internal gills are bathed with water containing oxygen dissolved in it. 9) While the internal gills are functioning, a pair of lungs develops as outgrowths from the pharynx on the ventral surface.

NSOU CC-ZO-04 60 10) The hind limbs appear prior to the forelimbs. 11) The forelimbs remain first hidden under the operculum and subsequently emerge through it. 12) At this stage both the internal gills as well as the newly formed lungs are functional. 13) When the lungs become fully developed, the internal gills become degenerated. 14) At this stage it looks like a miniature toad except having a tail. 15) As the limbs are developing, the animal enters into a period of starvation. 16) The material of the tail becomes eventually absorbed into the body. Structure of a freshly formed toad 1) After the absorption of tail, the young toad leaves the primal aquatic home and comes to the land and then starts hopping. 2) The mouth becomes wider and a pair of true bony jaws replaces the horny jaws. 3) It now changes its food habit to become carnivorous type, as a result the alimentary canal becomes short and less coiled. Types of changes in tadpole lerva The changes that take place in the tadpole can be divided into following four groups. A. Changes of tadpole in habit and habitat (i) With the metamorphosis, the metamorphosed larva leaves aquatic medium and frequently visits the land. (ii) The herbivorous tadpole larva changes into carnivorous specially consume the insects (insectivorous). (iii) The preying habits develop in the adults which become more active and swift moving. (iv) In the ftrst stage of adult toad, they jump into nearby pond and in other aquatic habitats and then jump on the land by their elongated hind limbs.

NSOU CC-ZO-04 61 B. Morphological metamorphic changes I. Regressive changes: (i) The tissues of tail and tail fin are completely absorbed into the body. (ii) The horny jaws With teeth are shed and mouth becomes a large transverse slit. (iii) The external gills disappear and the gill slits communicate to the pharyngeal cavity. (iv) The length of the alimentary canal is reduced substantially. (v) The changes of the blood vascular system take place and ultimately some blood vessels are reduced. (vi) The lateral line sense organ disappears. (vii) Operculum and spiracle disappear. II. Progressive changes: (i) The fore and hind limbs increase in size. (ii) The tongue becomes long and more elastic which is free and bifid posteriorly. (iii) The eyes become large and prominent and develop eye-lids and nictitating membrane. (iv) External nostrils communicate with buccal cavity through internal nostrils. (v) Tympanum and middle ear develop. (vi) Liver becomes more enlarged. (vii) Three chambered heart develops from two-chambered heart. (viii) Pronephros is replaced by mesonephros in kidney. C. Biochemical changes during metamorphosis (i) The concentration of serum protein becomes about double during metamorphosis. (ii) Biosynthesis and concentration of haemoglobin are greater in adult than in larvae. (iii) In the liver, DNA synthesis, lipid synthesis, enzymes for ornithine urea cycle increase during adult stage. (iv) Alkaline phosphatase and hydrolase decrease in adult stage of the anurans.

NSOU CC-ZO-04 62 D. Physiological changes (i) At the beginning of metamorphosis, the pancreas starts to secret insulin and glucagon hormones. This is related to the enhanced role of the liver. (ii) During the larval stage, the end product of nitrogen metabolism is ammonia. But after metamorphosis, the toads and frogs excrete most of their nitrogen in the form of urea. This shift from ammonotelism to ureotelism with the change of habitat from aquatic to land. 5.5.5 Hormonal control for metamorphosis Two hormones such as Triiodothyronine (T 3) and Tetraiodothyronine (T 4) or thyroxine are necessary for biochemical and morphological changes during metamorphosis. These thyroid hormones are produced by the induction of anterior pituitary lobe or pars distalis when it reaches certain degree of differentiation. Then it is capable to synthesize a hormone, thyrotropin (Thyroid Stimulating Hormone, TSH) which acts on the thyroid, stimulating the production and secretion of triiodothyronine (T 3) and thyroxine hormones. In pre-metamorphic stage the prolactin level is high but levels of thyroid stimulating hormone (TSH) and thyroid hormone (T 3 , T 4) are low. The hypothalamus - pituitary link is poorly developed. In pro-metamorphosis, the hypothalamus and pituitary link develops. The prolactin level is low but the levels of thyroid stimulating hormone (TSH) and thyroid hormones (T 3 , T 4) are high. In metamorphic climax, the prolactin level increases suddenly, then maintains steady low level. The TSH is high until the end of climax and the level of thyroid hormone (T 4) becomes low.

NSOU CC-ZO-04 63 Fig-2. Schematic representation of the larval development and metamorphosis of Bufo sp. 5.5.6 Metamorphosis of toad The young tadpole larva resembles a fish. It leads an independent and self-supporting life. This fish like tadpole larva completely metamorphoses into toad, and it is exclusively a progressive process. Daniel (1963) reports the hatching in about 4 days after laying. According to Mohanty-Hejmadi and Dutta (1978), the development is rapid being completed in 34-52 days. 5.6 Summary Amphibia, the first land vertebrates to become adapted to life on land. The phylum amphibia possess three living order, i.e., anura, urodela and apoda. Amphibians exhibit parental care.

NSOU CC-ZO-04 64 Tadpole is the larva of amphibians. Triiodothyronine (T 3) and Tetraiodothyronine (T 4) or thyroxine are necessary for biochemical and morphological changes during metamorphosis in amphibians. 5.7 Questions i) Write the general characteristics of amphibian. ii) Discuss in details about the classification of living amphibians with distinctive characters and examples. iii) Write a short note on the parental care in amphibians. iv) What is metamorphosis? v) How many types of metamorphosis are found in amphibian? Give details. vi) Discuss about the hormonal control for metamorphosis in amphibian. 5.8 Selected readings 1) The life of vertebrates by J. Z. Young; Year: 1981. Published in India by Oxford University Press, New Delhi. 2) Biology of Animals (Volume-II) by Arup Kumar Sinha, Simananda Adhikari and Banku Behari Ganguly; Yearl991; Pub: New Central Book Agency. 3) Text Book of Zoology Vertebrates (volume-2) 7th Edition by T. Jeffery Parkar and Williama Haswell (Edited by Marshall & Williams) Year: 1995. Pub: AITBS Publishers & Distributors, New Delhi-110051. 4) Vertebrates Comparative Anatomy, Function, Evolution (Fourth Editon) by Ken- neth V. Kardong. Year: 2010. Pub: Tata McGraw-Hill

NSOU CC-ZO-04 65 Unit 6 Reptilia Structure 6.1 Objectives 6.2 Introduction 6.3 General characteristics and classification up to order 6.3.1 General characters of reptilia 6.3.2 Classification scheme of reptilia 6.4 Affinities of Sphenodon 6.4.1 Introduction 6.4.2 Distribution 6.4.3 Habit 6.4.4 Habitat 6.4.5 Food 6.4.6 General characters 6.4.7 Evolutionary position of Sphenodon 6.4.8 Phylogenetic views 6.4.9 Discussion 6.5 Poison apparatus in snake 6.5.1 Poison gland 6.5.2 Fangs 6.6 Biting mechanism of poisonous snakes 6.7 Summary 6.8 Questions 6.9 Selected readings 65

NSOU CC-ZO-04 66 6.1 Objectives After studying this unit, learners would be able to understand the following— the general characteristics of reptiles. the classification of reptiles. General affinities of sphenodon. the systematic position of reptiles. Parental care in reptiles. Poison apparatus in snake. Structure of fang in snakes. Biting mechanism of poisonous snakes. 6.2 Introduction Reptiles are the true land vertebrates that left the habit of going to water for laying eggs. In fact, the emergence of reptiles as the true land-dwelling vertebrates offers the greatest dramatic event in the course of evolution. Reptiles are tetrapod vertebrates, that either have four limbs or limbless snake that are descended from four-limbed ancestors. Reptiles arose from a carboniferous amphibian stock which had probably developed the shelled amniotic egg. Most reptiles are oviparous, although several species of squamates are viviparous. The fetus develops within the mother, contained in a placenta rather than an egg shell. In the present chapter the general characteristics, classification, affinities of sphenodon, poison apparatus and biting mechanism in snakes will be discussed in more details. 6.3 General characteristics and classification up to order 6.3.1 General characters of reptiles 1) They are both terrestrial and aquatic (both marine and freshwaters) in habitat.

NSOU CC-ZO-04 67 2) Their skin is dry, cornified and usually covered by epidermal scales or scutes. 3) There are a few integumentary scent glands secreting pheromones during breeding seasons. 4) Single external nasal opening is present on the snout. 5) Vomero-nasal organ (organ of jacobson) is well-developed. 6) Single occipital condyle in the skull is present for the attachment with atlas. 7) Mandible consists usually six pieces of bones. 8) Vertebrae are procoelous. Sternum is greatly developed with ribs. 9) Two pairs of pentadactyle limbs are present. The limbs end in clawed digits. 10) The cloacal opening is either transverse or longitudinal. 11) A post-anal tail is present. 12) The heart is composed of two auricles and a partially divided ventricle (in crocodile the ventricle is completely divided). 13) The kidney is metanephric type. 14) Males possess copulatory organs. 15) Presence of twelve pairs of cranial nerves. 16) Fertilization is internal. 6.3.2 Classification scheme of reptiles Although different scientists classified reptilia based on the characters of different reptilians, but here we follow the classification given by Young (1981). The following is the schematic diagram of the classification of Reptilia. The (*)marked sub-class and orders are considered as extinct.

NSOU CC-ZO-04 68 R E P T I L I A Classification scheme of Reptilia Class Subclass Older Suborder *Cotylosauria Anapsida *Mesosauria Chelonia *Protorosauria *Synaptosauria *Sauropterigya *Placodontia *Ichthyopterygia *Ichthyosauridae *Eosuchia Lepidosauria Rhynchocephalia Lacertilia (=Sauria) Squamata Ophidia *Thecodontia Amphisbaenia Crocodilia Archosauria *Saurischia *Ornithischia *Pterosauria *Pelycosauria *Synapsida *Therapsida I. Subclass-1 : Anapsida General characters: 1) The roof of the skull is solid. 2) The skull is devoid of fossae behind the eyes.

NSOU CC-ZO-04 69 Order: Chelonia (Gk. Chelone = a tortoise) General characters: 1) Body is dorsoventrally flattened and more or less elliptical. 2) Body is dorsally covered by a shield like carapace and ventrally by a plate, plastron. 3) Neck, limbs and tails are retractile. Tail is very short. 4) Weak limbs are pentadactyle and in some marine forms modified into paddles. 5) In adults, teeth are absent and the jaws are covered by sharp horny plates. 6) The cloacal opening is longitudinal. 7) These are oviparous animals. 8) In the skull, quadrate bone is immovably articulated, i.e., monimostylic. 9) Thoracic vertebrae and ribs are usually fused with carapace. 10) Pectoral girdle consists of a scapula, a long pro-coracoid, and a coracoid. 11) The pelvic girdle is composed of ilium, ischium, and pubis. Examples: Trionyx (Indian soft shell turtle), Chelone (Green turtle), Dermochelys (Leather back turtle) etc. II. Subclass-2: Lepidosauria (Gk., Lepis = scale; Squaros = Lizard) General Characters: 1) The skull of this group is diapsid with two temporal vacuities. 2) Lizard-like reptiles with scaled skin. This subclass includes two living orders- (i) Rhynchocephalia ; and (ii) Squamata. Order-1: Rhynchocephalia (Gk., Rhynchos = a beak/snout; Kephale = a head) General characters: 1) Dorsal side is covered by small granular scales and on the ventral side the scales are trans-formed into transverse square plates of larger size. 2) Tail is bilaterally compressed and crested with power of regeneration. 3) At the dorsal side a median row of erective spines (frill) extends from the top

NSOU CC-ZO-04 70 of the head to the tip of the tail. 4) The eyes are large with vertical pupil. 5) The cloacal aperture is a transverse slit. 6) Males do not have copulatory organ. 7) Skull is composed of paired premaxillae, nasals, frontals, and parietals. The quadrate is immovable. 8) Vertebrae have amphicoelous centra with persistent notochord. 9) Vertebrae possess chevron bone. 10) Abdominal ribs are present. The ribs are single headed and bony. 11) The teeth are of acrodont type. 12) Vomerine teeth are present in youngs but in adults these are replaced by pads. 13) Brain is simple with a very well-developed parietal organ (third eye). Examples: Sphenodon punctatus and Sphenodon guntheri. Order-2: Squamata (Latin, sqamatus = scaly) General characters: 1) The skull of these animals bears superior temporal fossa. 2) The maxilla, palatine and pterygoid are immovably articulated with the skull. 3) The quadrate is movable. 4) Lower jaw is composed of several pieces of bones. 5) Teeth are either acrodont or pleurodont type and are borne usually on the maxillae, premaxillae and palatines. 6) Vertebrae are of procoelous type and possess chevron bone. 7) The ribs are single-headed. 8) Cloacal aperture is a transverse slit. 9) Organ of Jacobson is well-developed. This order includes three sub-orders.
NSOU CC-ZO-04 71 Sub-order-1 : Lacertilia General characters : 1) Elongated body, usually two pairs of limbs and long tail. 2) Distinct neck; upper and lower eyelids are usually movable. 3) Excepting the limbless lizards, the limbs are pentadactylus, each digit ending in a claw. 4) Teeth homodont type. 5) Urinery bladder present. 6) Cerebral hemisphere are short. 7) Quadrate is slightly movable. 8) 12 pairs cranial nerve. 9) Tympanum is distinct. Examples : Phrynosoma, Chamaeleou, Uromastyx Sub-order-2 : Ophidia General characters: 1) Cylindrical body with limbs. 2) Neck usually indistinct. 3) Limbs secondarily lost. 4) Eyelids absent and fused with the eyes. 5) Mictitating membrane immovable. 6) Conical recurved teeth. 7) Urinary bladder absent. 8) Brain extremely elongated andproject in between the eye. 9) 10 pairs cranial nerves. 10) Quadrate in highly flexable. Example—Python molurus, Boa constrictor, Vipera russelli
NSOU CC-ZO-04 72 Sub-order-3 : Amphisbaenia General characters : 1. These are worm-like lizards having no limbs. 2. The eye and ears are completely concealed under the skin. 3. The tail is very short. 4. The worm-like body is covered with soft skin possessing numerous rings, which are divided into little square. 5. Fossorial creatures having compact and highly ossified skull. 6. Teeth either acrodont or pleurodont type. Example—Amphisbaena fuliginosa, Blanus Subclass-2: Archosauria General characters: 1) The skull is of diapsid type. 2) Some forms are toothlen and in others only. Palatal teeth are lost. 3) The lower jaw is with vacuities between dentary and angular. Order: Crocodilia General characters: 1) Predatory, Semi-aquatic reptiles. 2) Large, solidly built, lizard-like body. 3) Long flattened snouts. 4) Laterally compressed tails. 5) Eyes, ears, and nostrils at the top of the head. 6) The skin is thick and covered in non-overlapping scales. 7) They have conical, peg-like teeth and a powerful bite. 8) They have a four chambered heart. 9) They are largely carnivorous, the various species feeding on animals such as fish,
NSOU CC-ZO-04 73 crustaceans, molluscs, birds, and mammals. 10) Females lay eggs in holes or in mounds and. unlike most other reptiles, care for their hatched young. Example: Crocodile 6.4. Affinities of Sphenodon 6.4.1 Introduction The order rhynchocephalia under the phylum reptilia includes five families of which four are extinct today. The only family sphenodontidae includes the sole living representative Sphenodon punctatum. It is regarded as a living fossil and is popularly call as "Hatteria" or "Tuatera". Sphenodon had many primitive features of its triassic ancestors, almost in an unchanged form while its contemporaries have all vanished. Thus, in search of the affinities of the Sphenodon is matter of great concern. 6.4.2 Distribution Members of the order rhynchocephalia was wide spread in North America, Europe, South Africa. But today Sphenodon punctatum is found only along the North coast of Newzeland. It is thus an example of relic distribution. The probable cause behind such restricted distribution is that it could not compete with large size reptiles and mammals and elsewhere, while such animal could not reach Newzeland thereby favorably flourishing growth occurred there. 6.4.3 Habit i) Sluggish and slow moving animal. ii) Primarily nocturnal. iii) Timid, but can attack any intruder in its burrow. iv) Carnivorous and mainly insectivorous. 6.4.4 Habitat Sphenodon lives in the burrow of soft soil. It is found in primarily in forest and secondarily in grassland.

NSOU CC-ZO-04 74 6.4.5 Food Sphenodon is carnivores, eating mainly insects. The diet mainly consists of beetle, crickets and other small insects, earthworms, snails, birds and their eggs and even small mammals. 6.4.6 General characters i) Lizard like body. The tail is bilaterally compressed and twisted. ii) The body is dull olive green in colour with yellow spots above and whitish below. iii) Pentadactylus and clawed digit adapted for walking. iv) The body covered with small granular scales except the lower side where the scales from transverse rows of large square plates. v) The skull is composed of paired pre-maxilla, nasals, frontal and parietal. A parital foramen and three temporal fossa are present. vi) Small, sharp and pointed acrodont teeth. vii) Transverse cloacal aperture present. viii) Lungs primitive type with simple sac like alveoli. ix) Sinus venosus distinct and absorbed in right auricle. x) It smells on the air borne odour while the food is being taken into the mouth. xi) Rod and cones are present in the retina of the eyes. xii) Urinary bladder present. Excreta mainly uric acid. xiii) Fertlization is external. 6.4.7 Evolutionary position of Sphenodon Sphenodon is undoubtedly a primitive and generalized type of reptiles but its systematic position varies according to views of different scientists. The anatomical peculiarities / general characters of Sphenodon have already been discussed. Affinities: with different groups I. With chelonia: Similarities:

NSOU CC-ZO-04 75 (i) The quadrate is immovable; (ii) Caudal ribs are fused with vertebrae; (iii) Urinarry bladder is present; (iv) Pecten is absent. Dissimilarities: (i) In Sphenodon the vomer is paired but in chelonian; (ii) Sternum is present in Sphenodon but it is absent in chelonian; (iii) Anal opening is transverse in Sphenodon but longitudinal in chelonis; (iv) The penis is absent in Sphenodon but present in chelonian; (v) The oviduct in Sphenodon opens dorsally by in chelonian it opens ventrally. Comments : Though some degree of similarities is apparent between Sphenodon and crocodilian, the dissimilarities are more pronounced. Thus, it is not justified to place the Sphenodon in the same taxonomic rank as that of the orders of crocodilian and chelonis. II.With lacertilia: Similarities: (i) General body structure is identical; (ii) Proatlus is present in both; (iii) Caudal vertebrae are separated by septum; (iv) Remnent of notochord is present between the vertebrae; (v) Ribs are single headed; (vi) Chevron bones are present; (vii) Cloacal glands are present; (viii) Oviducts opens dorsally. Dissimilarities: (i) In Sphenodon the quadrate is immovable but in lacertalia it is movable; (ii) The vertebrae are amphicoelus in Sphenodon but in lacertilian they are procoelus (except Gecko);

NSOU CC-ZO-04 76 (iii) Clavical and interclavical are present in Sphenodon but absent in limbless lacertilian; (iv) Conus arteriosus is present in Sphenodon but absent in lacertilian; (v) Uncinate process is present in Sphenodon but absent in lacertilian. Comments: Huxley (1869) strongly advocated that that the Sphenodon should be included under lacertilian as the differences between the two are very insignificant. Although this view was opposed by a few workers and therefore not accepted. III. With crocodilia: Similarities: (i) The quadrate is iommovable; (ii) Proatlus is present; (iii) The skull is of diapsid type; (iv) Ribs bear uncinate process; (v) Caudal ribs are fused with vertebrae; (vi) Abdominal ribs are present; (vii) Chevron bones are present. Dissimilarities: (i) The teeth are acrodont in Sphenodon but thecodont in crocodilian; (ii) The nasal opening is double in Sphenodon but single in crocodilian; (iii) The vertebrae are amphicoelus in Sphenodon but procoelus in crocodile; (iv) Clavical is present in Sphenodon but absent in crocodile; (v) Pectin is absent in Sphenodon but present in crocodile; (vi) Penis is absent in Sphenodon but present in crocodile. Comments: The dissimilarities are pronounced between them, hence, they may be placed separately. 6.4.8 Phylogenetic views 1. Gadow (1901): He refers Sphenodon as "the last living witness of Bygone ages. This primitive animal almost ideally generalized type of reptiles is living fossile".

NSOU CC-ZO-04 77 2. Newmann (1939): Rhynchocephalia is an aberrant group which first appear in the triassic and had a modest carrier. Through the mosaic and is now represented by one very conservative living species. 3. Sedgwick (1966): Sphenodon is neither an ancestral group nor is closely allied to ancestor of reptiles and or birds. The rhyncocephalia is essentially reptilian, i.e., it present all the typical features of reptilian organization in full development. 4. Romer (1966): Both the lizards and rhyncocephalias have been derived from the same general stock of primitive Eouscuchian which death back to upper permian. 6.4.9 Discussion Sphenodon has changed little since time of its origin and has laregely remained in eusochian evolution. Thus, it represents a very slow rate of evolution, i.e., an example of bradytilic evolution. On the other hand, taehytelic and horowtetic evolution means fast and average rate of evolution. Among its affinities with the living form Sphenodon shows the close affinities with the lacertilian (lizard). Both the group appear in the triassic period again of its affinities with the fossile reptiles, it shows a strong relationship with eousuchia particularly youngians and also to prolacerta. That eousuchian particularly the prolacerta is also most close to lacertiiian. The eousuchia, Sphenodon and lacertiiian shows a triangular relationship with each other. On the other hand, the Sphenodon has certain features like, double temporal fossa, akinate skull, absence of penis etc. which sharply differentiate it from lacertilia. It thus appear that the eousuchia one hand give rise to rhyncocephalians and on the other hand to the lacertilian through a prolacerta type of reptiles. So, it is wise to treate Sphenodon or rather rhyncocephalian as a separate order or a group from the lacertilian having a close relationship that was inhabitant from common ancestry on euosuchia. Considering foregoing discussion, Sphenodon is occupied the following systematic position— Class: Reptilia Sub-class: Lepidosauria Order: Rhyncocephalia Family: Sphenodontidae
NSOU CC-ZO-04 78 6.5 Poison apparatus in snake 6.5.1 Poison gland The poison apparatus of snakes consists of a pair of poison glands, their ducts and a pair of fangs. In poisonous snakes the poison glands are situated one on either side of the upper jaw. The poison glands are possibly the superior labial glands or parotid glands. Each poison gland is sac like and provided with a narrow duct at its anterior end. The duct passes forward along the side of the upper jaw and loops over itself just in front of the fang and opens either at the base of the fang or at the base of the tunnel on the fang. The poison gland is held in position by ligaments. An anterior ligament attaches the anterior end of the gland to the maxilla. A posterior ligament extends between the gland and the quadrate. Fan-shaped ligaments are situated between the side walls and squamoso- quadrate junction. 6.5.2 Fangs The fangs are sharply pointed and enlarged maxillary teeth. Snakes eject venoms by their two hollow maxillary teeth called fangs. Fangs (Fig-1.) are long, sharply pointed and hook like being extremely hard and calcified with a superficial enamel layer. Poisonous apparatus of a snake 1) Poison gland 2) Nostril 3) Fang 4) Tongue Fig 1: Diagram of a fang
NSOU CC-ZO-04 79 6.6 Biting mechanism of poisonous snakes Boltt and Ewer (l964) studied the biting mechanism on Puff adder (Bitis arietans) give a general idea about the biting mechanism of snake which is applicable to all poisonous snakes. The mechanism also entails the same story in case of Indian poisonous snakes, specially the cobra and viper groups. The mechamsm of biting is a complicated process and the sequences of biting are in three steps as follows— (a) Opening of the mouth: Just before striking, the digastric muscle contracts, as a result of which the mouth opens (see fig. 2B). (b)Rotation of maxilla: As the mouth opens, the lower jaw moves forward and a rotation of the squamosal, quadrate and mandible in relation to each other occurs and the sphenopterygoid muscles contract. This contraction results in the forward movement of pterygoid and up-pushing of the ectopterygoid. The upward movement of the ectopterygoid brings about a rotation of the maxilla on its own axis round the lacrimal and as the end result the fang is raised and comes to its striking position (Fig-2C, D). The fang is nearly horizontal in position when the mouth remains closed. But during opening of the mouth to bite, the fang assumes almost vertical position. It has been suggested that the quadrate is loosely attached to the posterior part of the pterygoid and the weak force, which is generated by the rotation of the lower end of quadrate, could not help in the forward movement of ptecygoid and ectopterygoid. The movement of the pterygoid and ectopterygoid is effected by the contraction of their own muscles, the protractor and levator pterygoidei (Fig. 3), which jointly act to push the pterygoid and ectopterygoid directly forward. As a result the maxilla rotates in its own axes. The erection of fangs is not related to the opening and closing of the mouth. The fangs can be erected independently.
NSOU CC-ZO-04 80 Fig-2 : Showing partly opened (A) and fusly opened (B) mouth of a poisonous snake. Note the relative position ol the fang, maxilla, lower jaw, quadrate and squamosal, (C and D) Schemes showing the relative position of principal bones involved in the erection of fang. Fig-3: Different types of muscles in the mouth (c) Closing of mouth: This is brought about by the contraction of the temporalis muscles and sphenopterygoid muscles. The point of the fang is directed backward while the mouth is closed. It takes a longer time to open the mouth than to close it.

NSOU CC-ZO-04 81 6.7 Summary Reptiles are the true land vertebrates that left the habit of going to water for laying eggs. Sphenodon is regarded as a living fossil and is popularly know as "Hatteria" or "Tuatora". The poison apparatus of snakes consists of a pair of poison glands, their ducts and a pair of fangs. The mechanism of biting of snake is a complicated process and composed of— (i) opening of mouth; (ii) rotation of maxilla and (iii) closing of mouth. 6.8 Questions i) Write the characteristics of reptilians. ii) Classify reptilian up to order with distinctive characters and suitable examples. iii) Discuss about the affinities of sphenodon. iv) Write about the evolutionary position of sphenodon. v) What is parental care? vi) Write in brief about the parental care in amphibians. vii) Draw the poison apparatus in snake. viii) What is fang? ix) Discuss about the biting mechanism of poisonous snakes. 6.9 Selected readings 1) The life of vertebrates by J. Z. Young; Year: 1981. Published in India by Oxford University Press, New Delhi. 2) Biology of Animals (Volume-11) by Arup Kumar Sinha, Simananda Adhikari and Banku Behari Ganguly; Year 1991; Pub: New Central Book Agency. 3) Text Book of Zoology Vertebrates (volume-2) 7th Edition by T. Jeffery Parkar and Williama Haswell (Edited by Marshall & Williams) Year: 1995. Pub: AITBS Publishers & Distributors, New Delhi-110051. 4) Vertebrates Comparative Anatomy, Function, Evolution (Fourth Editon) by Kenneth V. Kardong. Year: 2010. Pub: Tata McGraw-Hill.

NSOU CC-ZO-04 82 Unit 7 Aves Structure 7.1 Objectives 7.2 Introduction 7.3 General characteristics and classification up to order 7.3.1 General characters of class aves 7.3.2 Scheme of classification of aves 7.4 Archaeopteryx-a connecting link 7.5 Migration in birds 7.5.1 Introduction 7.5.2 Definition 7.5.3 Types of migration 7.5.4 Causes of bird migration 7.5.5 Modes of migration 7.5.6 Range of migration 7.5.7 Altitude of migration 7.5.8 Velocity of migration 7.5.9 Regulation of migration 7.5.10 Routes of migration 7.5.11 Guiding mechanism in bird migration 7.5.12 Stimulants for migration 7.5.13 Problems of migration 7.5.14 Evolutionary significance of migration: 7.6 Flight adaptation in birds 7.6.1 Introduction 82

NSOU CC-ZO-04 83 7.6.2 Principles for aviation 7.6.3 Types of flight adaptations in birds 7.7 Summary 7.8 Questions 7.9 Selected readings 7.1 Objectives After studying this unit, learners would be able to understand the following— The characteristics of aves. The classification of aves. Archaeopteryx and its importance. Migration in birds. The evolutionary significance of migration of birds. The flight adaptation in birds 7.2 Introduction Birds, also known as aves or avian dinosaurs, are a group of endothermic vertebrates, characterized by feathers, toothless beaked jaws, hard shelled eggs, a four-chambered heart, and a strong light weight skeleton. They constitute a highly specialized group of vertebrates which have attained the peak of evolutionary perfection. Many species of birds are economically important as food for human consumption and raw material in manufacturing process. Domesticated and undomesticated birds (poultry and game) being important sources of eggs, meat, and feathers. Peacock is the national bird of our country. They are essentially "glorified reptiles" and the discovery of fossil of Archaeopteryx, amply speaks about the reptilian origin of birds. The present chapter deals with the general characteristics, classification, archaeopteryx-connecting link, flight adaptations and migration in birds.

NSOU CC-ZO-04 84 7.3 General characteristics and classification up to order 7.3.1 General characters of class aves 1) Body is covered with feathers and has three distinct divisions with a flexible neck. 2) Two pairs of limbs, the anterior pair modified as wings for flight, and the posterior pair adapted for perching, walking or swimming. 3) Each foot is usually with four toes. 4) Mouth opens through a projecting beak or bill provided with horny sheath. 5) The skeleton is strong, bones fully ossified, and pneumatic. 6) Skull with a single occipital condyle; sutures obliterated. 7) Pelvis fused with a number of vertebrae but open ventrally forming synsacrum. 8) Tail vertebrae few and compressed posteriorly forming pygostyle in modern birds. 9) Sternum enlarged, usually with a median keel. 10) Syrinx, the voice box, is situated at the base of the trachea. 11) The lungs are compact, attached to the ribs and connected to thin-walled air sacs extending between internal organs. 12) Heart is four-chambered with two atria and two ventricles. Unlike mammals, red blood corpuscles are nucleated. 13) Urinary bladder absent, excreta semisolid. 14) Females usually with only left ovary and oviduct. 15) Fertilization is internal. 16) Birds are oviparous animal. 17) Eggs with large amount of yolk, telolecithal; cleavage is meroblastic. 7.3.2 Scheme of classification of aves Different scientists classified aves based on the characters of different birds, but here we follow the classification given by Young (1981). The following is the schematic diagram of the classification of aves.

NSOU CC-ZO-04 85 Class Sub-class Suber-order Order Archiornithes Archaeopteygiformes Odontognathae Hesperornithiformes Ichthyornithiformes Struthioniformes Rheiformes Casuariiformes Palaeognathee Apterygiformes Dinornithiformes Aepyornithiformes Timaniformes Neornithes Impennae Spheniseiformes Gaviiformes Neognathae Podicipitiformes Procellariformes Pelacaniformes Ciconiiformes Anseriformes Faleconiformes Galliformes Gruiformes Caprinulgiformes Diatrymiformes Trogoniformes Charadriiformes Columbiformes Coraciiformes Psittaciformes Piciformes Cuculiformes Passeriformes Strigiformes Apodiformes Colliformes A V E S

NSOU CC-ZO-04 86 Subclass-1: Archiornithes Mesozoic ancestral or lizard birds with long tail and teeth in both the jaws. Order: Archaeopterygiformes General characters: 1) Forelimbs bear remiges. 2) Long tail with many vertebrae, which gradually taper to the distal end. The rectrices are arranged in two lateral rows on each side of the caudal vertebrae. 3) The carpals and metacarpals free and hand with three clawed digits. 4) The eyes were large. 5) Enamelled crowned teeth on both the jaws. 6) The sacrum made up of only about six vertebrae. 7) Thin abdominal ribs or gastralia or so-called ventral ribs were on ventral wall of abdomen. 8) The cerebral hemispheres smooth, long and narrow and cerebellum small. Examples: Archaeopteryx lithographica, Archaeornis siemensi. Subclass-2: Neornithes General characters: 1) Tail greatly shortened usually ending in a pygostyle, around which the rectrices are arranged in a semicircle. 2) Except a few extinct forms all are without teeth. 3) The sternum is well-developed and usually keeled or carinate. The sub class neornithes have been divided into four superorders: Odontognathae, Palaeognathae, Impennae and Neognathae. Superorder-1 : Odontognathae General characters: 1) Clavicle not fused. Sternum is without keel. 2) Both the jaws are with teeth.

NSOU CC-ZO-04 87 3) Flightless, specialized for swimming, about 150 cm in length. Order-1: Hesperornithiformes General characters: 1) Flightless; adapted for swimming. 2) Forelimbs with vestigeal humerus only. 3) The hind limbs laterally directed with webbed feet. 4) The pygostyle absent. 5) Teeth pointed, arranged in grooves in both the jaws, Premaxilla without teeth. 6) The quadrate single, basipterygoid process absent. 7) Sternum without keel. 8) Long neck provided with heterocoelous vertebrae. 9) Pectoral girdle much reduced, and clavicles not fused. Examples: Hesperornis, Hargeria, Neogaeornis, Baptornis, Enaliornis etc. Order- 2: Ichthyornithiformes General characters: 1) The neck vertebrae is amphicoelous. 2) The sternum had a well-developed keel, and the wings are unlike modern birds. 3) Clavicles fused. Examples: Ichthyomis, Apatormiis etc. Superorder-2 : Palaeognathae General characters: 1) The feathers are primitive, without hooked barbules. Barbs remain free. 2) The rectrices are absent or irregularly arranged. 3) The wings reduced in size or vestigeal or absent. 4) Pygostyle small or undeveloped. 5) The sternum is flat, raft-like.

NSOU CC-ZO-04 88 6) The coracoid and scapula are comparatively small and completely closed. 7) The vomer is large and broad and separates the palatines; which do not come in contact with the cranium. 8) The quadrate articulates with the skull by a single or partially divided facets. 9) The males are with erectile penis and the females have clitoris. The young are precocious. The superorder has seven orders. Order-1: Struthioniforms General characters: 1) Flightless, terrestrial omnivores with small wings, usually kept folded during running but may be expanded to act as a steering. 2) Head, neck and leg sparsely feathered. 3) Feathers are without after shaft. 4) Tail feathers are replaced by tail coverts. 5) Hind limbs are strongly built and only 2 toes (3rd and 4th) in each foot are present. 6) The sternum lacks keel. 7) Pubic symphysis present. 8) Pygostyle absent. Example: Struthio camelo Order-2: Rheiformes General characters: 1) Each foot with three front toes, webbed at the base. 2) Sternum un-keeled. 3) At nesting a male defends 3-7 females, digs nest and all females lay about 50 lemon-yellow eggs in the same nest; male incubate them for about 40 days.

NSOU CC-ZO-04 89 Example: Pteronemia pennata. Order-3: Casuariiformes General characters: 1) Flightless, terrestrial, running herbivore birds with comparatively small wings supported by a single digit. 2) The neck and body densely feathered. 3) Feathers with after shaft nearly equal to shaft. 4) With incomplete lining of feathers on neck; inner one of the three toes is a defensive structure, provided with claw. Example: Dromaeus (Emu), Casuarius etc. Order-4: Apterygiformes General characters: 1) Relatively small, almost wingless, hen like, nocturnal, omnivorous running birds. 2) Bills long and slender with nostril at the tip. 3) Wings degenerated with vestigeal humerus, only one digit and no flight feathers. 4) Each leg bears four-clawed toes. 5) Body plumage fluffy, hair-like, without after shafts. 6) Sternum un-keeled. The eyes are small. 7) Lays only one white egg at a time. Eggs are largest of all the living birds. Example: Apteryx (Kiwi). Order- 5: Dinornithiformes General characters: 1) Feathers with large after shafts and without barbicels. 2) Beak short. 3) Hind limbs massive with four toes. 4) Sternum reduced and un-keeled. Coracoid, scapula and wing bones reduced or absent.

NSOU CC-ZO-04 90 Example: Dinornis. Order-6: Aepyornithiformes General characters: 1) Giant flightless Madagascar elephant birds. 2) Wings were relatively tiny but legs stout and powerful and with four toes. 3) Egg are largest of all known animal eggs; capacity about 10 litres. Example: Aqjyornis Order-7: Tinamiformes General characters: 1) Partridge are quail-like, almost tailless, herbivores, essentially cursorial birds. 2) Sternum is keeled, and the palate palaeognathus. 3) Pygostyle reduced. 4) The eggs with glossy white shell and incubated by males. Examples: Crypturellus, Eudromea etc. Superorder-3: Impennae Evolved from ancestors having wings used for both swimming and flight and gradually changed to form an effective paddle for swimming. The superorder has only one order. Order-1: Spheniseiformes General characters: 1) Body streamlined, and offers least possible resistance to diving and submarine activities. 2) Closely packed plumage; feathers small, scale-like, dense, over entire body without apteria. 3) Hind limbs modified for swimming; The feet are strongly webbed. 4) The integument is provided with, thick, fatty, insulating layer. 5) The bones, excluding certain skull bones, are solid. 6) Air sacs absent.

NSOU CC-ZO-04 91 7) The bones of featherless wings flattened and united to form a powerful, resistant paddle or flipper moving only at the shoulder joint. 8) Monogamous and one egg is laid at a time. Feed on fishes, crustaceans, squids, etc. Examples: Aptenodytes, Pygoscelis, Eudyptes, Eudyptula, Spheniscus etc. Superorder-4: Neognathae General characters: 1) Modern birds with well-developed wings, keeled sternum, and fully adapted for flight. 2) Beaks without teeth. 3) Slender vomer separates the palatines imperfectly. 4) The palatines are protruded posteriorly and in contact with the base of cranium and remain movably articulated with small pterygoids. 5) Tail vertebrae 5 or 6. 6) Pygostyle absent. 7) Forelimbs with metacarpals joined, and fingers included in wings. Order-1: Gaviiformes General characters: 1) Piscivorous birds adapted for diving and swimming. They are capable of flight. 2) The neck is long. Legs are posteriorly placed and completely encased with skin. 3) The digits webbed; wings short. 4) Eggs are laid in nests among piles of vegetation. Example: Gavia Order-2: Podicipitiformes General characters: 1) Fresh water, compact-bodied animals. 2) Toes lobate.

NSOU CC-ZO-04 92 3) The reduced tail bears degenerated tail feathers. 4) Lungs are placed far back. Examples: Podiceps, Aechmophorus, Podilymbus, Centropelara etc. Order-3: Procellariformes General characters: 1) Long-winged sea birds; come to land only in breeding season and build-up nest in holes. 2) Nostril tubular, arid horny sheath of hooked bill composed of several plates. 3) Hind toe vestigeal or none (as in diving petrels). 4) Plumage compact and oily. 5) Wings long, narrow, span may be over three metres. Examples: Diomedea, Puffinus, Pelecanoides etc. Order-4: Pelecaniformes General characters: 1) Voracious fish-eaters. 2) Nostril vestigeal or absent. 3) A gular pouch or throat is present, except in tropical birds. 4) In pelicans, body is heavy, long pouch used to scoop fishes from water. Examples: Pelecanus, Phalacrocorax, Sula, Anhinga, Fregata, Phaethon etc.. Order-5: Ciconiiformes General characters: 1) Long-necked body. 2) They are either with decorative plumages, bare areas on head (storks); bill abruptly de-curved at middle (flamingos). 3) The pattern of beak varies and with sharp cutting edges. 4) Except flamingos web between the toes are absent.

NSOU CC-ZO-04 93 5) Speedy fliers; legs adapted for quick walking on mudflats. Examples: Ardea, Egretta, Nycticorax, Phoenicopterus etc. Order-6: Anseriformes General characters: 1) All are efficient fliers and almost cosmopolitan in distribution. 2) Body covered with soft cornified epidermis containing numerous sense pits with harder cap at tip. 3) Tongue fleshy, legs short. 4) Feet webbed. 5) The tail is usually short and many feathered. Examples: Ansera, Coscoroba, Mergus, Oxyura etc. Order-7: Falconiformes General characters: 1) Powerful, predaceous birds are distributed almost everywhere except Antarctica. 2) Mandible sharp-edged. 3) Feathers are stiff. 4) Eyes laterally placed and with extremely sharp power of vision. 5) Mostly monogamous. Females incubate eggs. The males feed the females during incubation. Examples: Gypes, Gymnogypes, Aegypices, Falco, Accipiter etc. Order-8: Galliformes General characters: 1) Gregarious, non-migratory, ground dwelling game-birds, cosmopolitan in distribution. 2) The head is small and body compact. 3) The legs are massive, clawed and used for scratching soil for searching food. 4) Three toes are anteriorly directed.

NSOU CC-ZO-04 94 5) Wings, in the majority, short and round. 6) The beaks are strong built, arched, suitable for picking up grains or seeds. 7) Males are aggressive polygamous. Examples: Crax, Lagopus, Alectoris, Opisthocomus, etc. Order-9: Gruiformes General characters: 1) Small size, weak flight, or flightless. 2) Toes are not webbed. 3) Nest may be built on the ground. Examples: Grus (Cranes), Rallus, Fulica, Gallinula, Turnix, Monias, etc. Order-10: Diatrymiformes General characters: 1) Large flightless terrestrial birds. 2) Massive head, beak and neck. Example: Diatryma. Order-11: Charadriiformes General characters: 1) Plumage dense and firm. 2) Toes usually webbed, at least at the base. 3) More or less long-legged (shore birds), strong-winged (gulls), or with only three toes and legs far back in position. 4) Eggs heavily spotted. Examples: Charadrius, Jacana, Rostratula, Haemantopus etc. Order-12: Columbiformes General characters: 1) The wings are long, pointed and enable the birds to make sustained flight at a

NSOU CC-ZO-04 95 great speed. 2) Bills short and slender; the base of beak covered by a soft skin bearing longitudinal slit-like nostril called cere. 3) The head and neck small and compact. 4) Legs are small. All the toes lie in same plane and are provided with straight tarsus usually shorter than toes. 5) The crop is large producing 'pigeon milk.' 6) Monogamous but lives in groups. 7) Usually lay 2-3 eggs; both male and female incubate the eggs. Examples: Columbia, Pterocles, Syrrhypta, Streptopelia, Didunculus etc. Order-13: Psittaciformes General characters: 1) Adapted for arboreal life and can also climb. 2) Loud-voiced birds, chiefly frugivorous with brilliant plumage of green, blue, yellow or red. 3) Beak stout, narrow, sharp-edged, and hooked at the tip used for climbing. 4) The upper mandible is movably articulated with the frontal bone of the skull. 5) Bill with soft cere, often feathered. 6) The toes two in front and two behind, the outer hind toe is not reversible and used for grasping. 7) Live in flocks, but strictly monogamous. 8) The nest is built in the holes of trees. 9) The young are nourished till they attain maturity. Examples: Ara (Macaw), Kakatoe, Psittacula, Nestor, Rhynchopsitta etc. Order-14: Cuculiformes General characters: 1) Toes are two in front, and two behind. Outer toe reversible; the feet are not adapted for grasping.

NSOU CC-ZO-04 96 2) Bill moderate, tail long. 3) Many old-world cuckoos are parasitic, thfe females lay eggs in the nest of other birds like crow. Examples: Cuculus, Chalecites etc. Order-15: Strigiformes General characters: 1) Plumage sofit-textured. 2) Head large and round. 3) The beak is short. 4) Feet adapted for grasping, claws sharp. 5) Ear openings large, often with flap-like cover, sometimes asymmetrical. 6) Eyes large, round, directed forward and each in a disc of radial feathers. 7) Retina contains principally rods to perceive low intensity light. 8) The prey is swallowed whole. 9) Eggs are white. Nests are built in holes of trees or buildings. Examples: Bubo, Tyto, Asio, Otus, Nyctea etc. Order-16: Apodiformes General characters: 1) Legs very short, feet very small, wings pointed and bills small and weak (swifts) or slender with long tubular tongue (humming birds). 2) In swifts the mouth is broad and eyes are large. 3) In humming birds, plumage is brilliant, iridescent, specially on head and neck of males. 4) Feed on nectar, small insects and spiders from the blossom by tubular protrusible tongue and needle-like bill. 5) Eggs are white. Examples : Apus, Cypsiurns, Chaetura etc.

NSOU CC-ZO-04 97 Order-17: Coliiformes General characters: 1) Small body, passerine-like, colies or mouse birds with short legs, sharp curved claws. 2) The first and fourth toes reversible, which help in creeping on trees. 3) The feathers hair-like and soft; tail very long. 4) Usually a crest is present on the head. Example: Colius. Order-18: Trogoniformes General characters: 1) The bills are short, and stout with bristles at the base. 2) The tip of the beak hooked and, in some, indented. 3) Feet small and weak. The first and second toes are directed backwards and third and fouth toes anteriorly placed. 4) Feathers soft and lax, help in noiseless flight. 5) Tail long and stiff, supports against vertical surface at the time of digging. Examples: Herpaetes, Hypodermes, Calures etc. Order-19: Coraciiformes General characters: 1) In most, wings and legs are short and beak long. 2) In some, anteriorly directed toes are fused at the base (syndactylous) and in others one of the toes is reversed (zygodac-tylous). 3) Nests are built in holes of trees, etc. Examples: Alcedo, Ispidina, Dacelo, Chlorocerle etc. Order-20: Piciformes General characters: 1) The feet is zygodactylous. Second and third toes are directed forward and first and fourth pointed backward.

NSOU CC-ZO-04 98 2) Tail feather stiff with pointed tips. 3) Bill stout, tongue protrusible, roughed, or with barbs near tip. Examples: Picus, Sphyrapicus, Pynx, Ramphastos etc. Order-21: Passeriformes General characters: 1) Small perching birds or passerines, adapted to various habitats and distributed widely. 2) All are adapted for land life and the four digits remain in the same level. Examples: Muscivora, Passer, Fringilla, Aethopyga etc. Order-22: Caprinulgiformes General characters: 1) Colouration protective, helps the bird in concealing. 2) Plumage soft-and arranged in the fashion of that of owl. 3) Legs and feet small and weak, not adapted for grasping. 4) Bills are small, delicate, but the mouth opening wide and margined with long bristle-like feathers with specialised sensory receptors. Examples: Podargus, Nyctibius, Nyctidramus etc. 7.4 Archaeopteryx- a connecting link Archaeopteryx, meaning "old wing", is a genus of bird-like dinosaurs that is transitional between non-avian feathered dinosaurs and modern birds. The name derives from the ancient Greek "archalos" meaning "ancient", and "pteryx" meaning "feather" or "wing". Archaeopteryx- a connecting link (missing link) between reptiles and birds and it possess both the reptilian and avian characters. The reptilian and avian characters of Archaeopteryx are as follows: I. Reptilian characters: (i) Jaws are provided with homodont teeth; (ii) Long lizard like tail with twenty free caudal vertebrate;

NSOU CC-ZO-04 99 (iii) Bones are not pneumatic; (iv) Cervical vertebrae are 9-19 in number; (v) Amphicoelous vertebrae as in Sphenodon; (vi) Cervical and abdominal ribs are present. Ribs are single headed and without uncinate process; (vii) Sternum is weak or absent; (viii) Eyes are provided with sclerotic ossicles; (ix) Scales are present; (x) Carpels and metacarpals are free; there is no carpo-metacarpus; (xi) Pelvic girdle has an elongated ilium and a backwardly directed pubis. II. Avian characters: (i) Presence of feathers; (ii) Fore limb are modified as wings; (iii) Tail bears two rows of feathers; (iv) Brain case is rounded; (v) Bones in the skull is intimately fused; (vi) Beaks are present; (vii) Bones in the limbs and girdles are bird like (viii) A keel is present in the sternum; (ix) Tibia and fibula are separate; (x) V-shaped furcula is present. 7.5 Migration in birds 7.5.1 Introduction Migration is the seasonal or periodical mass movement of the animals away from and back to their natural habitat. The word migration means going from one place to another. Almost all the group of animals showing migratory habit, but birds are the classical example of animal migration. In bird, "migration" means two ways journeys,

NSOU CC-ZO-04 100 onward journey from "home" to " new places" and back journey from "new places" to "home". This movement occurs in the particular period of the year and birds usually follow the same route. 5.2 Definition Migration is one of the marvelous achievement of birds flight. Although this phenomenon is defined in many ways but Thompson has described bird migration as follows - "changes of habitat periodically, retuning at internal recurrent and alternative in direction which tend to serve optimum ertvironmental condition at all time". 5.3 Types of migration Birds migrate in a variety of ways. Following kinds of avian migration have been recognized by different ornithologists. I. Seasonal migration A. Latitudinal migration: In this type of migration, the direction is usually from northern, to southern hemisphere or from southern to northern pole. The distance is from few kilometers to thousands of kilometers. In terms of the occurrence of birds in an area bird species are : (i) Permanent resident: Species representing in an area throughout the year even though some individuals migrate. (ii) Summer resident: Species present only during the wormer part of the year, which includes breeding season, that may extend from early spring to late autumn. (iii) Winter visitor: Species, present only during winter or non-breeding period of the year, e.g, spot tail duck, brown headed plovers. (iv) Transient visitor: Species present only during the certain period which is neither the summer or breeding season nor the winter. E.g., Golden plover, Sand piper. (v) Accidental visitor: Species of birds that are rarer, irregular in occurrence. B. Altitudinal migration: Here the birds of high altitude migrate to low altitude and again return back to the high altitude, is known as altitudinal migration. The range of migration is about few kms up and down slops of the mountain. This is particularly marked among species of Himalayan range.

NSOU CC-ZO-04 101 C. Longitudinal migration: Longitudinal migration is also called East-West migration. This migration is found in the birds of southern hemisphere. Sea birds undergo this sort of migration. D. Erratic migration: Erratic, vagrant, irregular or wandering migration occurs in birds like great Blue Heron, Cuckoos, Plover etc. Here the birds do not follow the different laws of migration and hereby migration occurs in a haphazard manner. In such birds the adults and young ones may start from their home to disperse in any direction over a few hundred miles in search of food. E. Local migration: Local migration does not necessarily involved a change of latitudinal or altitudinal and is often quite limited in the distance covered. It may be due to seasonal changes, i.e., draught, heavy rains etc., or due to scarcity of food and water. E.g., Hawks, Pegions, Swifts, Swallows. II. Special type of migration Apart from the above mentioned types of migration there are some special types of migration like- A. Alimental migration: This occurs as a result of storage of food and water and may occure at any time of the year. E.g., Insectivorous birds. B. Climatic migration: Migration due to climate change of the environment daily or seasonally. C. Gonadal migration: This results from a need to occupy some special region or environment for some parts of the reproductive process. D. Lumar migration: Some marine birds migrate under the influence of tides rather than calendar year. 7.5.4 Causes of bird migration Generally the environmental factor is the main causative factor for bird migration. The following are believed to play an important role in bird migration. 1. Scarcity of food: Lack of food leads to migration of birds. Insectivorous birds migrate to other areas before the insects go into hiding to avoid the cold. Scarcity of food in winter in the northern hemisphere is a cause of bird migration in many cases, but the aquatic species leaves the northern hemisphere much before their food supply is cut off by the freezing of lakes, ponds and rivers.

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NSOU CC-ZO-04 102 2. Climatic change: Sudden or abrupt climatic changes or seasonal changes might compete the birds to migrate. Increase of cold might also be a cause of migration. 3. Breeding purpose: It is possible that birds migrate to favourable place to complete their breeding cycle as their original home has become unfavourable for breeding either to seasonal changes, decrease in day length or due to other factors. 4. Increased population: Increased population of a particular area is also another cause of bird migration. 7.5.5 Modes of migration A. Nocturnal migration: Some birds migrate only during night. During day time they take rest, procure food and then start to migrate again at night. Most song birds are nocturnal travelers that probably fly singly or widely spaced, loose groups. They initiate a fly of 30 minutes to 1 hour after sun set and fly continuously throughout most of the night covering approximately 300-600 km on each night of travelling. An individual usually does not fly each night. Example: Wood cocks, Wood piecers. B. Diurnal migration: There are birds which migrate only during day time starting their journey with sunrise. These diurnal migrants are known to fly in flocks and to follow along to propagate leading lines and become tired along their migratory route in a series of discrete one day flight. 7.5.6 Range of migration The range of migration varies among different birds. It may vary from one or few miles to thousands of miles. It depends upon the local climate condition and also the natural wind current. Example: (i) The Himalayan snow partidages cover a distance of only 1-2 miles during migration. (ii) The golden plover covers a distance of 11,250 km and the Arctic tern covers a distance of 22,500 km during migration. (iii) Penguins migrate by swimming about few hundred kilomiters. (iv) Swallows from North Europe to South Africa covers 8,650 km. (v) Cuckoo breeds in India and spend summer in Africa covering a distance of 7,250 km.
NSOU CC-ZO-04 103 7.5.7 Altitude of migration Diurnal migrants cover an altitude of 3000-14000 ft. However, nocturnal migrants cover an altitude of 5000-14000 ft. 7.5.8 Velocity of migration The flight speed of birds during migration varies in different groups of birds. It depends on the size of the birds and is affected by wind speed and wind direction. For example, Cranes and Finches fly with an average speed of 30 miles per hour. Maximum speed is attained by Indian swifts whose speed is about 170 miles per hour. 7.5.9 Regulation of migration Several species of migratory birds show a striking regularity year after year in their timings of arrival and departure. These birds normally migrate during particular time of year with very slight deviations. 7.5.10 Routes of migration Most species of birds usually follow definite routes of flight during migration. The routes are as follows— (i) Sea route: This rout is used by different birds. (ii) Coast birds: Afford migration highways from a large number of migrants. (iii) River and river valley routes: Migrating from planes to the hills and from the hills to the planes. During migration the birds cross rivers and river valleys following them as part of their routes. (iv) Mountain range: Few birds cross mountain ranges during migration. 7.5.11 Guiding mechanism in bird migration Birds have wonderful power of navigation and orientation. Even under odd conditions they do reach specific breeding and wintering destinations with grept regularity. Different theories have been proposed that birds are guided by a number of factors. A. Topographic landmarks: Diurnal migrants are influenced by general topographic features such as, rivers, river-vallys, coast lines, mountain range etc. Birds have quite good visual activity and have been shown to be capable of recognizing salient feature of the terrain and of remembering this information for long periods of time. This system

NSOU CC-ZO-04 104 is useful only for traversing areas, that have already become familiar as a result of previous flights. B. Sun orientation: The sun is an extremely important directional cue for diurnally migrating and homing birds. In principle, the sun could provide the necessary map information as well as serving as a compass. The general use of the sun appears to be as a dominant cue for maintaining a bearing that is determined by some other means. C. Stellar navigation: The birds are exclusively guided by the stars during night. Sauer (1958) suggested that the birds like warbler possess hereditary mechanism to orient themselves by the stars during nocturnal migration. It is possible that birds find their compass direction by reference the orientation by star patterns. D. Geomagnitism: Some ornithologists have suggested that the Earths magnetic field plays an important role in bird orientation. Griffith (1948) suggested that birds are sensitive to the Earths magnetic field and are guided by it. 7.5.12 Stimulants for migration Different factors have been advocated as the stimulants for migration. 1. Gonodal stimuli: It is widely accepted that migration towards the breeding ground is associated with gonadal changes and that the sex hormones play a primary stimulatory role in bird migration. Rowan (1931) first proposed that spring migration is stimulated by hormones secreted by developing gonads as that autumn migration is caused by gonad regression. However, available evidence suggests that gonads and sex hormones do not play a primary regulatory role in bird migration in general. 2. Endocrinal stimuli: Migration may be possibly stimulated by the endocrine system. The pituitary may play a primary regulatory role in migration. Gonadotrophin as well as the neurosecretary material of the hypothalamus before migration may act as a trigger for migration. 3. Photoperiodism: Photoperiodism is the response of living organism to the relative duration of cycles of light and darkness. The varying day length causes gradual change and fat deposition in birds, which may trigger the urge to migrate. 7.5.13 Problems of migration Factors, both man made and natural, may cause great problems to migratory birds. These are stromes and hurricans, strong currents of winds, fog, man made towers and light houses, etc.

NSOU CC-ZO-04 105 7.5.14 Evolutionary significance of migration 1. It will reduce the population density and allows the weaker individuals to survive specially who can not take part in migration. 2. Migration may sometimes lead to the isolation and make opportunity for the formation of new species. 7.6 Flight adaptation in birds 7.6.1 Introduction In many respecs birds are the most highly specialized animals of the craniates class. According to Young (1958) birds are regarded as the " masters of the air". Amongst every part of their organization is modified in accordance with the aerial mode of life. They have become flying machines largely through the evolutionary gifts of feathers, wings, hollow bones, warm blooded, a remarkable system of respiration, a strong large heart and powerful breast muscles. These modifications have fulfilled two primary requirements for any flying machine, high power and low weight. 7.6.2 Principles for aviation A. Downward pull of gravity: The flying animal must overcome the downward thrust of gravity which is the problem of first importance. B. Sustaining surface: Flying animas must have a flight surface either in the form of a membrane or specialized structures like the feathers. C. Lightness: The animals must be comparatively light particularly in relation to the strength of the muscles, that move the wing. They should have a well developed mechanism for wing movement and flight control. D. Body contour: The shape of the flying animal should be such as to provide minimum resistance against air. E. Maintenance of balance and steering: Flying animals must maintain balance and steer while propelling forward. F. Perfection of sense organs: Specialization of entire system is required to guide balance, vision, etc.

NSOU CC-ZO-04 106 G. Body metabolism: High rate of body metabolism is required to convert chemical energy into mechanical energy. 7.6.3 Types of flight adaptations in birds The bird provides both morphological and anatomical adaptations for flight. The following are the modifications in birds. I. Morphological adaptations: 1. Body contour: The birds have a spindle-shaped body to offer less air resistance during flight. This helps the birds to conserve energy and become more efficient at flying. 2. Compact body: The body of a bird is compact, dorsally strong and ventrally heavy to maintain equilibrium in the air. Their wings are attached on the thorax, the light organs like lungs and sacs are positioned high, heavy muscles placed centrally are other features that help in flight. 3. Body covered with feathers: The feathers are smooth, directed backwards, and closely fitting which make the body streamlined and reduce friction during flight. It lightens the body weight and protects it from the effect of environmental temperature. They also have a wide surface area for striking the air. Feather insulates the body and prevents any loss of heat from the body. This helps the birds to bear low temperatures at higher altitudes. Fig.1 : Different types of feathers 4. Forelimbs modified into wings: The forelimbs are modified into wings which is the only organ of flight. These consist of a framework of bones, muscles, nerves, feathers, and blood vessels. The wings have a large surface area, which support the bird

NSOU CC-ZO-04 107 in the air. The wings have a thick strong leading edge with a concave lower surface and a convex upper surface. This helps in increasing the air pressure below and reducing the air pressure above. Thus the bird can fly upward and forward during flight. Fig. 2: Organisation of feathers 5. Mobile neck and head: The birds have a long and flexible neck which helps in the movement of head important for various functions. They possess a horny beak which helps them to pick the grains and insects while feeding. 6. Bipedal locomotion: The anterior part of the body of a bird helps in taking off during flight. The anterior part of the body also helps birds to land. The hind limbs help in the locomotion on land and support the entire body weight of a bird. 7. Perching: While sitting on the branch of a tree, the toes of birds wrap around the twig. This is known as perching. The muscles are so well-developed that a bird can sleep in that position without falling. 8. Short Tail: The tail bears long feathers that spread like a fan and function as a rudder during flight. They also help in balancing, lifting, and steering while flying and perching. II. Anatomical adaptations 1. Flight muscles: The well-developed muscles control the action of the flight muscles. It is so well developed that it weighs about 1/6th of the whole body of bird. The flight muscles are striated. Additionally, the muscles on the wings are large. Other muscles help the above muscles in functioning.

NSOU CC-ZO-04 108 2. Light and rigid endoskeleton: The birds have a very stout and light skeleton. The bones are hollow, filled with air sacs. They are provided with a secondary plastering to increase their rigidity. The bones are fused and lack bone marrow. The birds lack teeth. The thoracic vertebrae are fused except for the last one. This plays an essential role in the action of wings striking the air. 3. Digestive system: The birds have a very high rate of metabolism. Therefore, food digests rapidly. The length of the rectum is reduced because of the minimum undigested waste. Birds have no gall bladder which reduces the weight of the bird. 4. Respiratory system: The respiratory system of birds is designed in such a manner that the food is oxidized rapidly and a large amount of energy is liberated. Since the metabolism rate is high, a large number of oxygen molecules are required by the body. For this, the lungs are provided with air sacs. Presence of air-sacs is one of the important characteristics of birds. Fig-3 : (a) The major muscles for flight (b) Air sacs in birds 5. Circulatory system: Rapid supply of oxygen is required by the blood due to rapid metabolism rate in birds. Therefore, birds require an efficient circulatory system. (a) (b)

NSOU CC-ZO-04 109 Birds have a four-chambered heart that performs double circulation. This prevents the mixing of oxygenated and deoxygenated blood. Also, the birds contain a large amount of haemoglobin in their nucleated red blood cells which helps in the quick aeration of body tissues. 6. Homoithermous: The temperature of the body of a bird remains high and does not change with the change in the environment. This facilitates the birds to fly at very high altitudes. 7. Excretory system: The nitrogenous waste is converted to less toxic organic compounds such as uric acid. They have no urinary bladder. The uriniferous tubules efficiently absorb water. 7.7 Summary Birds constituting a specialized group of vertebrates evolved from reptiles during Mesozoic era. The invasion of bird into the air was a remarkable incidence in geologic past. True adaptation into the aerial life only possible by modifications of almost every part of the body together. All such modified parts have their own contribution during flight and if any one of these is disturbed, the whole set up may be disturbed leading to loss of flight. Thus not only air sacs or feathers or pneumaticity, but the coordinated function of all the modified parts render true flight. 7.8 Questions i) Write the general characteristics of class aves. ii) Classify aves up to order with distinctive characters and suitable example. iii) Discuss that "Archaeopteryx-a connecting link". iv) Write in brief about the migration in birds. v) What is flight adaptation? vi) Write a brief note about flight adaptation in birds. 7.9 Selected readings 1) The life of vertebrates by J. Z. Young; Year: 1981. Published in India by Oxford University Press, New Delhi

NSOU CC-ZO-04 110 2) Learning birds through latest portfolio.of theory and practice. Edited by P.K. Verma and Nandita Pande (Editor-in-Chief: Brian Jenkins); Year: 2002; Pub: Dominant Publisher and Distributors, New Delhi-110002 3) Biology of Animals (Volume-II) by Arup Kumar Sinha, Simananda Adhikari and Banku Behari Ganguly; Year l991; Pub: New Central Book Agency 4) Text Book of Zoology Vertebrates (volume-2) 7th Edition by T. Jeffery Parkar and Williama ; Ecited by Marshall & Williams) Year: 1995. Pub: AITBS Publishers & Distributors, Nev. Delhi-110051 5) Vertebrates Comparative Anatomy, Function, Evolution (Fourth Editon) by Kenneth V. Kardong. Year: 2010. Pub: Tata McGraw-Hill

NSOU CC-ZO-04 111 Unit 8 Mammals Structure 8.1 Objectives 8.2 Introduction 8.3 General characters and classification up to order 8.3.1 Definition of classification 8.3.2 General characters of mammals 8.3.3 Scheme of classification of mammals 8.4 Affinities of prototheria 8.4.1 Introduction 8.4.2 Reptilian affinity 8.4.3 Avian affinity 8.4.4 Mammalian affinity 8.4.5 Concluding remarks 8.5 Adaptive radiation with reference to locomotory appendages 8.5.1 Definition of adaptive radiation 8.5.2 Adaptive radiation in limb structure of mammals 8.5.3 Remark 8.6 Summary 8.7 Questions 8.8 Selected readings 8.1 Objectives After studying this unit, learners would be able to understand the following— The characteristics of mammals. The classification of mammals. 111

NSOU CC-ZO-04 112 The affinities of prototheria. Idea about the adaptive radiation in mammals. The adaptive radiation in mammals with reference limb structure. 8.2 Introduction Mammals (Latin mamma means "breast") are vertebrate animals constituting the class-Mammalia, and is characterized by the presence of mammary glands which in females produce milk for feeding (nursing) their young, a neocortex (a region of the brain), fur or hair, and three middle ear bones. These characteristics distinguish them from reptiles and birds, from which they diverged in the late Triassic period. The modern mammalian orders arose in the Paleogene and Neogene periods of the Cenozoic era, and have been among the dominant terrestrial animal groups from 66 million years ago to the present. Most mammals are intelligent, with some possessing large brains, self awareness and use tools. The present chapter will discuss about the general characters of mammals, classification of mammals, affinities of prototheria, adaptive radiation with reference to locomotory appendages mammals. 8.3 General characters and classification up to order 8.3.1 Definition of classification Classification means the ordering of animals into the definite groups on the basis of their similarity and interrelationship. 8.3.2 General characters of mammals 1. Body covered by epidermal hair. 2. Integumentary glands are mainly, sweat (sudoriferous), sebaceous (oil), scent (odoriferous) glands. 3. Mammary glands are present. 4. External pinna is present. 5. Eyes with upper and lower eyelids and often with eyelashes. 6. Nictitating membrane is translucent and hairless; it is vestigial in higher mammals.

NSOU CC-ZO-04 113 7. A muscular diaphragm is present in between the thoracic and abdominal cavities. 8. Endo-thermal homoeothermic animals. 9. Red blood corpuscles are non-nucleated, biconcave and usually circular in form. 10. Four-chambered heart is highly powerful. 11. Only left aortic arch is present in the arterial system. 12. Cerebral hemispheres are very large and highly convoluted. 13. Cerebellum is large, complex and solid. 14. Presence of a single urinary bladder. 15. Testes remain in scrotal sacs except in prototheria. 16. Small eggs are devoid of yolk. 17. Fertilization is internal. 18. Viviparous animals. 19. The skull has double occipital condyles. Quadrate absent. 20. A bony palate is formed by the union of premaxillae, maxillae and palatines that separates the nasal passage from the buccal cavity. 21. The lower jaw is composed of a pair of bones; the dentaries. 22. Vertebrae are acoelous type. 23. Ribs are double-headed-capitulum and tuberculum. 24. The teeth are heterodont, thecodont and diphyodont type. 25. Paired forelimbs and hind limbs are present. 26. The digits of the limbs are provided with either claw or nail or hoof. 27. Twelve pairs of cranial nerves. 28. Kidneys are metanephric type. 8.3.3 Scheme of classification of mammals In the present text, classificatory scheme of mammals as proposed by J. Z. Young (1981) is followed. For description, only living groups are considered. The extinct groups are marked with asterisks (*).

NSOU CC-ZO-04 114 Subclass-1: Prototheria (Greek: protos = first, therion = beast) General characters: (i) The females lay eggs. (ii) The testes are abdominal. (iii) The cloaca receives the openings of urinary bladder, vas deferens and ureters. (iv) Ribs are single headed. (v) The mammary glands lack teats. (vi) External pinna absent. (vii) In childhood, teeth are present but in adults teeth are lacking.

NSOU CC-ZO-04 115 This subclass includes four orders of which only monotremata is the only living group. Order: Monotremata General characters: (i) Body is covered over with soft hair. Hair on the dorsal side may be coarse or spine-like. (ii) Webbed digits are ended in sharp claws. (iii) Pinna is distinct but small. (iv) Brain lacks corpus callosum. (v) Tail may be present or absent. (vi) Dental formula: i = 0/5, c = 1/1, p = 2/2, m = 3/3. (vii) Eggs are large and undergo meroblastic cleavage. (viii) Tongue is long and sticky. (ix) Sutures are obliterated in the skull. Examples: Ornithorhynchus, Tachyglossus, Zaglossus, Echidna etc. Subclass-2: Theria (Greek: therion = beast) General characters: (i) Females do not lay eggs but give birth to young ones. (ii) Mammary glands are provided with nipples or teats. (iii) Pinna or external ear is present. (iv) The ureters open directly into the urinary bladder. (v) Teeth are present throughout the life period. (vi) Testes are situated in the scrotum. (vii) Ribs possess two heads for articulation with vertebrae. This subclass includes three infraclasses, of which pantotheria is extinct. Infraclass-1: Metatheria (Greek: Meta = next to) General characters: (i) The youngs are born in an immature condition and undergo further development in the marsupium of females.

NSOU CC-ZO-04 116 (ii) Mammary gland with teats and opens into the marsupium. (iii) Epipubic bone of the pelvic girdle protects the marsupial sac. (iv) Placenta is chorioviteline type. This infraclass includes single order. Order: Marsupialia (Latin: Marsupium = a sac) General characters: (i) Body in covered with soft fur. (ii) Pinna is well developed. (iii) Most of the female members possess marsupium. (iv) Tail is well-developed and helps in balancing. (v) The fourth toe is largest. All digits are clawed. (vi) Forelimbs are shorter than the hind limbs. (vii) Dental formula is: i = 5/4, c = 1/1, p = 3/3, m= 4/4. (viii) Caudal vertebrae are with chevron bone. (ix) Atlas is incomplete and is provided with cartilage in the ventral incomplete side. Examples: Macropus (Kangaroo), Didelphis (Opossum), Petaurus (Flying opossum) etc. Infraclass-2: Eutheria (Greek: eu = true) General characters: (i) The youngs pass through a considerable period of prenatal growth. (ii) Brain is highly-developed; the two hemispheres are connected by corpus callosum. (iii) The anal and urinogenital apertures are separate. (iv) The tympanic bone is ring-like and forms a tympanic bulla. (v) Dental formula is: i = 3/3, c = 4/1, pm = 4/4, m = 3/3. In some cases teeth are absent. (vii) Epipubic bone in the pelvis is absent.

NSOU CC-ZO-04 117 Cohort: Unguiculata General Characters: (i) These eutherians possess nails or claws in their digits. This cohort contains six living orders. Order-1: Insectivora (Latin: insecta = in sects; voro = to eat) General characters: (i) Body covered with hair, some possess dorsal spines which are modified hair. (ii) Nocturnal and insectivorous animals. (iii) Skull is constricted in the middle. (iv) The zygomatic arch and bony palate are incomplete. (v) Teeth have sharp molar cusps. (vi) Each limb possesses five digits with claws. (vii) Locomotion is plantigrade type. (viii) Caecum in the intestine is small or absent. (ix) Scrotum is absent and the testes are internally situated. (x) Uterus is bicornuate type. (xi) Mammary glands are many and are distributed all along the two milk-lines on the ventral surface. Example: Talpa (Mole), Tupaia (Tree-shrew), Erinaceus (Hedgehog) etc. Order-2: Chiroptera (Lptin: cheir = Hand; pteron = wing) General characters: (i) The forelimbs are modified to form wings. (ii) The bones of the digits of the forelimbs are elongated except pollex. (iii) These bones support a membrane that runs between forelimbs and hind limbs. This membrane is called as patagium. (iv) An inter-femoral membrane is present between the femurs. It is supported by a cartilaginous calcar of the ankle.

NSOU CC-ZO-04 118 (v) A short tail is often included in the inter-femoral membrane. (vi) Pollex is small, free from the wing and bears claw. (vii) The hind limbs are weak, having five clawed-digits. (viii) Pinna is well-developed. (ix) Nocturnal animals and are able to fly and catch prey in the dark with the help of their special radar system. This capacity is called echolocation. (x) The sutures of the skull is obliterated. (xi) The ribs are flat and fused with the vertebrae to become rigid during flight. (xii) The hind limbs are rotated, so the knee is directed backward. (xiii) The testes are abdominal in position. (xiv) Only one young is born at a time. (xv) The sternum is provided with a flat keel for the attachment of pectoral muscle. Examples: Pteropus (Fruit bat), Rhinolophus (Horseshoe bats), Desmodus (Vampire bats) Order-3: Dermoptera (Latin: Derma = skin; pteron = wing) General characters: (i) These are herbivorous, tree-living and their size is like that of a large squirrel. (ii) The lower incisors are combed. (iii) The tympanic ring forms the bulla and the lower margin of the external auditory meatus. (iv) Brain is primitive and the optic lobes are not covered by cerebrum. (v) Fingers are not elongated to support the wings as in bats. Example: Cynocephalus (= Galeopithecus) (Flying lemur or colugo). Order-4: Edentata (Latin: E/ex = without; dens = tooth) General characters: (i) Incisors and canines are absent but molars are long and similar in appearance. (ii) Enamel and root of the teeth are absent but pulp cavity is persistent.

NSOU CC-ZO-04 119 (iii) Tongue is sticky in nature. (iv) Skull is small in comparison to body size. (v) The zygomatic arch is reduced or absent. (vi) Olfactory lobe of the brain is well-developed. (vii) In the pectoral girdle, clavicle is present but the coracoid and acromion are fused. (viii) In the pelvic girdle, ischium is united with anterior caudal vertebrae. (ix) Posterior thoracic and lumbar vertebrae are with additional pair of zygapophyses. Example: Dasypus (Nine banded armadilo), Myrmecophaga (Giant ant-eater), Bradypus (Three toed sloth) etc. Order-5: Pholidota (Greek: pholis = scale) General characters: (i) Horny scales are present in an imbricated fashion. (ii) The ventral side of the body is covered with hair. (iii) Eyes are small and pinna is ill-developed. (iv) Tail is long and tapering. (v) The short and powerful limbs possess five clawed-digits in each. (vi) The claws of the forelimbs are curved and sharp. (vii) Locomotion by hind limb is plantigrade in nature. (viii) Tongue is long, sticky and protrusible and is retained in a sac. (ix) Teeth are absent. (x) Skull is long and cylindrical. Example: Manis crassicaudata (Indian Pangolin), M. pentadactyla (Chinese Pangolin). Order-6: Primates (Latin: primus = first; Primate = One first in rank) General characters: (i) Body is covered with thick hair except the palm, sole and some parts of the face.

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NSOU CC-ZO-04 120 (ii) Neck is short and mobile. (iii) Forelimbs are shorter than hind limbs. (iv) Pentadactyl limbs possess digits with flat nail. (v) The pollex or thumb, hallux or first toe are smaller than other digits and are opposable. (vi) Locomotion is plantigrade type. (vii) A tail is present. (viii) Mammae are two and thoracic in position. (ix) Testes lie in scrotal sac. (x) The eyes are directed forward and the vision is binocular and stereoscopic. (xi) Teeth show reduction in number. (xii) Zygomatic arch is complete. (xiii) Foramen magnum faces downward. Example: Homo sapiens (Man), Gorilla, Presbytis (Langur), Hylobates (Gibbon), Loris (Slender loris), etc. Cohort: Glires General characters: (i) Teeth are specialized for gnawing. (ii) Skull is long and low. (iii) Temporal fossa widely opens to the orbit. (iv) Brain is small with small cerebral hemispheres. (v) Limbs are pentadactyle. (vi) Radius and ulna are separate. This cohort is divided into two orders - (i) Rodentia and (ii) Lagomorpha. Order-1: Rodentia (Latin: rodere = to gnaw) General characters:
NSOU CC-ZO-04 121 (i) Body is covered with soft hair. (ii) Eyes are small but pinna is well-developed. (iii) Limbs are provided with blunt claws. (iv) Forelimbs are smaller than the hind limbs. (v) Locomotion is plantigrade type. (vi) Intestine and caecum are large. (vii) Testes are inguinal. (viii) Females possess abdominal teats. (ix) Single pair of large, chisel-shaped incisors are present both in upper and lower jaws. (x) There are two premolars in the upper jaw and one in lower jaw. (xi) The scapula is provided with acromion process. Example: Sciurus (Squirrel), Petaurista (Flying squirrel), Rattus (Rat), Cavia (Guineapig) etc. Order-2: Logomorpha (= Duplicidentata) (Latin: logos = hare; morph = form) General characters: (i) Body is covered with soft hair. (ii) Eyes are large and pinna is long. (iii) Pentadactyle limbs possess clawed digits. (iv) Hind limbs are larger than forelimbs. (v) The upper lip is provided with a cleft in the middle. (vi) Tail is almost vestigial. (vii) Testes lie inside the scrotum. (viii) Mammary glands are abdominal in position. (ix) Maxillae are laterally fenestrated. (x) There are two pairs of incisors in the upper jaw, while it is one pair in lower jaw.
NSOU CC-ZO-04 122 (xi) Canine absent and diastema is present. (xii) There are three premolars in upper jaw and two in lower jaw. (xiii) Scapula is with acromion and metacromion process. (xiv) Tibia and fibula are fused. Example: Lepus (Hare), Oryctolagus (Rabbit), Ochotona roylei (Himalayan mouse) etc. Cohort: Mutica General characters: (i) These animals lack vocal cords, but can emit sound for various purposes, which is called 'whale song'. (ii) Completely aquatic throughout their life cycle. Order: Cetacea (Latin: cetas = whale) General characters: (i) The large, torpedo shaped body devoid of hair. (ii) The skin is smooth and skin glands are absent. (iii) The nictitating membrane of eye, pinna of ear and nail of the digits are absent. (iv) Forelimbs are modified to form flippers (v) Hind limbs are absent. (vi) The tail terminates in a horizontal fin, called fluke. (vii) Dorsal fin is fleshy; it is also a neomorphic structure. (viii) A thick subcutaneous fat layer, called blubber, is present. (ix) The lungs are highly elastic and extensible. (x) Brain is highly developed but olfactory lobe is reduced. (xi) Two mammary glands are located in the inguinal area. (xii) Single, large, well-formed young is born at a time. (xiii) The cranium is dorsoventrally flattened and the facial part is elongated.
NSOU CC-ZO-04 123 (xiv) Cervical vertebrae are fused to form a bony mass. (xv) Sacral vertebrae are absent. (xvi) Caudal vertebrae are with chevron bones. (xvii) Ribs lack heads. (xvii) Humerus is short, stout and its head moves freely in the glenoid cavity. Example: Platanista (Ganges dolphin), Balaenoptera (Blue whale) etc. Cohort: Ferungulata (i) Modern carnivores and hoofed animals. (ii) From the fossil records it is evident that all of them arose from a common ancestral population in palaeocene period. The cohort ferungulata is divided into five super orders. Superorder-1: Ferae (i) All the living members of this group are carnivorous. Order: Carnivora (Latin: carno = flesh; voro = to eat) General characters: (i) Pentadactyle limbs, with digits ending in sharp claws; claws may be retractile. (ii) Locomotion is either digitigrade or plantigrade type. (iii) Intelligence in the form of mental alertness and coordinated actions is evident. (iv) Brain is highly developed. (v) Intestine is short and caecum is small or absent. (vi) Testes are present in scrotal sac. (vii) Mammae are abdominal in position. (viii) Placenta is deciduate and zonary. (ix) Uterus is bicornuate in shape. (x) Skull is short. Sagittal and lambdoidal crests are well-developed. (xi) Zygomatic arch is strongly built.

NSOU CC-ZO-04 124 (xii) Each jaw possesses three pairs of incisors. Canines are large, sharp and pointed. (xiii) The atlas is large and is provided with wing like lateral processes. (xiv) Thoracolumbar vertebrae are 20 to 21 in number. (xv) Sternum is long narrow and made up of 8 to 9 sternibrae. Sternal ribs are not calcified. Examples: Canis (Wolves, Dogs, Jackals etc.), Vulpes (Fox), Ursus (Bear), Procyon (Raccon), Ailurus (Panda), Ailuropoda (Giant Panda) etc. Superorder-2: Protungulata This super order includes one living order. Order: Tubulidentata (Latin: tubulus = small tube; densf= teeth) General characters: (i) Body is covered by a dull-grey skin with unevenly distributed hair. (ii) Head is elongated to form a tubular snout. (iii) Pinna is long in size. (iv) Forelimbs possess clawed digits. (v) Hind limbs possess five toes with clawed digits. (vi) Small mouth possesses long, protrusible tongue. (vi) The cheek teeth are 4 or 5 in number. Incisors and canines are absent. (vii) Ant-eater in habit. Example: There is only one representative species present till now. Orycteropus after (ardvark) living in Africa and known as cape ant-eater. Superorder-3: Paenungulata (= near ungulates). General characters: (i) All are herbivorous animals. (ii) The legs are with long upper segments; ulna and fibula is complete. (iii) They possess several digits, with nail but no well-marked hoofs. (iv) The incisors and canine become reduced to single pair of large tusks in each jaw and the molars are specialised for grinding.

NSOU CC-ZO-04 125 Order: Hyracoidea (Greek: hyrax = shrew; eides = form) General characters: (i) These are rabbit-like animals, with short tail and short pinna. (ii) Locomotion is plantigrade type. (iii) Forelimbs possess four functional digits and fifth one remains as vestige. (iv) There are three digits in each hind limb. First and third digits possess hoof while second digit is clawed. (v) The caecum has a pair of caecal pouches. (vi) Abdominal testes are present. (vii) Mammae are pectoral in position and two in number. (viii) Uterus is paired; the placenta has an annular avascular allantois and haemochorial in nature. (ix) Single pair of large and curved upper incisors with persistent root is present. (x) Canines are absent; the lower incisors are comb-like and four in number. Example: Procavia (= Hyrax), Dendrohyrax (Tree hyrax). Order: Proboscidea General characters: (i) These are largest living land vertebrates. (ii) Thick skin with scanty hair. (iii) An enormously elongated nose and upper lip present. (iv) Nostrils are situated at the tip of the trunk. (v) Eyes are small but pinna is large. (vi) Pentadactyle limbs are pillar-like. Digits are hoofed. (vii) The immensely large hypsodont molars with numerous sharp transverse ridges are parts of the powerful grinding apparatus. (viii) Cerebral hemispheres are relatively small and leave the cerebellum uncovered. (ix) Stomach and intestine are simple; the caecum is long and sacculated.

NSOU CC-ZO-04 126 (x) Testes lie close to kidneys, scrotal sac is absent. (xi) Only one young is born at a time; gestation period 22 months. Example: Flephas (Asian elephant), Loxodonta (African elephant). Order: Sirenia (Greek: siren = sea nymph) General characters: (i) Herbivorous animals highly adapted for aquatic life. (ii) They have a streamlined body form, with few hair and thick blabber. (iii) The muzzle is round and the upper lip is protruding. (iv) Nostrils are located on the upper surface of head and are provided with valves. (v) Neck is short and pinna is absent. (vi) Eyes are small with muscular eyelids. (vii) There are no hind limbs and the pelvic girdle remains only as small rods. (viii) The forelimbs are large; the digits are joined to form paddles, with a full pentadactyle structure. (ix) Caudal vertebrae are well-developed. (x) A strong terminal horizontal fin is present. (xi) Ribs are round and the diaphragm is oblique. (xii) Lungs contain large air sacs. (xiii) Brain is small and the ventricles are exceptionally large. (xiv) Testes are abdominal. Uterus is bicornuate. (xv) The young are born in water and nursed at pectoral teats. Example: Dugong (= Halicore) (Sea cow), Manatus (= Trichechus) (Manatee). Superorder-4: Mesaxonia (i) Axis of the limbs passes through the third digit (middle axis), which is called the mesaxonic condition. Ihe remaining digits are reduced. Order: Perissodactyla (Greek: perissos = odd; daktylos = finger)

NSOU CC-ZO-04 127 General characters: (i) Herbivorous mammals having streamlined body. (ii) The neck and facial parts are elongated. (iii) Tail is with long tuft of hair. (iv) The powerful limbs are suitable for fast running. (v) The lower part of the limbs became elongated and the upper segments shortened. (vi) Among the five digits, the first and fifth digits are lost. The second and fourth digits remain as splints. The middle or third digit is stout and is provided with hoof. (vii) Olfactory lobe is highly developed. (viii) The incisors are three in each quadrant of the jaws. (ix) The canine may be reduced or absent and there is often a diastema. (x) Ulna and fibula are reduced. (xi) The femur is provided with a prominent process on the other surface of the shaft. The process is called third trochanter. (xii) Placenta is of diffuse epitheliochorial type, with a large allantoic sac. Example: Tapirus (Tapir), Rhinoceros (Rhinos - Indian and Javan), Dicerorhinus (Horses, Asses, Zebras). Superorder-5: Paraxonia (i) Axis of the limbs passes through the third and fourth digits. Order: Artiodactyla (Greek: Artios = even; daktylos = finger) General characters: (i) These are toed ungulates and latest mammalign herbivores. (ii) Neck is elongated but tail is small. (iii) Usually possess a pair of epidermal horns. (iv) Gait is digitigrade type. Hoofs have developed on the toes. (v) The long metapodials have become united to make the cannon bone.

NSOU CC-ZO-04 128 (vi) The eyes are large with horizontal pupil. Pinna is large with an acute sense of hearing. (vii) Tongue is long, mobile, prehensile and pointed. (viii) The canine may form tusks. (ix) Molars are of hypsodont and solenodont (moon-tooth) condition. (x) Stomach is complicated and divided into several chambers. (xi) Mammae are abdominal or inguinal in position and may be more than one pair. (xii) The olfactory organ and related parts of the brain are well-developed. (xiii) The uterus is bicornuate type. Examples: Hippopotamus (Hippo), Camelus (Camel, dromedary - Asia), Ceruus (Red deer), Dama (Fallow deer), Giraffa (Giraffe), Gazella (Gazelles), Bison (Buffalo), Capra (Goat), Ovis (Sheep). 8.4 Affinities of prototheria 8.4.1 Introduction Prototheria is the subclass of mammals which consists of five orders, namely, monotremata, morganucodonta, docodonta, tricodonta and multituberculata. Most of the animals in this group are extinct. The egg-laying monotremes are known from fossils of the cretacious and cenozoic periods. They are represented today by the plytipus. Although prototheria resemble the reptiles and birds with some advanced characters, but establishing mammalian ancestry considering its affinity with these groups. Following are the affinities of this group with that of reptiles, birds and mammals. 8.4.2 Reptilian affinity 1. Presence of cloaca. 2. Presence of ectopterygoid in skull. 3. Vertebrae without epiphysis and with cervical ribs. 4. Ribs are single headed. 5. Cervical ribs are present.

NSOU CC-ZO-04 129 6. Thoracic ribs are single headed. 7. A median T-shaped interclavicle is present. 8. Acetabulum in echidna is perforated. 9. Body temperature is not constant. 10. Cochlea of internal ear with lagina. 11. Ureters lead into a urinogenital sinus. 12. Corpus callosum is absent and anterior commissure is well developed. 13. Testis abdominal. 14. Oviparous and meroblastic segmentation. Remark: Presence of strong reptilian features in monotremata speaks of its primitiveness, but possess some advanced characteristics like higher mammals. 8.4.3 Avian affinity 1. Beak of the platypus resembles that of birds. 2. Teeth in adults are absent. 3. Presence of webbed feet. 4. Oil gland is present. Remark: The relationship between monotremes and birds does not stand on a solid ground. The characters seen in both of them are due to common reptilian ancestry. 8.4.4 Mammalian affinity 1. Presence of hair, mammary glands, oil gland and sweat glands. 2. Double occipital condyles. 3. Presence of palate. 4. A typical mammalian diaphragm is present in the body cavity. 5. Skull is dicondylic. 6. Sternum is segmented. 7. Lobes of liver typically mammalian.

NSOU CC-ZO-04 130 8. Heart 4-chambered. 9. Only left aortic arch present. 10. Circulatory system is typically mammalian. 11. Presence of large ear ossicles. 12. Cochlea is slightly coiled. 13. Fertilization is internal. 14. A slender caecum demarcates two intestines. 15. Lobes of liver typically mammalian. 16. R.B.C. small, circular and non-nucleated. 17. Presence of 4 optic lobes (corpora quadrigemina). 18. Presence of milk glands secreting milk. Remark: Though monotremes show affinity with non-mammalian groups, the above mentioned characters strongly speak for close and firm affinity with mammals. 8.4.5 Concluding remarks There are two theories which explain the phylogeny of monotremes. One theory explains that monotremes evolved independently from early mammal-like reptiles and continued to survive in isolation as basically primitive mammals with certain specializations. Another theory advocates that monotremes have been derived from marsupials. Among the mammals monotremes are very much controversial due to their salient features. Thus, it seems to conclude that monotremes originated as a side line from the main line of mammalian evolution and have retained the characters through which ancestors of higher mammals have passed. 8.5 Adaptive radiation with reference to locomotory appendages 8.5.1 Definition of adaptive radiation The concept of adaptive radiation in evolution was developed by H.F. Osborn in 1898. The diversification of different species of a genus or different group of organisms of related species in different ecological or geographical areas for survival is known as

NSOU CC-ZO-04 131 adaptive radiation. This adaptive diversification leads to the origin of new species. Examples often given as evidence include Darwin's finches of the Galapagos Islands, varied limb structure of mammals, Australian marsupials, etc. 8.5.2 Adaptive radiation in limb structure of mammals Mammalian limbs are the modifications of the pentadactylus limb. As the animals were terrestrial, thus these terrestrial ancestors were the ancestors of modern mammals. Of late, adaptive radiation occurred in five different lines or habitats with modifications in their limb structure (Fig-1). 1. One evolutionary line radiates to form arboreal forms which have adapted limbs for life in trees (e.g., squirrels, sloths, monkeys, etc.). 2. Another line leads to aerial representing mammals adapted for flight (e.g., bats). They are the only true flying mammals. Along this line we can place the gliding mammals such as "flying squirrel" in the same arena. 3. Third line of radiation gave rise to cursorial forms (e.g., horses and antelopes). They have developed limbs suitable to rapid movements over the surface of the ground. Along this line also developed other mammals with less strongly modified limbs, such as wolves, foxes, hyaenas, lions etc. 4. Fourth line of radiation formed the burrowing mammals, the fossorial mammals. Some of the fossorial mammals, like the moles, have modified their forelimbs for digging but they are poorly adapted for locomotion on the ground. While others like pocket gophers and badgers are expert diggers but they have retained structures enabling them to move readily on the surface of ground. 5. Fifth line of radiation leads to the aquatic mammals: (i) Whales and porpoises having limbs strongly adapted for aquatic life, but they cannot move about on land. (ii) Seals, sea lions and walruses have also strongly modified limbs for aquatic life but they are also able to move about on land. (iii) The third group includes accomplished swimmers such as others and polar bears which are equally at home in water or on land.

NSOU CC-ZO-04 132 8.5.3 Remark All the mammals of different radiating lines have limbs more or less adapted for some particular mode of locomotion. All the lines start from a common centre representing the short, pentadactylus limb of terrestrial mammals. From the centre, evolutionary lines radiate out in various directions. Hence, adaptive radiation is evolution in several directions starting from a common ancestral type. On the other hand, possession of this common limb pattern indicates close relationship not only among mammals but also by birds, reptiles and amphibians except fishes. Fig-1 : Adaptive radiation of divergent evolution in mammals, based on locomotion

NSOU CC-ZO-04 133 8.6 Summary Mammals are vertebrate animals characterized by the presence of mammary glands, fur or hair and three middle ear bones. Classification means ordering of animals into the definite groups on the basis of their similarity and interrelationship. Prototheria is the subclass of mammals represented today by Plytipus. The adaptive diversification leads to the origin of new species. 8.7 Questions i) Write the general characteristics of mammals. ii) Classify mammalian up to order with characters and suitable examples. iii) Discuss about the affinities of prototheria. iv) What is adaptive radiation? v) Discuss adaptive radiation in mammals with reference limb structure. 8.8 Selected readings 1) The life of vertebrates by J. Z. Young; Year: 1981. Published in India by Oxford University Press, New Delhi. 2) Biology of Animals (Volume-11) by Arup Kumar Sinha, Simananda Adhikari and Banku Behari Ganguly; Year 1991; Pub: New Central Book Agency. 3) Text Book of Zoology Vertebrates (volume-2) 7th Edition by T. Jeffery Parkar and Williama Haswell (Edited by Marshall & Williams) Year: 1995. Pub: AITBS Publishers & Distributors, New Delhi-110051. 4) Vertebrates Comparative Anatomy, Function, Evolution (Fourth Editon) by Kenneth V. Kardong. Year: 2010. Pub: Tata McGraw-Hill.

NSOU CC-ZO-04 134 Unit 9 Comparative anatomy of heart, kidney and brain Structure 9.1 General plan and comparative account of heart 9.1.1 Objectives 9.1.2 Introduction 9.1.3 A brief account of comparative anatomy of heart 9.1.4 Heart in different vertebrate groups 9.1.4.1 Cyclostomata 9.1.4.2 Fish 9.1.4.3 Amphibians 9.1.4.4 Reptiles 9.1.4.5 Birds 9.1.4.6 Mammals 9.2 General plan and comparative account of kidney 9.2.1 Objectives 9.2.2 Introduction 9.2.3 Basic structure and origin of kidney 9.2.4 Kidneys in different vertebrate groups 9.2.4.1 Cyclostomata 9.2.4.2 Fish 9.2.4.3 Amphibia 9.2.4.4 Reptiles 9.2.4.5 Birds 9.2.4.6 Mammals 134

NSOU CC-ZO-04 135 9.3 General plan and comparative account of brain 9.3.1 Objectives 9.3.2 Introduction 9.3.3 General plan of brain in vertebrates 9.3.4 Brains in different vertebrate groups 9.3.4.1 Cyclostomata 9.3.4.2 Elasfnobranch 9.3.4.3 Bony fish 9.3.4.4 Amphibia 9.3.4.5 Reptiles 9.3.4.6 Birds 9.3.4.7 Mammals 9.4 Questions 9.5 Selected readings 9.1 General plan and comparative account of heart 9.1.1 Objectives After studying this unit, learners would be able understand the following— The structure and characteristics of heart. The comparison of heart in different groups of vertebrates. 9.1.2 Introduction Heart in the vertebrates is a structure of modified blood vessel with thin walled venous collecting chamber, thick walled arterial forwarding chamber and the valves to prevent the back flow of blood. The heart is also a hollow muscular organ that rythmically contracts and relaxes. During each contraction-relaxation cycle, blood is drawn from the veins into a thin walled collecting chamber, the atrium, and is then passed to a second thick walled chamber, the ventricle, which forcibly contracts to distribute the blood to the arteries. Backflow is prevented by one-way valves.

NSOU CC-ZO-04 136 9.1.3 A brief account of comparative anatomy of heart The structure of heart has become modified in different group of vertebrate according to the shape and physiology of the animals. Fish have a simple two chambered heart which is, in essence, just a thickening of a section of the circulatory system, and the blood flows in a single circuit from heart to gills to body and back to the heart. Starting with the amphibians, the first vertebrates with lungs, the circulatory system adds a second loop or circuit. This design has the blood flow through the heart twice, on each trip around the system, once on the way to the lungs and once on the way back from the lungs, giving it an extra boost. This is called double circulation. In amphibians, there are two atria but only a single ventricle, this results in the mixing of deoxygenated and oxygenated blood, but amphibians also gather oxygen through their moist skin, so this inefficiency is not critical. Beginning with the reptiles, a septum or wall develops that partly divides the deoxygenated blood from the oxygenated one in the ventricle. This is important because reptiles, with a watertight skin, rely entirely on their lungs for oxygen. Reptiles also have the unique ability to redirect or shunt blood leaving the heart back through the heart without passing through the body circuit, and to shunt deoxygenated body blood back through the body without going to the lungs. Being a reptile, the crocodilians have fully extended the septum and have a four-chambered heart, but there is speculation that dinosaurs may have had this innovation as well. Birds and mammals have the same four-chambered design, which has increased efficiency because deoxygenated and oxygenated blood cannot mix within the circulatory system. 9.1.4 Heart in different vertebrate groups 9.1.4.1 Cyclostomata: (i) The heart of Myxine is "S" shaped and three chambered structure consisting of sinus venosus, auricle and ventricle. The conus arteriosus is ill developed but truncus arteriosus is well developed. Conus arteriosus is the forwarding part of the heart. It is enclosed by the pericardium. Truncus arteriosus is the basal portion of the artery. (ii) In Ammocoetes larva, the heart is elongated and modified constriction of the ventral aorta.

NSOU CC-ZO-04 137 (iii) In Petromyzon, the heart is similar to Myxine but is supported by a cartilaginous plate and truncus arteriosus is absent. 9.1.4.2 Fishes: All the fishes have single circuit heart, through which impure blood passes to the gills and therefore, it is called branchial heart. The heart is "S" shaped and the compartment are arranged in a linear series. They contain only venous blood thus it is called venous heart. A. Etesmchmnches: (i) Heart consist of sinus venosus, auricle, ventricle and conus arteriosus. (ii) Sinus venosus and auricle are thin walled while ventricle and conus arteriosus is thick walled. Sinus venosus receives blood from ductus cuvieri and hepatic vein. (iii) The atrio-ventricular opening is guarded by a row of semicircular valve. The number of valves in conus arteriosus is numerous and usually arranged in three longitudinal rows. (iv) In some Elasmobraches, the auricle is divided completely into right and left halves by an inter-auricular septum. B. Teleosts: (i) Conus arteriosus is short and represented by one or two sets of valves. In some cases conus arteriosus is absent. (ii) The base of ventral aorta becomes muscular called Bulbous arteriosus, which is not actually a part of the heart. (iii) In the heart of Catla appendages of ventral aorta are observed. C. Ganoids: The heart possess the valves in the conus arteriosus and are arranged in three longitudinal rows. The heart is similar with the elasmobraches. D. Dipnoi: (i) They are partly terrestrial and the heart is like terrestrial vertebrates. (ii) Auricle is divided incompletely into left and right halves by intra-auricular septum. The oxygenated blood from lungs comes into the auricle, so mixing of pure and impure blood occurs in the auricles. (iii) The auriculo-ventricular cushion is peculiar and the A-V aperture may be opened or closed by raising or lowering the cushion.

NSOU CC-ZO-04 138 (iv) Conus arteriosus becomes spirally twisted and the cavity becomes complicated by the presence of valves. (v) A spiral valve is present which extends forward to the anterior end of conus arteriosus. (vi) Three rows of proximal valves are present in the conus arteriosus of Protopterus and Lepidosiren. In Neoceratodus, conus arteriosus lacks spiral valves, although a series of semilunar valves are present. The valves in the conus arteriosus are so arranged that the blood from right side of the ventricle is directed to the heart to the branchial arches. By this way mechanism towards the separation or systemic and pulmonary circulation is achieved. Fig-1. Diagramatic view of fish heart 9.1.4.3 Amphibia: (i) Heart consists of one sinus venosus, two auricle and undivided ventricle and a conus arteriosus. (ii) Conus arteriosus is made up of two regions, i.e., pylangium and synangium. The portion of the conus next to the ventricle is called pylangium while the distal part is synangium. Distal part becomes extended as bulbas arteriosus in some urodales. The left auricle is absent in piethodontid urodales where the lungs and pulmonary veins are missing. (iii) The left auricle is absent in plethodonid urodales where the lungs and pulmonary veins are missing. (iv) The auricles are separated by a complete inter-auricular septum. It is perforated in salamander.

NSOU CC-ZO-04 139 (v) The venous blood returns to the right auricle while left auricle receives oxygenated blood. In all amphibians, where the conus arteriosus is present, there are two sets of valves which prevent the back flow of blood. (vi) In amphibians, due to the presence of two auricles, oxygenated and deoxygenated blood comes to the heart separately but due to the presence of one ventricle mixing of pure and impure blood takes place. Therefore, amphibian heart is called transitional heart. Fig-2. Diagramatic view of frog heart 9.1.4.4 Reptiles: (i) Reptilian heart consists of two distinct auricles and a ventricle which is internally divided by an intra-ventricular septum into left and right portion. (ii) In Chelonian, snake and lizards the septum is well developed but does not close off the left hand portion of the ventricle to the right hand portion. The left portion is larger and further divided into cavum venosum and cavum arteriosum. This secondary portion is formed by the fusion of trabeculae. (iii) In Crocodiles, the cavity of the ventricle is completely divided into left and right

NSOU CC-ZO-04 140 portion through at the point of contact. The crossing of left and right systemic arches there is an aperture called Foramen of Panizza, but the mixing of pure and impure blood does not occur. (iv) Conus arteriosus is absent in the reptiles and the aortic arches arise directly from the ventricle. (v) Sinus venosus shown a tendency to become fused with right auricle except Sphenodon, where sinus venosus is not properly distinguishable. (vi) In reptiles, ventricle is incompletely divided into two chambers and therefore there is a tendency to become double circuit heart. Hence, the heart is called incomplete double cuicuit heart. (vii) Conus arteriosus is fused with right ventricle and is present as a funnel shaped remnant. (viii) The pulmonary artery arises from the right ventricle through an ostium, which is provided with valves. (ix) Left ventricle is larger and also thick walled. Auriculo-ventricular opening is guarded by bicuspid valve. (x) Left aortic arch arises from the left ventricle. Fig-3. Diagramatic view of reptilian heart

NSOU CC-ZO-04 141 9.1.4.5 Birds: (i) In birds, heart is double circuit system having a completely divided ventricle and two auricles. So complete separation of pure and impure blood occurs. (ii) The heart of bird is comparatively larger and the rate of heart beat is much higher than other animals. For example, 500/minute in sparrow. 9.1.4.6 Mammals: (i) The heart is located in a space with the thorax. The space is called Mediastinum. (ii) The heart is four chambered consisting of two auricles (left and right) and two ventricles (left and right). Sinus venosus is absent. (iii) The right auricle receives the venous blood. An internally located ridge within the right auricle divides it into two regions- sinus venarum cavernum and right auricle. (iv) Sinus venarum cavernum is smooth walled while the auricle is lined with fine muscular ridges. (v) The left auricle is smaller in size. (vi) Right ventricle is thick walled. Right auriculo-ventricular aperture has tricuspid valve. Fig-4. Diagramatic view of mammalian heart

NSOU CC-ZO-04 142 Fig-5. Evalution of heart in different classes of vertebrates (A : Auricle; V: ventricle; RV : Right ventricle; LV : Left ventricle; LA : Left auricle; RA : Right auricle; SV : Sinus venosus)

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NSOU CC-ZO-04 143 The following figure will give an idea about evolution of heart in different vertebrate groups. 9.2 General plan and comparative account of kidney 9.2.1 Objectives After studying this unit, tainers would be able to understand the following— The structure and characteristics of kidney. The comparison of kidney in different groups of vertebrates. 9.2.2 Introduction Urinary system of vertebrates includes kidney and their ducts, while reproductive system includes male and female gonads and their ducts. The kidneys are a pair of bean- shaped organs present in all vertebrates. Kidneys excrete harmful metabolite nitrogenous wastes and regulate the composition of body fluid. Though the kidneys and gonads remain functionally unrelated, the two systems are intimately related morphologically in vertebrates because the male urinary ducts are also used for discharging gamates. For this reason it is more convenient to treat and describe the two systems as the urogenital or urinogenital system. All vertebrates have kidneys. Like the human kidney, they are made up of many nephrons. However, there are differences in the structure and functioning of various vertebrate kidneys that adapt them to the environment in which the animals live. 9.2.3 Basic structure and origin of kidney Kidneys are a pair of compact organ lying to the dorsal to the coelom in trunk region one on either side of dorsal aorta. Kidneys are of different types in vertebrates. 1. Embryonic
kidney:

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Each kidney is composed of a large number of units called uriniferous tubules or			

nephrons. Kidney tubules arise in the embryo from a special part of mesoderm called mesomere or nephrostome. The embryonic kidney is differentiated into three parts: A. Peritoneal funnel: It is the free end of nephrone, opens into splanchnocoel to a wide aperture called coelomostome or nephrostome. B. Malpigion body: It has two parts, cup shaped bowmans capsule and a glomerulus. In larval form and in embryo they may be aglomerular or without capsules. NSOU CC-ZO-04 144 C. Tubules: Tubules are convoluted ductulus that conduct the filtrate, while some are reabsorbed. Finally, the ductulus join into the longitudinal duct which opens behind into embryonic cloaca. 2. Archinephros: (i) This is the hypothetical primitive kidney of ancestral vertebrates, which is also regarded as a complete kidney or holonephros, as it extends the entire length of the coelom. These are segmentally arranged, one per body segment. (ii) Each tubule is opened by a peritoneal funnel or nephrostome into the coelom. Near each nephrostome an external glomerulus (without capsule) is suspended in the coelom. (iii) All the tubules were drained by a common longitudinal Wolffian or archinephric duct opening into cloaca. (iv) Such kidneys are found in the larvae of Myxine (cyclostomes), but not in adult. It is supposed that, all the kidneys of later vertebrates have been given rise during the course of evolution. 3. Pronephros: (i) Pronephros develops from the anterior most part of the nephrons on either side immediately behind the head of the embryo, therefore it is called head kidney. (ii) A pronephros consists of 3-15 tubules segmentally arranged, one opposite to each of the anterior mesodermal somites. (iii) There are three pronephric tubules in frog larva, seven in human embryo and about a dozan in a chick embryo. (iv) Each tubules opens into coelom by a funnel or nephrostome. (v) When glomeruli project into the coelom with no bowmans capsule, called external glomeruli. But in some, the glomeruli are surrounded by bowmans capsule, these are called internal glomeruli. (vi) The uriniferous tubules of each pronephros open into a common pronephric duct which grows back to enter the embryonic cloaca. (vii) In some, there is a large cavity forming pronephric chamber. Glomeruli project into the pronephric chamber where they may unite to form a single compound glomerulus called glomus.

NSOU CC-ZO-04 145 (viii) A pair of pronephric kidney appear in all vertebrate embryos but they become functional only in some cyclostomes and embryos of all anamniotes. In others, they degenerate during their course of development but their ducts persist. 4. Mesonephros: (i) Mesonephros develops from the just posterior part of the pronephros of the nephrostome, soon after its degeneration, (ii) At first, the new mesonephric tubules join with the existing pronephric duct and are segmentally disposed. Later on the tubules nephron multiply by budding so that their segmental arrangement is disturbed due to increased number of tubules per segment. (iii) Mesonephros are functionally better because mesonephric tubules are numerous, longer and develop internal glomeruli, enclosed in capsules forming malpigion bodies. Thus, they remove liquid waste directly from coelomic fluid. (iv) With disappearance of pronephros, the old pronephric duct becomes the mesonephric or wollfian duct. (v) In anamniotes, the mesonephros extends throughout the length of the coelom behind the pronephros and is formed from the entire nephrostome left behind the pronephros, while in amniote embryos the mesonephros is form only from the middle part of the nephron and it does not extend throughout the length of the coelom. Hence, the term ophisthonephros is used for the kidney of adult anamniotes. The mesonephros'of anamniotes is not exactly equivalent to that of aipniote embryos. 5. Metanephros: (i) Functional kidney of the higher vertebrates or amniotes is a metanephros.

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It is formed from the posterior end of the nephrogenic mesoderm. (ii) When metanephric tubules develops the mesonephric tubules disappear except

that it associated with the testis in male and for vasa efferentia. (iii) A large number of highly convoluted tubules arose from metanephros and hence at the posterior part of the nephron the rate of element of waste is higher. (iv) A new urinary duct is developed which is called metanephric duct or ureter. It is budded off from the base of the wolffian duct anteriorly and open into it. The
NSOU CC-ZO-04 146 ureter empties water into cloaca or urinary bladder in mammals. (v) The metanephros shows greatest organization of their tubules having glomerulus, capsule, renal tubules which is again differentiated into Henle's loop, proximal convoluted tubule (PCT) and distal convoluted tubule (DCT). Fig-6: Basic structure of kidney in vertebrates 9.2.4 Kidneys in different group of vertebrate 9.2.4.1 Cyclostomes (i) The pronephros is retained in adult hag fish (Myxine) which is hardly marked off from the mesonephros. The pronephros lies dorsal to the pericardial cavity. (ii) In Eptatretus, the pronephric duct is present but in Myxine lacks such duct. The pronephric tubules have no communication with the exterior. (iii) In Petromyzon, the pronephros does not persist in an adult. The mesonephros is the functional adult kidney. The mesonephros tubules are complicated and lack segmental disposition but in Myxine mesonephric tubules have segmental arrangement. 9.2.4.2 Fishes (i) Adult fishes possess opisthonephros type of kidney. In most fishes, kidneys are NSOU CC-ZO-04 147 extremely elongated structures and extend the entire length of the body cavity. Usually the posterior side of the kidneys are fused and the anterior end remain free. The anterior part of the kidney is almost non-renal. (ii) In Elasmobranchs, the kidneys in two sexes differ structurally. In males, the anterior non-renal part of the kidnay is well formed and sub serves reproductive reproductive function, but in females, the anterior part of the kidney is functionless and degenerated. (iii) In telelosts, the anterior portion of the kidney is converted into lymphatic tissue and does not perform any renal function. There is no connection between testis and kidney. Marine teleost possess fewer number of glomerulus than the fresh water forms. In some cases, the kidneys are wholly glomerular. In toad fish, Opsanus tau, the kidneys are aglomerular. 9.2.4.3 Amphibia (i) The kidneys in amphibian are of ophisthonephros type and the shape of the kidney corresponds to the shape of the body. (ii) In urodales, and in the primitive frog (Ascaphus) the kidneys are elongated. Each kidney is divided into an anterior narrow non-renal part and a broad posterior renal part. (iii) In caecilians, the kidneys are extremely elongated and occupy the whole length of the body cavity. (iv) In case of anurans, the kidney become condensed and divided into lobes. (v) The kidney tubules serving as the carriers of sperms may retain their glomeruli in caelilians and a salamander (spelirpes), but in most amphibians the glomerulus is lost. The testis discharges through the kidneys by the vasa efarentisa. So, the wolffian duct serves as the urinogenetal duct in males and as an ureter in females. 9.2.4.4 Reptiles (i) The functional excretory organs in adult are the metanephric kidney. The shape of the kidneys in different reptiles is variable and the shape correspond the shape of the body cavity. The glomerulus inside the kidney is reduced in reptiles. (ii) In lizards and crocodiles, the kidneys are much elongated and are housed in the

NSOU CC-ZO-04 148 posterior part of body cavity. The posterior ends of the kidney shows a tendency of fusion in many lizards. (iii) In snakes, the kidneys are slender and the position of the kidneys in the body cavity is asymmetrical, i.e, one kidney is located above the other side. (iv) In turtles, the kidneys are more compact than the other groups. 9.2.4.5 Birds (i) The structure and function of kidneys are similar throughout the class. The glomeruli show the general trends of reduction. (ii) In pigeon, there is a pair of flat three lobed metanephric kidneys lying dorsally in the hollow of the pelvic girdle. They have masses of numerous coiled uriniferous tubules, each having a small glomerulus and short specialized portion called loop of Henle, which reabsorbs water from the glomerular filtrate. From each kidney arises a narrow metanephric duct or ureter, which opens into the urodaeum of the cloaca. 9.2.4.6 Mammals (i) The kidney in mammals is metanephric. It is paired, bean shaped structure and is retroperitoneal in position. It is covered by a connective tissue or capsule. The median side of each kidney bears a depression called hillum. At this point ureter and renal veins leave the kidney and renal artery and nerves enter the kidney. (ii) The cortical region possess renal corpuscles and convoluted portions of the tubules while the medulla is made up of a large area occupied by a number of renal pyramids. (iii) In many mammals (Proboscidea, Cetacea, Artiodactyla etc.), the kidney retains embryonic lobulated condition. In others the kidney surface is smooth in adult stage.

NSOU CC-ZO-04 149 9.3 General plan and comparative account of brain 9.3.1 Objectives After studying this unit, learners would be able to understand the following— The structure and characteristics of brain. The comparison of brain in different groups of vertebrates. 9.3.2 Introduction With the evolution and development of lateral symmetry in the animal kingdom and for their necessity, one end of the animal is being used for locomotion and the other end, first coming in contact with the environment developed a concentration of nervous tissue as well as sense organs. These structures enabled the animals to cope with their environment in such a manner that they could survive better. The term cephalisation is used in referring to such localization of structures and functions in the head region. The central nervous system is the first organ that develops inside the embryo. It is ectodermal in origin. 9.3.3 General plan of brain in vertebrates The main subdivision of brain in vertebrates is as follows: Brain Fore brain Mid brain Hind brain (Procencephalon) (Mesencephalon) (Rhombencephalon) Telencephalon Diencephalon Optic lobes Metencephalon Mylencephalon (cerebellum) (medulla oblongata) Telencephalon: This is the most frontal part of the brain comprises of two cerebral hemispheres. It comprises of two parts, viz., cortex or pallium and medulla or corpus striatum. At the tip of the telencephalon there are two olfactory lobes or rhinincephalon. Two rhinocoels are present in these olfactory lobes. First and second ventricles are present in the two cerebral hemispheres. ↓ ↓ ↓ ↓ ↓ ↓ ↓ ↓

NSOU CC-ZO-04 150 Diencephalon: The third ventricle is bounded by diencephalon. The ventricle portion has a small elevated hypothalamus which holds pituitary gland. On the dorsal side there lies another structure, the pineal body. The third ventricle and the cerebral hemisphere are connected by foramen. Cerebellum: This is the hind brain consist of a superficial layer of grey matter, the cortex overlying a mass of white matter. It has large parallel furrows on its surface. The fourth ventricle is present within the cerebellum which connects with the second by a canal. Medulla oblongata: The most posterior part of the brain is medulla oblongata. The posterior part of the medulla oblongata is narrow and comes out from brain box through foramen magnum and forms a long structure, the spinal cord. Fig-7: General plan of the structure of mammalian brain 9.3.4 Brains in different vertebrate groups 9.3.4.1 Cyclostomes (i) Telencephalon is small, paired optic lobes weakly differentiated corpus striata. (ii) Well developed pineal body. Anterior to it lies the parietal body. (iii) Epiphysis and pineal body are photoreceptive organs. (iv) One pair of optic lobe possess large optic vesicles. Prosencephalon Mesencephalon Rhombencephalon Telencephalon Diencephalon Metencephalon Mylencephalon Spinal cord } } }

NSOU CC-ZO-04 151 (v) Infundibulum is small. (vi) Havenular ganglia present and have two outgrowths. (vii) Roof of the fourth ventricle has an extensive vascular network forming choroid plexus. (viii) The metencephalon is a rudimentary lip like structure but no pons. 9.3.4.2 Elasmobranch (i) Corpus striata is a bulging structure. (ii) Olfactory lobes constitute the bulk of the telencephalon. From each olfactory lobe the conspicuous olfactory stalk arise terminating in an olfactory bulb. (iii) Posterior limit of the telencephalon is marked by a transverse invaginated fold or velum. (iv) Epiphysis is stalked. (v) Parietal organ disappears after the temporary appearance during embryonic development. (vi) The infundibulum develops a pair of elongated swellings. (vii) Well developed optic lobe is partially covered by cerebellum. It is larger and active in dogfish than the sluggish rays and scates. (viii) In Torpedo, two electric lobes that project into the fourth ventricle which supplies nerves to the electric organs. 9.3.4.3 Bony fishes (i) Brain is small and the roof of procencephaion is thin and non nervous. (ii) Convex corpus striata occupy the floor of thin region. (iii) Shortened epiphysis. (iv) Optic lobes are large. (v) Cerebellum is small in dipnoans and ganoids, but large in most teleost, specially in most active ones. (vi) Olfactory lobes are large and have no olfattory peduncles but are closely located in front of the cerebral hemispheres, each contains rhinocoels, while continues with lateral ventricle.

NSOU CC-ZO-04 152 (vii) Dieancephalon is small and hidden dorsally by the mid brain. (viii) The pineal body projects in front because it has a stalk. On the ventral side there lies an infundibulum to which the pituitary gland is attached. (ix) Two large optic lobes with layers of neurones in its roof into which pass the fibres of the optic nerves. (x) Cerebellum is large and bent upon itself, the anterior part does not project in front as in others but forms a valvula cerebella, which extends under the optic lobes. It is characteristics of bony fishes and controls active movement. 9.3.4.4 Amphibia (i) Olfactory lobes are large, continuous with the distinctly separated cerebral lobes lie closely side by side and joined medially too. (ii) Corpus striata projects upward from the telencephalon floor only slightly allowing for fairly large lateral ventricles and invaginate anterior to choroid plexus inside the cerebral lobes. (iii) Diencephalon uncrowned, visible from above without inferior or saccus vasculosus. It has vestigial pineal body represented by a simple hollow stalk. (iv) In adult anurans, the epiphysis is represented by a small median vesicle, the pineal gland close under the dorsal wall of the cranium. (v) Skull is stegocephalus has a dorsal foramen which shows the presence in those primitive amphibians of either pineal or parietal eye. But parietal body is absent in modern amphibians. (vi) The mid brain is well developed. It forms two large optic lobes, each having an optic ventricle or optocoel. Optic lobes are so spread apart as occupying a more lateral in position. (vii) Cerebellum is very small in most forms, rudimentary in caecilians and in some urodales. 9.3.4.5 Reptiles (i) Cerebrum is more or less developed. Corpus striata are so large that lateral ventricles are reduced. (ii) Olfactory lobes are hardly distinguishable from the neopallial part of the telencephalon. In lizards and alligators with prominent projecting snouts, the olfactory lobes are extended into stalks and bulbs.

NSOU CC-ZO-04 153 (iii) In diencephalon, thalamus is large. Hypophysis is attached to the infundibulum and definitely into anterior and posterior part. (iv) On the dorsal wall of the third ventricle, the parietal, pineal and a third evagination, the paraphysis embryologically present, but in adult undergoes degeneration. (v) Except crocodiles and alligators, the epiphysis is present as a glandular pineal structure. (vi) In Sphenodon, the parietal organ reaches highest development, in which it extends as far as transparent window. On the roof of the skull, there is a third median eye with retina and a lens. (vii) In snakes, there are four optic lobes. (viii) Cerebellum is small but in swimming reptiles it is fairly developed. (ix) Medulla oblongata with eight pairs of cranial nerves. (x) Stegosaurus was indeed oldest Dinosour, the most peculiar is that it has two brain. 9.3.4.6 Birds (i) The brain of the birds is more of an "eye brain" than a "nose brain" thus showing an advance over its forerunner. (ii) Cerebral cortex is well developed than reptiles,with large corpus striata. The lateral ventricles are reduced due to increase thickness. (iii) Olfactory lobes are fairly prominent in tooth bearing createceovus birds but in modem birds, it is absent or degenerating. (iv) No trace of parietal organ; degenerating pineal body. (v) The greatly developed optic lobes are crowned over laterally in position. But backward growth of cerebrum tends to burry the diencephalon and mesencephalon from the dorsal side. (vi) The cerebellum consisting of a well defined median vermis as two lateral lobes. It is large in extremely active birds. 9.3.4.6 Mammals (i) The primitiver tertiary mammals had a reptilian type of brain. In modern mammals, it is advanced than that of birds. (ii) Cerebrum is highly developed by the development of corpus striatum and large

NSOU CC-ZO-04 154 corpus callosum. But in marsupials and monotermes, corpus callosum is small. (iii) In marsupials and monotermes, the archipallial olfactory parts of the brain is prominent but in higher forms, it is reduced. In man, seals and whales, it is entirely lacking. Fig-8 : Comparative account of brain of representative vertebrates (dorsal view) cerebral

NSOU CC-ZO-04 155 (iv) Endocrine organs are connected with epiphysis. Diencephalon is covered by cerebral hemisphere. (v) Optic lobes are two in lower forms but four in higher forms and relatively smaller. The corpora quadrigemina is covered by massive cerebrum. (vi) Cerebellum is so much enlarged that they meet dorsally. (vii) In addition to vermis, the lateral lobes floculi are of considerable size. (viii) There is a definite bands of fibres encircling the brain stem, is known as pons. (ix) Medulla oblongata is short and located under the prominent cerebellum. 9.4 Questions 1. Describe the structure of heart. 2. Give a comparative account of heart in tetrapoda with diagram. 3. What is the significance of reptilian heart. 4. What is nephron? 5. Write a comparative account of mammalian kidney. 6. Write the subdivisions of brain? 7. Write a comparative account of mammalian brain. 9.5 Selected readings 1) The life of vertebrates by J. Z. Young; Year: 1981. Published in India by Oxford University Press, New Delhi 2) Biology of Animals (Volume-II) by Arup Kumar Sinha, Simananda Adhikari and Banku Behari Ganguly; Year l991; Pub: New Central Book Agency 3) Text Book of Zoology Vertebrates (volume-2) 7th Edition by T. Jeffery Parkar and Williama Haswell (Edited by Marshall & Williams) Year: 1995. Pub: AITBS Publishers & Distributors, New Delhi-110051 4) Vertebrates Comparative Anatomy, Function, Evolution (Fourth Editon) by Kenneth V. Kardong. Year: 2010. Pub: Tata McGraw-Hill
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based on the comparative studies of larval stages of echinoderms and hemichordates.

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Tornaria larva of hemichordates resembles echinoderm larvae of bipinnaria, auricularia, dipleurula and doliolaria, which all possess ciliary bands and apical tuft of cilia

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Seven pairs of gill slits are present. 8) Well developed dorsal fin is present. 9) Branchial basket is complete. 10) Brain is well developed. 11)

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4/17	SUBMITTED TEXT	12 WORDS	100%	MATCHING TEXT	12 WORDS

The nasal sac opens into pharynx through a canal. 6) Eyes are

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5/17	SUBMITTED TEXT	11 WORDS	100%	MATCHING TEXT	11 WORDS

Pineal eye is reduced. 11) Ear has only one semicircular canal. 12)

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Development of lamprey The eggs of lamprey are telolecithal, having a large amount of yolk. Cleavage is holoblastie but unequal resulting in the formation of

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Gastrulation occurs by invagination and the blastopore takes up a postero-dorsal position and becomes converted into arms. The development of the central nervous system is peculiar in lampreys. It develops as a solid cord or keel which hollows to form the

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8/17	SUBMITTED TEXT	24 WORDS	43%	MATCHING TEXT	24 WORDS

The eggs are collected by the male and he throws them in such a way that the eggs can adhere to the lower surface

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9/17	SUBMITTED TEXT	23 WORDS	81%	MATCHING TEXT	23 WORDS

Body is divisible into head and trunk. Tail may be present in some amphibians. 4. The skin is smooth or rough having glands

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10/17	SUBMITTED TEXT	23 WORDS	75%	MATCHING TEXT	23 WORDS

present, they are hidden beneath the skin (e.g., Caecilians). 6. Paired fins are absent. Unpaired fins may be present. Two pairs of limbs are

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11/17	SUBMITTED TEXT	34 WORDS	74%	MATCHING TEXT	34 WORDS

gills are present at least in the larval stage; some adult forms also carry external gills in addition to lungs (e.g., Necturus, Proteus). 8. Skull is dicondylic, i.e., with two occipital condyles for articulation with

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12/17	SUBMITTED TEXT	34 WORDS	54%	MATCHING TEXT	34 WORDS

tailed amphibians (e.g., salamander) are ammonotelic. Frogs and toads are ureotelic. NSOU CC-ZO-04 52 12. Alimentary canal, urinary and reproductive tracts open into a common chamber called cloaca which opens outside through cloacal aperture. 13.

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13/17	SUBMITTED TEXT	15 WORDS	89%	MATCHING TEXT	15 WORDS

The eyes have eyelids. Nictitating membrane is well developed. 15. Ten pairs of cranial nerves

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14/17	SUBMITTED TEXT	14 WORDS	78%	MATCHING TEXT	14 WORDS

is external. However, in Salamander and lehthyophis (blind worm) fertilization is internal. 18. Development is

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15/17	SUBMITTED TEXT	16 WORDS	78%	MATCHING TEXT	16 WORDS

the tadpole larvae are attached to the males and are carried from one pond to other.

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16/17	SUBMITTED TEXT	14 WORDS	71%	MATCHING TEXT	14 WORDS

Each kidney is composed of a large number of units called uriniferous tubules or

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17/17	SUBMITTED TEXT	20 WORDS	73%	MATCHING TEXT	20 WORDS

It is formed from the posterior end of the nephrogenic mesoderm. (ii) When metanephric tubules develops the mesonephric tubules disappear except

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PREFACE In a bid to standardize higher education in the country, the University Grants Commission (UGC) has introduced Choice Based Credit System (CBCS) based on five types of courses viz. core, generic, discipline specific elective, ability and skill enhancement for graduate students of all programmes at Honours level. This brings in the semester pattern which finds efficacy in sync with credit system, credit transfer, comprehensive continuous assessments and a graded pattern of evaluation. The objective is to offer learners ample flexibility to choose from a wide gamut of courses, as also to provide them lateral mobility between various educational institutions in the country where they can carry their acquired credits. I am happy to note that the university has been recently accredited by National Assessment and Accreditation Council of India (NAAC) with grade "A". UGC (Open and Distance Learning Programmes and Online Programmes) Regulations, 2020 have mandated compliance with CBCS for U.G. programmes for all the HEIs in this mode. Welcoming this paradigm shift in higher education, Netaji Subhas Open University (NSOU) has resolved to adopt CBCS from the academic session 2021-22 at the Under Graduate Degree Programme level. The present syllabus, framed in the spirit of syllabi recommended by UGC, lays due stress on all aspects envisaged in the curricular framework of the apex body on higher education. It will be imparted to learners over the six semesters of the Programme. Self Learning Material (SLMs) are the mainstay of Student Support Services (SSS) of an Open University. From a logistic point of view, NSOU has embarked upon CBCS presently with SLMs in English / Bengali. Eventually, the English version SLMs will be translated into Bengali too, for the benefit of learners. As always, all of our teaching faculties contributed in this process. In addition to this we have also requitioned the services of best academics in each domain in preparation of the new SLMs. I am sure they will be of commendable academic support. We look forward to proactive feedback from all stakeholders who will participate in the teaching-learning based on these study materials. It has been a very challenging task well executed, and I congratulate all concerned in the preparation of these SLMs. I wish the venture a grand success. Professor (Dr.) Subha Sankar Sarkar Vice-Chancellor

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NETAJI SUBHAS OPEN UNIVERSITY Under Graduate Degree Programme Choice Based Credit System (CBCS) Subject : Honours in Zoology (HZO) Course :

Animal Diversity Course Code : GE-ZO-11 Unit 1 ? Protista : General Characters of Protozoa; Life Cycle of Plasmodium 7-16 Unit 2 ? Porifera : General Characters and canal system in Porifera 17-26 Unit 3 ? Radiata : General Characters of Cnidarians and Polymorphism 27-34 Unit 4 ? Acoelomates : General Characters of Helminthes; Life cycle of Taenia solium 35-42 Unit 5 ? Pseudocelomates : general characters of nemethelminthes; Parasitic Adaptations 43-50 Unit 6 ? Coelomate Protostomes : General Characters of Annelida; Metamerism 51-57 Unit 7 ? Arthropoda : General Characters; Social Life in Insects 58-65 Unit 8 ? Mollusca : General Characters of Mollusca, Pearl Formation 66-71 Unit 9 ? Coelomate Deuterostomes : General Characters of Echinodermata; Water Vascular System in Starfish 72-79 Unit 10 ? Protochordata : Salient Features 80-84 Unit 11 ? Pisces : Osmoregulation, Migration of Fishes 85-90 Unit 12 ? Amphibia : General Characters; Adaptations for Terrestrial Life; Parental Care in Amphibia 91-100 Unit 13 ? Amniotes : Origin of Reptiles; Terrestrial Adaptations in Reptiles 101-107 Unit 14 ? Aves : The- Origin of Birds; Flight Adaptations 108-115 Unit 15 ? Mammalia : Early Evolution of Mammals; Primates; Dentition in Mammals 116-128

Unit 1 ? Protista : General Character of Protozoa; Life Cycle of Plasmodium Structure 1.1 Objectives 1.2 Introduction 1.3 Salient features of protista 1.4 General characters of protozoa 1.5 Life cycle of Plasmodium 1.6 Conclusion 1.7 Summary 1.8 Glossary 1.9 Questions 1.10 Suggested readings 1.1 Objectives By studying this unit, the students will be able to understant about the general idea on protista and the life cycle of the malarial parasite, Plasmodium. 1.2 Introduction R.H. Whittaker (1969) introduced five kingdom system of classification of organisms. That is, he divided all the organisms into five kingdoms viz, Kingdom : Monera, Kingdom: Protista, Kingdom: Fungi, Kingdom: Plantae and Kingdom: Animalia. All unicellular organisms are grouped under Protista. 1.3 Salient features of protista 1. Microscopic, unicellular and eukaryotic organisms. 2. Most have mitrochondria and other cellular organelles. Nucleus may be one, two or many. 8 GE-ZO-11 ? NSOU 3. Aquatic or terrestrial but in moist enviorment. 4. Free living and parasitic. Protista is represented by several groups of organism, namely, Chrysophytes, Dinoflagellates, Euglenoids, Slime moulds and Protozoa. Chrysophytes include diatoms and golden algae. Dinoflagellates are pigmented marine organisms and Euglenoids are mostly freshwater organisms and are autotrophs. On the other hand slime moulds are terrestrial and heterotrophs and thereby they adapted to live as parasites or predators. 1.4 General characters of protozoa Shape : Single-celled organisms represent various shapes and some group is habituated to change the shape constantly (i.e., Amoeba) while some could be seen with definite shape just like a slipper (i.e., Paramoecium). Size : Microscopic, usually ranges from 1 micrometre to several milimetre. But, the largest forms i.e., the deep-sea dwelling xenophyophores—the foraminiferans may bear a shell upto 20 cm in diameter. Habitat : Aquatic as well as terrestial; but the terrestrial inhabit moist soil and damp places. Aquatic forms are equally adapted to live in freshwater and marine enviorment. However, many of them may be seen in air in the form of cyst. The parasitic forms are found in the body of the hosts. They may be found singly or in colony. Structure : The unicellular organism's body is composed of cytoplasm and nucleus. Also, various organelles could be seen inside the cytoplasm. The cytoplasmic mass is enclosed by the plasma membrane. The nucleus is also enclosed by a membrane. Outside the plasma membrane variously projecting fine structures like cilia, flagella as well as pscudopodia could be seen as the extended part of the plasma membrane. In shelled forms tread like pseudopodia make their way outside through the minute pores of the shell. Locomotion : Pseudopodia, cilia and fleglla are the locomotory organelles or protozoans. But, some parasitic groups are nonmotile. Pseudopodia are temporary whereas cilia and flagella are permanent locomotory organelles. Nutrition : (i) Holozoic or Zootrophic or Heterotrophic, (ii) Saprozoic or Saprophytic and (iii) Parasitic, mode of nutrition. In holozoic nutrition protozoans

NSOU ? GE-ZO-11 9 used organism smaller that their body size as food. This mode of nutrituion is associated with ingestion, digestion, assimilation and egestion. In case of saprophytic nutrition nourshing substances enter into the body by diffusion through body surface or protozoa. Bacteria produced simpler compounds, dead or decomposed bodies of animals or plants are the nourshing substances in this type of nutrition. Mostly, flagellate protozoans exercise this type of nutrition. Parasitic protozoans derive nutrients from the host. In case of Monocystic the digested or decomposed materials of the host are drawn into the body on way of diffusion. Entamoeba being gut parasitice holozoic nutrition. Respiration : Free molecular oxygen from the surrounding media enter the body by diffusion. Some parasitic protozoans get oxygen from the body of the host while many such protozoans are able to survive without oxygen and they, thus termed as anaerobic protozoa. However, the chicken intestinal parasitic flagellate Histomonas meleagridis is able to grow in presence or absence of oxygen, and thus, is known as 'facultative aerobe'. Excretion : Excretory products are water, carbon dioxide and nitrogenous compounds. These remain in soluble from. These are, in due course of time, removed from the body either by diffusion or by contractile vacuole in protozoans occurring in hypertonic water media, while marine or parasitic protozoans inhabiting isotonic media lack contractile vacuole. Response to stimuli : The reaction to stimulus is ascertained by observing the movements of protozoans in changing direction in response to the stimulus. These movements are to two types—taxis and kinesis. Reproduction : Reproduction is effected both by asexual and sexual means. Fission, budding and schizogony are the modes of asexual reproduction. In fission one cell (individual) splits into two (binary fission) to give rise two daughter individuals while in other cases the said individual may spilt into several small fragents (multiple fission) to produce a daughter individual from each of such fragments. In case of multiple fission (also known as schizogony) daughter cells are produced due to multiple fission of the nucleus followed by segmentation of cytoplasm to form separate mass around each smaller nucleus, as in Amoeba. In budding, buds form around a nucleus and pinch off of the cell to give a new individual. Sexual reproduction is effected through (i) Syngamy and (ii) Conjugation. In syngamy complete fusion of two cells or gametes, resulting in the formation of zygote. In case of conjugation temporary union of two organisms for the exchange of genetic material takes place as in Paramoecium. 10 GE-ZO-11 ? NSOU Economic importance : Protozoans help to maintain the food-chain and thereby play significant role to maintain the food-chain to regulate biodiversity. As certain protozoans are parasitic in nature, they, on way of their survival strategy cause serious dieases in animals and humans and thus, malaria, trypanosomiasis, leishmaniasis (Kala azar), amoebiasis, giardiasis are of serious concerned. Study of the shells of shelled protozoa like Foraminifera embedded in the rock is an important indicator for geologists who are involved in oil exploration. Fig. 1 Amoeba Fig. 2 Paramoecium Fig. 4 Plasmodium Fig. 5 Opalina Fig. 3 Trypanosoma Examples : Amoeba (Fig:1), Paramoecium (Fig:2), Trypanosoma (Fig:3), Plasmodium (Fig:4) and Opalina (Fig:5) Attached flagellum Free flagellum Cytoplasm Nucleus Undulating membrane Parabasal body Kinetoplast Pellicle

NSOU ? GE-ZO-11 11 1.5 Life cycle of Plasmodium Members of the genus Plasmodium

belong to sporozoan protozoa. They are parasitic organisms and depend on two different species as hosts to complete their life cycle. Plasmodium species are very important because of their involvement in causing serious disease—malaria, in humans. There are five Plasmodium species viz. P. falciparum, P. malariae, P. vivax, P. ovale and P. knowlesi known to cause malaria in humans. Of these P. Knowlesi is a zoonotic malaria parasite, transmitted between non-human primate hosts by the Anopheles mosquito, and causing spill-over infections in humans where the parasite, vector, hosts and human converge [Abeyasinghe, 2016 (WHO)]. Thus all these Plasmodium species can infect humans and cause illness i.e. malaria. As regards to human malaria, Plasmodium complete the life cycle in two host human host (intermediate host) and the mosquito host (definitive host). In all cases mosquito belongs to the genus Anopheles acts as definitive host. The life cycle of Plasmodium is completed through the following events : (i) Infection of human with sporozoite. (ii) Asexual reproduction (iii) Sexual reproducation The events (i) and (ii) take place exclusively in human body while the event (iii) though starts in human body is completed in the mosquito host. The female Anopheles mosquito, to satisfy its nutritional requirement for the development of the eggs, takes blood by biting the intermediate host (human) and also other animals (for malaria in other animals). During a blood meal the malaria infected female Anopheles mosquito injects saliva, infected with sporozoites of Plasmodium, into the blood stream of human host (Fig:6). Fig. 6 Life cycle of malarial parasite Life Cycle of the Malaria Parasite human blood cell cycle human blood cell sexual stage: male or female gomotocytes form mosquito stages gametas ookinete oocyst mos- quito stage human human fiver stage sporozoite

12 GE-ZO-11 ? NSOU Human cycle : Human cycle of Plasmodium initiates with the inoculation of sprozoites into the blood circulation. In the next state of life cycle asexual reproduction takes place. This stage is divided into exoerythrocytic phase and erythrocytic phase. Following inoculation the sprozoites find their way to the first target, the liver within 30-60 minutes. The sprozoites penetrate the liver cells and start dividing to produce schizonts in 6-7 days. From a single schizont thousands of merozoites are produced. This is known as exoerythrocytic schizogony. These merozoites then are released into the blood stream indicating the end of the exoerythrocytic phase of asexual reproduction stage of Plasmodium. It is to be mentioned here that sprozoites of P. vivax and P. ovale may not follow the reproduction path and stay dormatic (hypnozoites) in the liver. They may be activated after a long time leading to relapses entering the blood stream (as merozoites) after weeks, months or even year. The exoerythrocytic phase is not pathogenic. Thereafter, no sign or symptoms of the disease could be seen at this phase. The duration of this phase varied with the species of Plasmodium. Merozoites in the blood stream move towards the second target, the red blood cells (RBCs). They penetrate into the RBC and initiate the erythrocytic phase. After invasion a ring stage appears first inside their RBCs which ultimately turned into trophozoite. The trophozoite resemble a ring and is called signet ring stage. The trophozoites are unable to digest the haem from haemoglobin, so they convert the same into haemozoine and then digest the globin which is used as a source of aminoacids for their reproduction. The next stage is the erythrocytic schizont. Each mature schizont gives birth to new generation—the merozoites. The merozoites assembled themselves in the form of petals of a rose-flower called rosette stage. The merozoites are either microgametocytes (males) or microgametocytes (females). The rupture of red blood cells by merozoites releases certain factors and toxins which could directly induce the release of cytokinins such as TNF and interleukin-1 from macrophages resulting in chills and high grade fever. The time needed for the gametocytes to attain mature state differs for each Plasmodium species :3-4 days for P. vivax and P. ovale, 6-8 days for P. malariae and 8-10 days for P. falciparum. Mosquito cycle : The female Anopheles Mosquito, in course of sucking blood from the body of a malaria infected persons ingest both a sexual and sexual forms Plasmodium but only
NSOU ? GE-ZO-11 13 the sexual forms survive and subsequent stages are developed inside the gut. The nucleus of microgametocyte divides three times producing 8 nuclei. Ultimately 8 filamentous motile appendages emerge and each nucleus with each flagellum is called microgamete or malegamete. Each such nucleus fertilizes a macrogamete (developing from macrogametocyte) forming a zygote. This is completed in 20 minutes to 2 hours time period. The zygote moves actively and becomes so-called 'ookinete'. Then, the ookinete penetrates the midgut wall of the mosquito and comes to rest under the outer lining epithelium of the gut wall. There, it, then transformed into a spherical mass or oocyst surrounded by cyst wall. Inside the oocyst, the ookinete nucleus divides to produce thousands of sporozoites (Sporogony). Thus, the parasite completes the third stage (stage of sexual reproduction) or the sprogony. Thereafter, the nucleus of the sporozoite divides repeatedly and a large number of sickle-shaped sporozoites are formed from one oocyst. The oocysts rupture and the sporozoites are released into the haemocoel of the body cavity of mosquito. Subsequently, the sporozoites find their way to salivary glands though only few hundreds of sporozoites could manage to accommodate themselves there. The said mosquito, at the onset of blood meal injects its infected saliva into the next victim and thus making the beginning of a new cycle (Fig-6; Table-1). Table-1: Duration of each different phase in the life cycle of different species of Plasmodium. P. vivax P. malariae P. ovale P. falciparum 1. Pre-erythrocytic phase (days) 6-8 14-16 9 5-7 2. Erythrocytic cycle (hours) 48 72 50 48 3. Incubation period (days) 12-17 18-40 16-18 9-14 or even 6-12 months or more or more 4. Sporogony (days) 8-10 14-16 12-14 9-10 1.6 Conclusion Kingdom Protista, contains simple eukaryotic organisms, usually composed of a single cell or a colony of similar cells. Of the differnt groups of Protista, except Protozoa, all are autotrophs. Protozoans being heterotrophs lead a life either as predators or parasites. Of the parasitic protozoans the species belongs to Plasmodium are the causative agents of human malaria and the female Anopheles mosquito is very much involved not only to ensure the completion of life-cycle of these parasites but also to spread the malaria disease from man to man.

14 GE-ZO-11 ? NSOU 1.7 Summary i) Protista are single-celled eukaryotic organisms. ii) Protozoans are protista but heterotrophic in nature. iii) Free living protozoans are predacious in habit while parasitic protozoans derive their nourishment from host. iv) Plasmodium being sporozoan protozoa are very much involved with creation of malaria disease in humans. v) Plasmodium vivax, P. ovale, P. falciparum are notable human-malaria- causing agents while P. knowlesi creates malaria in monkeys and apes but sometimes in humans also. Thus, P. knowlesi is involved with zootonic malaria. 1.8 Glossary Protist : Any member of a group of diverse eukaryotic, unicellular, microscopic organisms which may share certain characters with plants and animals. Eukaryotic : An organism whose cells have nucleus enclosed with membrane and with membrane bound organelles. Pseudopodium : A temporary protrusion of the surface of an amoeba for movement and feeding. Cilium : It is a slender protuberance of the cell body of the eukaryotic ciliate organisms which is known as locomotory organalle. Fagellum : It is a long whip-like structure that helps flagellated protozoans in locomotion. Malaria : An intermitent and remittent fever caused by a protozoan parasite which invades the red blood cells and is transmitted by Anopheles mosquitoes in many tropical and subtropical regions. Intermediate host : An organism (host) that supports the immature or non- reproductive forms of a parasite. Definitive host : An organism (host) which supports the adult or sexually reproductive forms of a parasite.

NSOU ? GE-ZO-11 15 Sporozoite : A motile spore-like stage of Plasmodium which is the infective agent introduced into the host (man). Signet ring stage : Due to a large food vacuole and the peripherally situated nucleus young spherical trophozoites of Plasmodium species inside the red blood cells look like a signet ring. Ookinete : The elongated motile zygote of a parasite of the malaria mosquito that forms an oocyst in the mosquito gut. Conjugation : The process of temporary union of two organisms (Paramoecium) for the exchange of genetic material. 1.9 Questions 1. State the characteristic features of Protista. 2. Mention different groups of Protist organisms with examples. 3. State the general characters of Protozan organisms. 4. Mention the type of locomotory organelles of protozoans with example. 5. Name the Plasmodium species known to cause malaria in humans. What in zoonotic malaria? 6. Describe the human cycle of Plasmodium parasite. 7. Describe the mosquito cycle of Plasmodium parasite. 8. By the help of a flow chart show the sequential events in the life cycle of Plasmodium parasite. 9. Explain the following : (a) Schizont (b) Sprogony (c) Oocyst (d) Gamogony (e) Contractile vacuole(f) Conjugation (g) Budding (h) Sprozoite. 1.10 Suggested readings 1. Medical parasitology by D. R. Arora, CBS Publishers and distributors Ltd, Amazon, 2018. 2. Handbook of the protists by John M. A., Alastair G. B. Simpson, C. H. Slamovits. etds. springer, Cham, Switzerland, 2017.

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Unit 2 ? Porifera : General Characters and Canal System in Porifera Structure 2.1 Objectives 2.2 Introduction 2.3 General characters of porifera 2.4 Canal system in porifera 2.4.1 Components of a typical canal system 2.4.2 Types of canal system in sponges 2.4.3 Machanism of water circulation of porifera 2.4.4 Functions of canal system in porifera 2.5 Conclusion 2.6 Summary 2.7 Glossary 2.8 Questions 2.9 Suggested readings 2.1 Objectives By studying this unit, students will be able to understand— i) about the characteristic features of poriferan animals. ii) To study the types and significance of canal systems developed by the poriferan organisms. 2.2 Introduction Commonly poriferans are known as sponges. This animal group was separated from other metazoans very early in the history of evolution. Fossil sponges are among the oldest known animal fossils, dating from the late Pre-Cambrian. The member of fossil genera of sponges recorded so far, exceeds 900. At present

18 GE-ZO-11 ? NSOU appoximately 5000 living species of sponges are grouped, in respect to their characteristic features, into Hexactinellida, Demospongiae and Calcarea. The animals belong to the Phylum Porifera are characterized by having pores all over the body— as the name implied (Latin "porous" means pore and "ferre" means to bear/carry). 2.3 General characters of porifera Habitat : Aquatic animals mostly found in marine enviornment while few species belongs to Fam. Spongillidae live in freshwater. Size and shape : Some sponges are only a few centimeters in size. Many sponges are shapeless and are less than a centimeter, while some sponges are with a definite shape—either vase-like or tube or like branches to tree and may be 1-2 meters in height. Also some species are broad rounded in shape and up to 2 meters in diameter. Body organisation : Mostly with asymmetrical body while some are radially symmetrical. Multicelluar with cellular level of organisation without true tissues. Cells are arranged in outer layer as well as in inner layer. Pinacocyte cells are known as skin cells. They lined the exterior of the body wall of the sponges. They are tightly packed together. Choanocyte

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cells (Fig. 1) line the interior body wall of sponges. Choanocyte cell has a central flagellum which is surrounded by a collar of microvilli.

Between the two cell layers, a space known as mesenchyme or mesohyl could be seen. Mesenchyme contains some loose cells and spicules (Fig. 2) in a proteinaceous matrix. Of these, archaeocyte cells (Fig. 3) are totipotent, that is, they are able to change into other types of sponge cells. Also, sclerocytes, myocytes and porocytes are found in sponges. Sclerocytes secrete spicules while the other cells, called spongocytes secrete spongin fibres. Myocytes and porocytes have the power to contract themselves. In sponges a continuous single cavity called paragastric cavity or spongocoel is present within the body. In most cases the cavity is thrown into folders to form a complex canal system. Canal system in sponges is meant for water transport. Water enters through minute pores known as ostia in the body wall into a central cavity known as spongocoel, from where it goes out through the comparatively larger pore—the osculum. Myocytes and porocytes which surround canal openings and pores can contract to regulate water flow through the sponge.
Choanocytes or
NSOU ? GE-ZO-11 19 collar cells regulate the direction of movement of water in the canals by the beating of flagellae. Fig. 1: Choanocyte Fig. 2: Spicule Fig. 3: Archaeocyte and other cells Food and feeding : Sponges feed on detritous particles, plankton, bacteria etc. that is brought close by water currents created by the choanocytes. Food items are taken into individual cells by phagocytosis and digestion occurs within individual cells. Respiration and excretion : Water moves through the canal system. Oxygen present in incoming water diffuses into the sorrounding cells. Carbon- dioxide and other wastes diffuse into the water and are carried out. Reproduction : Sponges are mostly hermaphrodites. They have no reproductive organs as well as gonads. Sponges are able to reproduce both by asexual and sexual means. Fragmentation, gemmeule formation, budding, both external and internal, are the mode of asexual reproduction. In sexual reproduction, being hermaphrodite,
20 GE-ZO-11 ? NSOU individuals produce eggs and sperms at different times. The sperm is released in water frequently. The sperm travels in water and enters into the respective site of the other sponge individual waiting for fertilization of the eggs produced by the same, the so-called female one. After fertilization a larva is released into the water. Within a short period the larva settle and develop into juvenile sponges. Economic importance : Commercially sponges play a vital role in our economy. The bath sponges are beneficial to man because of their skeleton which has many commercial uses. Examples : Fig. 4: Scypha sp. Fig. 5: Hyalomena sp. Fig. 6: Cliona sp. 2.4 Canal system in porifera The perforations of the body of sponges by a large number of ostia is characteristic of phylum porifera. But in all cases these pores are nothing except the terminal point of a canal. Thus, from all the pores canals lead to a large canal, the spongocoel which opens to the extirior through a larger pore, the osculum. Depending upon body structure of sponges there may be many such openings i.e. oscula. The entire physiological activities of the sponges depend on the water current and the exchanges between the body and the exterior are maintained through the water current. 2.4.1 Components of a typical canal system A typical canal system is composed of (i) Incurrent canal, (ii) Excurrent or radial canal and (iii) Prosopyle.
NSOU ? GE-ZO-11 21 Incurrent Canal : It opens to the outside by a small pore known as incurrent pore or ostium. It ends blindly internally. Radial canal or Excurrent Canal : It is closed externally but opens internally by minute pores or apopyles into spongocoel. Prosopyle : It is a smaller canal or pore connecting incurrent canal with radial canal. Incurrent canals are lined by flat squamous cells which help to form water current. The radial canals are lined by collar cells having openings at the surface. These cells are porovided with flagella. The lashing movements of flagellum help to capture and to push the food particles into the cell-mouth. The spongocoel opens to the outside by osculum. 2.4.2 Types of canal system in sponges Depending upon the complexity in body organisations in different groups of sponges the canal systems are also divided into four distinct types : Ascon type, Sycon type, Leucon type and Rhagon type (Fig. 7). Fig. 7: Four types of canal systems in porifera
22 GE-ZO-11 ? NSOU Ascon Type :Simple and primitive type of canal system. It encloses a large spongocoel which is lined by choanocytes.
The wall is pierced by numerous microcopic apertures, the
ostia which extend from the external surface to the spongocoel.
Ostium is intracellular

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and disposes in a porocyte. The spongocoel is completely lined by a layer formed by choanocyte cells but interrupted only by the porocyte (Fig. 8). This type of canal system is mostly seen in calcareous sponges. (e.g. Leucosolenia clathrina). Fig. 8: Porocyte In ascon type of canal system the course of water current is as follows : Dermal pore Internal ostia Spongocoel Exterior Osculum Sycon type : This type is little bit complex than the ascon type because, here the wall is pushing outward into finger like projections called radial canals, at regular intervals. In this system choanocytes are found only in the radial canals. It may be of (a) Simple sycon type, (found in Sycetta sponges) (b) Complex sycon type (found in Scypha) and (c) Sycon type with cortax (found in Grantia, Grantiopsis sponges). Course of water current in simple sycon type is as follows : Exterior Ostia Radial canal Oscula Spongocoel Apopyle ? ? ? ? ? ? ? ? ? ? ?
NSOU ? GE-ZO-11 23 Course of water current in complex sycon type is as follows : Exterior Dermal ostia Incurrent canals Prosopyles Osculum Spongocoel Excurrent canal Apopyle Radial canal Course of water current in sycon type with cortex type is as follows : Exterior Ostia Dermal space Dermal pore Incurrent canal Osculum Spongocoel Excurrent canal Apopyl Radial canal Prosopyle Rhagon type : In this type of canal system the osculum is located at the summit of conical body.

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Spongocoel is bordered by oval flagellated chambers, opening into it by apopyles.

The mesenchym is traversed by incurrent canals. The rhagon type is little complex than the complex syconoid type. This type of canal system is seen in the larval stages of demospongiae. The course of water current in rhagon type is as follows. Exterior Dermal ostia or Prosopyle Flagellated chamber Oculum Spongocoel Apopyle Leucon type : In this type of canal system the choanocytes lining the radial canals evaginate into many small chambers which repeat the same process to give rise to a cluster of small flagellated chambers. The incurrent canals lead to small round flagellated chambers open by apopyles into excurrent canals. Leucon type again may be of (a) Eurypylous type (seen in Plankina, Tetilla), (b) Aphodal type (seen in Geodia, Stellata) and (c) Diplodal type (seen in Oscarella, Spongilla). The main advancement of leuconoid canal system over syconoid type are : (i) Choanocytes are limited to small chambers. (ii) Development of mesenchyme in a better way. (iii) Elaboration and complication of the incurrent and excurrent water passages. ?
24 GE-ZO-11 ? NSOU Course of water current in leucon type of canal system : Dermal ostia Subdemal spaces and many Prosodus (when present) incrruent canals Exterior Prosopyles Flagellated chambers Apopyles Osculum Large canals Excurrent canals (many) Aphodus (when present) 2.4.3 Machanism of water circulation of porifera Beating of flaglla by the choanocyte cells produces water current which draws the water inside through ostia and also forces the water to get out through the osculum (Fig: 7) 2.4.4 Functions of canal system in porifera Canal system serves the purpose of feeding, respiration and excretion in sponges. 2.5 Conclusion Porifera i.e. sponges are though multicellular organisms with various types of cells, no tissue level organisation could be seen in these animals. They have developed the canal system for the entry of water from the enviornment and remove the same from the body following ensuring feed, respiration and containing the excretory end/or other waste materials. Complexity in canal system in different groups of sponges indicates an evolutionary trend towards development of tissue level organisation and organ formation in the next higher groups of animals. 2.6 Summary i) Sponges are aquatic organism. They depend on water current regulated by the flagellated cells occurring along the outer surface of the canal forming walls, from the enviornment to the exterior through the body channel. ii) Spongocoel is the main canal while the other canals are shorter and narrower. ? ? ? ? ? ? ? ? ? ? ?

NSOU ? GE-ZO-11 25 iii) There are many pores on the surface of the body known as ostia which allow entry of water into the body and the larger openings, the oscula are very limited in number help to remove the water from the body. iv) Feeding, respiration and excretion are regulated by the canal systems. v) Depending upon the complexity in body structure the canal system have been modified into ascon, sycon, rhagon and leucon types. vi) Sponges reproduces both asexually and sexually and in sexual reproduction after fatilization, a large stage is released into the water. 2.7 Glossary Ostia : A series of any pores all over the body of a sponge. Osculum : A large opening to the outside through which the current of water exits after passing through the spongocoel in sponges. Choanocyte : A flagellated cell which helps to form the choanoderm in sponges with a view to regulate the direction of water current along the canal system. Gemmule : It is internal bud which develops in sponges to accomplish asexual reproduction. Mesoglea : A translucent non-living jelly-like substance found between the two epithellial cell layers in the body of sponges. It acts asa hydrostatic skeleton. Prosopyle : In sponges, a pore through which water is drawn from outside into a sac-like chamber formed by the evagination of the body. 2.8 Questions 1. What is spongocoel? 2. Define apopyle and prosopyle? 3. What is radial canal? 4. State the location and function of choanocytes in sponges. 5. What is canal system? How many types of canal systems are there in Porifera. State the significance of Porifera? 6. Describe the following : (a) Ascon type of canal system.

26 GE-ZO-11 ? NSOU (b)

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Sycon type of canal system. (c) Leucon type of canal system. (d) Rhagon type of canal system. 7.

By the help of flow chart present the course of water current through the different types of canal systems of Porifera studied by you. 2.9 Suggested readings 1. Sponges (Porifera). W.E.G. Muller (Ed) Springer, Germany 2003. 2. The cell biology of sponges. T.H. Simpson. Springer-Verlag, New York. 1984. 3. The sponges. H.V.P. Wilson. Nabu Press, 2012. 4. Invertebrate Zoology. E.I. Jordan and P.S. Verma. S. Chand and Company Limited, New Delhi (Revised Edition) 2018.

Unit 3 ? Radiata : General Characters of Cnidarians and Polymorphism Structure 3.1 Objectives 3.2 Introduction 3.3 General characters of cnidarians 3.4 Polymorphism in cnidaria 3.4.1 Basic unit of polymorphism 3.4.2 Origin of polymorphism 3.4.3 Significance of polymorphism 3.5 Conclusion 3.6 Summary 3.7 Glossary 3.8 Questions 3.9 Suggested readings 3.1 Objectives By studying this unit, students will be able to gain knowledge on the characteristic features of Radiata in respect to the features of Cnidarian and the phenomenon of division of labour i.e., polymorphism. 3.2 Introduction Depending upon the body plans from the study of histological view point certain animals were recognized as Radiata. Because, their body is radially symmertrical. Therefore, these animals belong to Radiata. These animals are with two germ layers i.e. diploblastic. Radiata contains two phyla-Cnidaria and Ctenophora. The name cnidarian comes from the Greek word "cinods" which means stinging nettle. It contains over 11,000 species and are excusively aquatic, predominantly marine. Cnidocytes are the specialized cells found in this group which help to capture the prey. Polymorphism is an interesting aspect from the evolutionary view point of animals. Because, this refers to the occurrence of structurally and functionally more than two different types of individuals within the same organism. This may be condidered as unique

28 GE-ZO-11 ? NSOU characteristic feature in cnidarian by producing verieties of zooids, especially the polyp and medusa forms, within the colony to ensure efficient functioning of the biological activities on way of division of labour among the colony forming zooids. 3.3 General characters of cnidarians 1. Mostly marine but few cnidarians are found in freshwater (e.g. Hydra). 2. Usually colonial though solitary forms could also be seen (e.g. Hydra). 3. Diploblastic with externally epidermis and internally gastrodermis. These two layers are separated by a jelly like layer called the mesoglea. 4. In each tissue layer presence of different types of cells is well marked. These are nerve cells, contractile epithelial cells enzyme secreting cells, and nutrient absorbing cells, as well as the presence of intercellular connection. But, no organ system is developed. 5. The whole surface of the body, except the pedal disc, is provided with a large numer of stinging cells or cnidoblasts (Fig:1). They are found in maximum number in tentacles which are located surrounding the hypostome. Each cnidoblast contains a capsular nematocyst inside. Cnidoblast cells help in food collection (capturing), defence and locomotion. 6. The cells that produce nematocysts are Spines Stylet Cnidocil Refractile Rods Supporting Fibrits Lasso Nucleus Cytoplasm Tread Tube Operculum Fig. 1: Cnidoblast cell called nematoblasts or cnidoblasts. There are four types of nematoblasts viz. (i) penetrant (ii) large glutinant, (iii) small glutinant and (iv) volvent. 7. Interstitial cells are undifferentiated mesenchyme cells. They are capable to convert in any type of epithlial cells. These are rather reserve and the main totipotent cells in cnidarians. 8. Gastrovascular cavity is the only internal cavity is a blind sac. Because it has only one opening— the mouth and the same is located at the centre of the hypostome. The anus is absent and the mouth also acts as anus. 9. Digestion is extracellular and intracellular. a

NSOU ? GE-ZO-11 29 10. Body forms are usually soft and transparent but some shows bioluminescence. 11. Gaseous exchange takes place through general body surface (no specialized respiratory, circulatory and excretory organs). 12. Circulation of various substances takes place at the cellular level. i.e. from cell to cell. 13. No nervous system but non-polar neurons are distributed irregularly in the body. 14. Statocysts or tentaculocysts are present as the organ of balance in free swimming forms. 15. The phenomenon of polymorphism i.e. occurrence of more than one kind of individuals in the same species. The two basic forms polyp and medusa are well marked in cnidarians. Polyp form is sessile (eg. sea anemone, hydra) while medusa is free swimming (e.g. Aurelia popularly known is jelly fish). Polyp reproduce asexually while medusa reproduces sexually. The other forms of zooids are gastrozooids, gonozooids, dactylozooids, tentaculozooids etc. 16. Metagenesis or alternation of generation, another notable biological phenomenon, is well marked in cnidarians. It is a phenomenon whereby, in the life cycle of an organism, a diploid asexual phase and a haploid sexual phase regularly alternate with each other in case of alternation of generation while in metagenesis a diploid asexual phase and a diploid sexual phase regularly alternate with each other. Fig. 2: Hydra Fig. 3: Sea anemone Fig. 4: Coral (Astraea)

30 GE-ZO-11 ? NSOU 17. Reproduction in polyp forms is effected due to budding, during favourable periods. Though male and female organisms are seen but there exists no sexual dimorphism. 18. Gonads simple but without ducts. 19. In-situ fertilization, holoblastic cleavage. Development may be direct or indirect. In case of indirect development, planula and ephyra larval stages are seen. Examples :Hydra (Fig. 2) Sea anemone (Fig. 3), Coral (Astraea) Fig. 4), Obelia (Fig. 5), Physalia (Fig. 6) 3.4 Polymorphism in cnidaria In Cnidaria polymorphism (Fig:7) means the occurrence of structurally and functionally more than two different kinds of individuals within the same organism. These different forms are known as zooids (gastrozooids, dactylozooids, tentaculozooids, gonozooids etc.). Of these zooids the polyp and medusa are considered as basic zooids. 3.4.1 Basic unit of polymorphism The zooids can be divided into two fundamental forms which can be derived from each other. (i) Polyp form (Fig. 7) It is characterized by : (a) Tube like body with one end closed but sedentary in habit. (b) Preoral end is provided with hypostome, mouth and tentacles while aboral end is fixed. Fig. 5: Obelia Fig. 6: Physalia

NSOU ? GE-ZO-11 31 (c) Mouth is round and situated at the centre of hypostome leading to coelenteron. (d) Mouth is encircled by 6-8 elongated tentacles. (e) It may be encased by a transparent covering- the hydrotheca. (ii) Medusoid form (Fig. 7) : It is characterized by : (a) Body umbrella-shaped with convex exumbrellar surface and ventral concave subumbrellar surface. (b) Mouth and manubrium are located in the subumbrellar surface. (c) Radial and circular canals are prominent. (d) The bell margins are provided with tentacles. (e) Usually a velum is present. (f) Gonads present. (g) Free-swimming forms. Fig. 7: Polymorphism in Cnidaria VELELLA

32 GE-ZO-11 ? NSOU 3.4.2 Origin of polymorphism There are different theories viz. poly-organ theory, poly-person theory, medusa theory, etc. but the main purpose of polymorphism is to assign different functions to different forms with a view to divide the labour to achieve the resultant effects of different functions. 3.4.3 Significance of polymorphism Polymorphism assigned different form of zooids to perform different functions, such as gastrozooids for feeding, dactylozooids for protection, tentaculozooids for sensory function, gonozooids for reproduction etc. Theerefore, the aim is to establish a fact for the division of labour. Of these form—polyp forms are associated with the feeding, protection, testing and asexual reproduction while medusa is concerned with sexual reproduction. 3.5 Conclusion Cnidarians are characterized by the presence of cnidoblast cells which help to capture the prey. Diploblastic organisms but with various forms of individuals in the form of zooids are seen with a view to perform definite function. These zooids are grouped into two forms viz. polyp and medusa. Polypoid forms are sedentary while medusoid forms are free- swimming. Due to the presence of diffenent forms of zooids in respect to accomplishment of specific function the phenomenon of polymorphism have been developed in cnidarians. 3.6 Summary i) Cnidarians are aquatic, mostly marine diploblastic, colonial or solitary animals. ii) The outer layer epidermis and the inner layer gastrodermis are separated by a jelly like layer called mesoglea. iii) Presence of specialized cells viz. nerve cells, contractile epithelial cells, enzyme secreting cells, untrient absorbing cells and the intercellular connections is well marked. iv) Except basal disc the body surface is provided with cnidoblast cells which are abundant in tentacles and hypostome. It helps to capture food, in defence and swimming. v) The interstitial cells are able to produce different types of cells on way of conversion.
NSOU ? GE-ZO-11 33 vi) A sac-like gastrovascular cavity which has only one opening which serves as mouth and anus. vii) Bioluminesence is observed. viii) Circulation of substance takes from cell to cell. ix) Non-polar neurons are seen in the body. x) Different zooids are produced to perform differnt functions. Of these, polypoid forms are sessile and medusoid forms are free-swimming. xi) Metagenesis or alternation of generation is well marked and larval stages are developed following fertilization and development of zygote. xii) Essentially polymorphism is nothing but a colonial mode of living style by producing different forms in the body of a single organism. 3.7 Glossary Cnidocyte : In Cnidaria cnidocyte is a special type of cell which contains one giant secretory organelle or cnida that defines the phylum Cnidaria. Cnida is used to capture prey and for protection from predators and/or enemies. Polyp : Polyp is a sessile organism of cnidarian species (sea anemone, hydra). Medusa : Medusa is a free-swimming form of cnidarian species (jelly fish). Polymorphism : Occurrence of stracturally and functionally more than two types of individuals within the same individual. That is, occurrence of polyp, medusa and other types of zooids in a cnidarian species. Zooid : Zooid is a single individual that is of course, a part of a colonial animal. Mesoglea : Translucent, non-living jelly-like substance found between the two epithelial cell layers in the body of a cnidaria. 3.8 Questions 1. Define Zooid. Name any two types of zooids studied by you in cnidarian animals and explain any one type of such zooid. 2. Draw, label and describe the structure of a cnidoblast cell and add a note on its functions. 3. State the differences between polyp and medusa.
34 GE-ZO-11 ? NSOU 4. Define polymorphism. Give an account of polymorphism in Cnidaria. 5. Write notes on : (a) Asexual reproduction in hydra and (b) Gastrodermis in Cnidaria. 6. State any five distinguishing features of Cnidaria. Mention the types of gametes and larvae are found in Cnidaria. 7. What are the basic components that enable Cnidaria to develop the ground for polymorphism? State the significance of polymorphism. 3.9 Suggested readings 1. Introduction to general Zoology, K.K. Chaki, G. Kundu and S. Sarkar. New Central Book Agency (p) limited, 2008. 2. Invertcbrate Zoology-E.I. Jordan and P.S. Verma. S. Chand, 2009. 3. Siphonophora (Cnidaria : Hydrozoa) of Canadian Pacific waters. G.M. Mapstone and M.N. Arai. NRC Research press 2009.
Unit 4 ? Acelomates : General Characters of Helminthes; Life cycle of Taenia solium Structure 4.1 Objective 4.2 Introduction 4.3 General characters of helminthes 4.4 Life-cycle of Taenia solium 4.5 Conclusion 4.6 Summary 4.7 Glossary 4.8 Question 4.9 Suggested readings 4.1 Objectives By studying this unit, students will be able to gain knowledge on— (i) acoelomate animals like flatworms; and (ii) the life cycle of Taenia solium. 4.2 Introduction Invertebrate animals lacking a coelom are known as acoelomates. These animals are grouped into flatworms and nemerteans. 4.3 General characters of helminthes 1. Eukaryotic, multicellular, free-living or parasitic animals. 2. Worm-like body with bilateral symmetry. 3. Distinct head and tail region. 4. Well marked tissue differentiation with distinct ectoderm, mesoderm and endoderm.

36 GE-ZO-11 ? NSOU 5. Body shape may be round (round worm), flat or tape-like (flat worm or tape- worm), or hook-like (hook-worm) and the length of the body may be ranged from less than one millimetre to over one metre. 6. Digestive, circulatory, nervous, excretory (presence of flame cells) and reproductive systems are well marked in most cases. 7. Parasitic forms spend either live completely in the host body or sometimes depend partially on the host to complete their life cycle. 8. Many parasitic helminthes lack a digestive system and thereby, they are adapted to absorb nutrients from host's body fluids and/or tissues. 9. In some cases nervous system is in reduced form. 10. Becasue of parasitic nature in most cases locomotion is absent or is reduced to a great extent. 11. Reproductive system is very complex. They may be unisexual or bisexual. Eggs when released outside may infect another host. Examples : Fasciolo hepatica (Fig:1), Taenia solium (Fig:2) Fig. 1 Fasciola hepatica Fig. 2 Taenia solium

NSOU ? GE-ZO-11 37 4.4 Life cycle of Taenia solium Taenia solium also known as pork tapeworm, is a tapeworm belongs to the class Cestoidea, phylum Platyhelminthes. It is an intestinal, mainly zoonotic, paraste found throughout the world and is most common in the geographical areas where pork is eaten. Man is its definitive host while pig is the intermediate or larval host. 4.4.1 Structure (i) Ribbon-like body, two-three meters long having about 800-900 segments or proglottids (Fig: 3). (ii) Head or scolex (Fig: 4) is pear-shaped with 28 curved chitinoid hooks arraged in two rows. There are four adhesive suckers. (iii) Following head an elongated but unsegmented region is well marked, known as neck. (iv) The rest of the body after neck is known as strobila. The strobila is segmented and contains 800-900 segments called proglottids. (v) Each proglottid represents a complete hermaphrodite sexual unit. Fig. 3 Proglottid of Taenia Fig. 4 Head of Taenia

38 GE-ZO-11 ? NSOU 4.4.2 Reproductive organs 1. Reproductive organ appears first in most cases at the 200 th segment. The male reproductive organ appears first and then female organs develop. The worm grows and subsequent segments were added gradually. The male part of the said reproductive organ attained maturity at about 400 th segment. The segments following 400 th segment are filled with highly developed uterus fully loaded with developing embryos. The male reproductive organ consists of a many lobed testis with ducts, vas-deferens and cirrus. The cirrus open into the atrium in the male genital aperture (Fig: 5) 2. The female reproductive organ consists of a paired ovary with their ducts, uterus, yolk glands, shell gland, ootype, receptacolum seminalis and the vaginal opening in the atrium through the female genital aperture. The gravid uterus looks like long stem with 5-10 lateral branches (Fig: 5). 3. Fertilization internal. In Taenia self-fertilization occurs. Eggs are fertilized by sperms of same proglottid or may be fertilized by the sperms of proglottid situated anterior to it. Zygote coated with yolk and surrounded by egg shell passes to the uterus. Fig. 5: Reproductive organs of Taenia lateral nerve cord testes vasa efferentia vasa delerons cirrus or penis genital artium common gonopore genital papilla vagina fertilization duct Mehlis's glands vitelline duct vitelline gland ootype lateral longitudinal excretory canal uterus fertilized egg capsules seminal receptacla ovarian bridge ovary oviduct uterne canal transverse excretory canal

NSOU ? GE-ZO-11 39 4. The ripe proglottids detached in chains of 5-6 and and removed from the body with the faeces of the host. 5. Proglottids are now eaten by the pigs and the six-hooked or hexacanth embryos are liberated following digestion of the segments. 4.4.3 Life cycle (Fig: 6) 1. The eggs of T. solium following removal with the faeces of human host remian alive for days to months in the environment. The pigs become infected by ingesting vegetation contaminated with eggs/gravid proglottids. Fig. 6: Life cycle of Taenia 2. Inside pig's intestine the egg hatches and the onchosphere or hexacanth embryo is produced. Onchosphere is round in shape and covered by two membranes. Six curved chitinous hooks are present at one end. 3. The embryo invades the intestinal wall with the help of hooks and reaches the voluntary or striated muscle where the hooks are lost. 4. Then, the embryo through the portal vein enters the general circulation and reaches at the liver and thereafter to the right side of the heart, then to the lungs, 40 GE-ZO-11 ? NSOU then to the left side of the heart and finally enters into the systemic circulation. Finally, it migrates to the striated muscle. 5. In the muscle the embryo grows to a ball like structure containing fluid inside and assumes the shape of a bladder. 6. At one point of the bladder an invagination takes place. In the inner surface of this invagination 28 hooks and 4 suckers, characteristics of the scolex (head) of adult Taenia, are developed. 7. The invagination bocomes everted and the suckers and hooks come to the surface. 8. Now the embryo looks like a bladder with a head and neck. This is known bladder worm or cysticercus stage. The pig's flesh infested with cysticercus cellulosae (Cysticercus of T. solium is also known as cysticercus cellulosa (pl. cellulsae) due to the presence of cellulose layer on the wall of cysticercus larva.) is known as measly pork. 9. When a piece of imperfectly cooked measly pork is eaten by man the bladder i.e. cysticercus is dissolved in the gastric juice. 10. The swelling of albuminous materials due to the action of gastric juice, inside the cysticercus causes the fluid to come out into the cavity and thus enables the head to come out through the pore. 11. The head attaches itself with the wall of the intestine by the help of hooks and suckers. With time the worm grows and a series of proglottids developed to attain the adult stage to the worm. 12. The worm attains sexual maturity within 2-3 months. 13. Inside the host the worm may survive up to 24 years or sometimes more. 14. Next cycle begins when a piece of under cooked measly pork is consumed by man. 4.5 Conclusion Helminthes are eukaryotic multicellular animals. They are causative agents of different kinds of worm diseases of man and animal. Of these parasitic worms, the flatworms Taenia solium is responsible for the disease taeniasis in humans. T. solium passes its life cycle in two host—pig is the intermediate host (larval host) while man is the definitive host (adult's host). The worm finds its entry into human's body through the measly pork. The main-way to get rid of such a disease is to avoid eating pork-meat having cysticercus infestation.

NSOU ? GE-ZO-11 41 4.6 Summary i) Helminthes are commonly known as worms, most of them are parasitic in nature. ii) They may be round, flat or hook like in shape. iii) Body could be differentiated distinctly into the head and tail regions. iv) Though many kinds of organs to perform various types of biological activities are well marked, of them presence of flame cells to ensure excretion effectively and the reproductive organs to ensure maximum rate of production of young individuals are noteworthy. v) Taenia solium is also known as pork tapeworm, depends on two hosts—pig (the intermediate host) and the man (the definitive host) to complete the life cycle. vi) The man is infected by consuming pork meat infected with the cysticercus stage of Taenia (measly pork). vii) Cysticercus develops into the adult worm inside the human host. viii) The mature worm releases gravid proglottids, few in number, in the form of chain through the faeces of human host. ix) The eggs (hexacanth embryos) are released into the environment following disintegration of uterine membrane and remain in water or in contact of vegetations. The pigs on way of swallowing vegetations ingest these larval stages of the worm. x) The larval stage or onchosphere develops inside the pig's gut and the scolex emerged out to be hooked with the gut wall. xi) The embryo after proper development enters into the circulation and comes in contact with the liver, heart, lungs and then enters into the systemic circulation. xii) The embryo is filtered out and finally finds its position in the muscle of the pig. Consumption of such a pork-meat intiates human infestation by Taenia. 4.7 Glossary Cestoda : Cestoda is a class of parasitic worms in the flatworm phylum Platyhelminthes. Proglottid : Any segment in the strobili of tape worm containing a complete sexually mature reproductive stystem. Hermaphrodite : Organisms bearing both the male and female reproductive organs together in the same body.

42 GE-ZO-11 ? NSOU Primary host : Host which harbours the adult stage of a parasite. It is also known as definitive host. Intermediate host : Host in which larval stages of a parasite find their shelter and nutrition. Onchosphere : It is the larval form of the tapeworm which subsequently develops into a cysticercus. Flame cell : It is the specialized excretory cell found in tapeworm. Measly pork : Pork-meat infected with the cysticercus larval form of T. solium. 4.8 Questions 1. State any 5 characteristic features of helminthes. What are host and parasite? 2. What is hexacanth embryo? State its characteristic features. What is measly pork? 3. What is scolex? Describe the structure of a scolex. 4. What is onchosphere? State its significance in respect to spreading of taeniasis disease. 5. Describe the life cycle of tapeworm Taenia solium. 6. Describe the structure of a gravid proglottid. Explain how pigs are involved to regulate the life cycle of Taenia solium. 7. Write notes on: (a) Flame cell (b) Hexacanth embryo (c) Cysticercus (d) Measly pork 4.9 Suggested readings 1. The tapeworm. Nicholas A. Price. Demy publshing, 2008 2. Parasitology. K.D. Chatterjee. CBS, 2009 3. Invertebrate Zoology. E.L. Jordan and P.S. Chand. S. Chand, 2009 4. Invertebrate general zoology. K.K. Chaki, G. Kundu and S. Sarkar. New Central Book Agency (p) Limited. 2008

Unit 5 ? Pseudocoelomate : General Characters of Nemathelminthes; Parasitic Adaptations Structure 5.1 Objectives 5.2 Introduction 5.3 General characters of nemathelminthes 5.4 Parasitic nematodes 5.5 Parasitic adaptations in nematodes 5.6 Conclusion 5.7 Summary 5.8 Glossary 5.9 Questions 5.10 Suggested readings 5.1 Objectives By studying the unit, students will be able to learn about pseudocoelomate animals with special emphasis on the general characters of nemathelminthes and the parasitic adaptations in nematodes. 5.2 Introduction A pesudocoelomate is an organism with body cavity which is not lined by mesoderm as it is not derived from the mesoderm, as in a true coelome or body cavity. A pseudocoelomate is also known as a blastocoelomate, as the body cavity is derived from the blastocoel, or cavity within the embryo. Nematodes or round worms, rotifers, acanthocephalans and nematomorphs or horse hair worms are pseudocoelomate animals.

44 GE-ZO-11 ? NSOU 5.3 General characters of nemathelminthes Nemathelminthes (or Aschelminthes) [Nematos—thread, Askos—bladder, Helminthes—worm] 1. Narrow, elongated, light-yellowish brown colour, round, worm like body. 2. Body is covered by tough and resistant cuticle. 3. Four longitudinal streaks, one dorsal one ventral and two lateral, are present on the body surface. 4. Various pores are present on the body surface. 5. Organ system level of organization. 6. Body cavity is filled with muscles and as these are pseudocoelomates the body cavity is not lined by mesodermal layer. 7. Internal cephalization is distinct. External differentiation between the anterior and posterior region is faint. 8. Mouth is anterior, terminal and well marked with constrictions. It is bounded by three lips—one median and dorsal while two ventro-lateral. 9. Complete but straight tube like digestive canal could be recognized into three regions—the club-shaped foregut or oesophagus, the voluminous mid gut (endodermal in origin) and the hind gut or rectum which is lined by cuticle. 10. Sense organs poorly developed in the form of papillae termed as amphids, found in association with anus. 11. Respiratory and circulatory systems are absent. 12. Respiration is aerobic in free-living form and anaerobic in parasitic form. Respiration is effected through body surface. 13. Excretory system consists of longitudinal canals or lateral excretory ducts. Protonephridia having renette cells help in excretion also. Excretory pore is ventral and near the anterior end. 14. Nervous system though not well developed, the circumpharyngeal nerve ring and longutudinal dorsal and ventral nerve cords are prominent. The ventral nerve forms a ganglion just in front of the anus (Fig: 1).

NSOU ? GE-ZO-11 45 Fig. 1: Anatomy of nematode 15. Unisexual and with distinct sexual dimorphism. In male the tail end is curved ventrally in the form of a hook with a conical tip where anus opens. Thus the said aperture serves a common passage for rectum and genital duct. Two copulatory setae protrude from the said aperture. The genitalia consists of a single coiled tubule differentiating into testes, vas deference, vesicular seminiferous and ejaculating duct opening in the anus. In female the posterior extremity is conical and straight. The anus is located slightly anterior to the posterior extremity on the ventral side, guarded by one pair of post anal papillae. In female about one third of the entire anterior end, the body is narrower gradually. This region is marked as vulvar waist. The valva is located on the ventral surface of the vulvar waist. Ovaries are paired tubes which pass gradually into oviducts, seminal receptacles and uteri. The uteri join to form an unpaired, conical vagina which opens into the female gonophore.

46 GE-ZO-11 ? NSOU 16. Fertilization may be self or cross but internal. A female usually produces 20,000 eggs daily which pass out of the host with its faeces. 17. Development is direct or indirect. In case of indirect development Rhabditiform, Filariform and Microfilariaform larvae may be seen. Moulting takes place at certain intervals and after fourth moulting beween 25 th and 29 th day, the young continues to grow to attain the normal size. Sexual maturity attains within 6-10 weeks. Fig. 2: Pelodera strongyloides in copulation Examples : Freeliving nematods : Caenorhabditis elegans, Prochromadora helenae, Pelodera strongyloides (Fig: 2) These nematodes are beneficial as they are very much involved to unlock nutrients from the detritus. Thus they play important role in the cycling of nutrients and providing energy in a variety of environment. Also many of them are used as food in aquaculture of some edible species. 5.4 Parasitic nematodes Nematodes are found as parasities in plants and animals. Therefore, they cause Fig. 3: Wuchereria bancrofti certain dreadful diseases in the concerned host-species. The species like Trichinella spiralis (causes trichinosis disease in some vertebrates), Dirofilaria immitis [Heartworm] (attack the lung, heart of dog, cat and ferrets), Agamermis decaudata (parasite of grasshopper), Heterodera rostochiensis (plant parasite, forms galls implants), Dracunculus medinensis (cause dracunculiasi disease in humans, mostly in Africa, residing just beneath the skin), Wuchereria bancrofti (cause elephantasis disease in man) (Fig: 3), Loa loa (cause loa loa in man), Onchocerca volvulus (cause river blindness in man), Ascaris

NSOU ? GE-ZO-11 47 lumbricoides (cause ascariasis disease in humans and domestic animals), Ancylostoma duodenale (cause ancylostomiasis in humans) (Fig: 4). Fig. 4: Ancylostoma duodenale 5.5 Parasitic adaptations in nematodes Parasitic nematodes have undergone remarkable physical and biochemical adaptations to ensure their survival and propagation. Of these adaptive features (i) Cylindrical reduced body size with pointed ends (ii) development of invasion apparatus such as hooks and suckers and (iii) body wall is covered with cuticle formed of albuminous proteins. The reduced body size helps them to occupy the niche in the internal or external surface of the host. The albuminous proteins in the cuticle of the body-wall is resistant to the digestive enzymes of the host. (iv) produce enzyme inhibitors that protect from the host's digestive enzymes. (v) locomotory organs are absent as they are protected from enemies being with the host body and also being ensured of supply of nutrients from the host, (vi) alimentary canal is poorly developed because of availability of semidigested food material from the intestine of the host, (vii) mostly anaerobic and required energy at the first step is available to them from the anaerobic glycolysis of glycogen because of accumulation of fatty acids by the parasite. In some cases presence of cytochrome enables them aerobic respiration. Thus, they are facultative anaerobes, (viii) sense organs are confined to lips in the form of papillae (ix) hypotonic or hypoosmotic to intestinal fluid thus ensures the stability of body-volume, (x) eggs are numerous in nature and are covered with thick warty chitinous shell. This protect them from the adverse effect of the digestive enzyme of the host, prolonged dryness and cold weather for several days.

48 GE-ZO-11 ? NSOU 5.6 Conclusion Nemathelminthes are worm-like pseudocoelomate animals. Most organ system are poorly develped. No respiratory and circulatory system while excretion is effected by protonephridia with active participation of renette cells. Nervous system though not well developed but presence of circumpharyngeal nerve ring, longitudinal dorsal and ventral nerve cords are prominent. A ganglion is located just in front of the anus. Unisexual with distinct sexual dimorphism. Development may be direct or indirect. In case of indirect development Rhabditiform, Filariform and Microfilariaform larvae are seen. Both free living and parasitic forms found under varied ecological conditions. Parasitic form have undergone a remarkable physical propagation. Some parasitic nematodes cause serious diseases in man and animals. With these adaptive features nematodes are highly adapted animals to maintain their existence. 5.7 Summary i) Nemathelminthes are pesudocoelomate worm-like, free-living or parasitic animals. ii) Ogan system level of body organization though some system viz. respiratory and circulatory systems are absent. iii) Complete tube-like digestive canal. iv) Amphids are found in association with mouth and phasmids are found in association with anus. v)

No respiratory and circulatory system. vi) Respiration is aerobic in free-living forms

and anaerobic in parasitic forms. vii) Protonephridia having renette cells help in excretion. viii) Nerve ring dorsal and ventral nerve cord and ganglion could be seen in nervous system. ix) Unisexual with distinct sexual dimorphism. Male and female reproductive systems are well developed. Development is direct or indirect development passes through larval stages viz. Rhabditiform, filariform and microfilariaforms. x) Sexual maturity takes place within 6-10 weeks. xi) Parasitic forms are reduced in body size, cylindrical body with pointed ends.

NSOU ? GE-ZO-11 49 xii) Invasion appaatus like hooks and suckers are well developed. xiii) Body wall is covered with cuticle. xiv) Enzyme produces by the parasitic forms helps them to protect from the host's defence mechanism. xv) Eggs are numerous and are protected from adverse conditions by the help of thick warty chitinous shell. 5.8 Glossary Pseudocoelomates : Animals in which body cavity is not derived form the mesoderm and thus not lined by mesoderm. Amphids : Poorly developed sense organs in the form of labial papillae. Phasmids : Caudal papillae in some nematodes which are chemosensory in nature. Renette cells : Cells those help in excretion in nematodes. Sexual dimorphism : It refers to morphologically different two sexes due to the presence of distinct characters for identification of males and females of the same species. Elephantasis : A disease of man caused by the nematode Wuchereria bancrofti. Suckers : The organs for attachment with the host's body. 5.9 Questions 1. What do you mean by pseudocoelomates? 2. Cite example of two pseudocoelomate animals. State any five characteristic features of a pseudocoelomate animal studied by you. 3. State the salient features of male and female reproductive organs of a nematode. 4. How many types of larvae could be seen in nematodes? What type of fertilization is effective in nematodes? How eggs of a nematode come out of the host body to the exterior? When does fourth moulting take place in a developing nematode? How many weeks are needed to attain sexual maturity following attainment of adult stage after final moulting?

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50 GE-ZO-11 ? NSOU 5. Name any 4 diseases of man caused by nematodes. Mention any five types of morphological adaptations of nematodes to lead a parasitic life. 6. Enumerate the parasitic adaptations in nematodes. 7. Write notes on : (a) Economic importance of nematodes. (b) Loa loa and river blindness. (c) Amphids and phasmids. 5.10 Suggested readings 1. K.C. Ghose and B. Manna (2015). A textbook of Zoology. New Central Book Agency, Kolkata. 2. K.K. Chaki, G. Kundu and S. Sarkar (2014). Introduction to General Zoology, Vol. 1. New Central Book Agency, Kolkata. 3. A.J. Marshall and W.D. Williams (1985). Textbook of Zoology. Vol. 1. Invertebrates. The Macmillan press Ltd. London. 4. J.A. Pechenik (2000). Biology of the invertabrates. 4 th edn. Tata McGraw- Hill edition. The Tata MacGraw-Hill Publishing Company Ltd. New Delhi.

Unit 6 ? Coelomate Protostomes : General Characters of Annelida, Metamerism Structure 6.1 Objectives 6.2 Introduction 6.3 General characters of annelida 6.4 Metamerism 6.5 Conclusion 6.6 Summary 6.7 Glossary 6.8 Questions 6.9 Suggested readings 6.1 Objectives By studying this unit, students will be able to- (i) gain knowledge on the coelomate protostomes; (ii) study the characteristic features of different groups of annelid animals and the phenomenon of metamerism. 6.2 Introduction Annelids are true coelomate animals. Coelom is the fluid-filled body cavity which is completely lined by tissue created from the mesoderm, the middle layer of the primary cells found in an embryo. The majority of coelomate invertebrates develop as protostomes ("first mouth") in which the oral end of the animal develops from the first developmental opening, the blastopore i.e. blastopore becomes the mouth. (Fig: 1). Thus, the animals bearing these characters in respect to their history Fig. 1: Protostome

52 GE-ZO-11 ? NSOU of development are termed as coelomate protostomes. These animals are primitive invertebrates such as annelids, arthropods and molluscs. 6.3 General characters of annelida Annelida (from Latin anellus, "little ring") a group of segmented or ringed worms are found worldwide from deepest marine sediments to the soils in our yards. The extant species belong to ragworms, earthworms and leeches. The characteristic features of the phylum Annelida are as follows. 1. Elongated, triploblastic, bilaterally symmetrical vermiform body. 2. Aquatic (marine and freshwater), terrestrial, burrowing or sedimentary and free living or commensal or parasitic. 3. Metamerically segmented body: externally by transverse grooves and internally by septa into a number of division. Each division is known as a segment or metamere or somite. 4. Organ grade system body organization. 5. Single layer epidermis which is made of columnar epithelial cells. It is covered by a thin non-chitinous cuticle. 6. Dermo-muscular body wall is contractile. It consists of outer circular and inner longitudinal muscle fibers. 7. Appendages when present are paired. 8. Chitinous setae or fleshy appendages i.e. parapodia are locomotory organs. These locomotory organs are repeated segmentally. 9. Schizocoelous coelom usually divided into compartments by transverse septa. It is well developed in leeches. Cells or corpuscles are present in coelomic fuid. 10. Complete and straight alimentary canal extends form mouth to anus. Extracellular digestion. 11. Moist skin or gills of parapodia and head help in respiration. Respiratory pigments are red haemoglobin or green chlorocruoins. 12. Closed blood vascular system with dorsal and ventral longitudinal vessels connected with each other by small vessels. 13. Excretion is effected through the coiled tubes; the nephridia which communicate the coelom to the exterior. NSOU ? GE-ZO-11 53 14. Nervous system is made of a pair of cerebral ganglia (the so-called

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brain) and double ventral nerve cord having segmentally arranged ganglia and lateral nerves in each segment. 15. Tactile organs, buccal receptors, statocysts, photoreceptor cells and sometimes eyes with lenses

act as receptor organs. 16. Hermaphroditic or unisexual; cleavage spiral. Reproduction though mostly sexual but in some species asexual reproduction is also in practice. 17. In monoecious forms development is direct but indirect in dioecious form. 18. Indirect development takes place through the trochophore larval stage. 19. Regeneration is a common event. Examples : Nereis (Nereis dumerilii) (Fig: 2), Aphrodite [sea mouse] (Aphrodita aculeata) Fig : 3), Chaetopterus [parchment worm] (Chaetopterus variopedatus), Sabella [Fanworm] (Sabella spallanzanii), Tubifex [sludge worm] (Tubifex), Pheritima (Earthworm) (Fig: 4), (Pheretima posthuma), Hirudo (leech) (Fig: 5), (Hirudo medicinalis). Fig. 2: Nereis Fig. 3: Aphrodite Fig. 4: Earthworm Fig. 5: Leech

54 GE-ZO-11 ? NSOU 6.4. Metamerism Metamerism is the phenomenon of having a linear series of body segments fundamentally similar in structure though not all such structures are entirely alike in many single life form because some of them perform special function. This is clearly visible in an earthworm. A close look to the outer surface of the earthworm's body would reveal the fact that, the tube like elongated body is made of a number of ring- like segments joining with each other. Thus, these serial repetition of segments and organ systems (skin, musculature, nervous system, circulatory system, reproductive system and excretory system) is known as metameric segmentation (Fig: 6) or mentamerism. That is, each metamere is provided with a part of almost all the organ systems. In annelids some anterior segments look different in nature. Therefore, typical homonomous segmentation is absent. In embryonic stages the metamerism is complete and uniform. But in adult condition it will change due to cephalization. The origin of mentamerism is not clearly known. Several theories have been proposed to explain the development of matamerism viz. (1) Fission theory, (2) Pseduometamerism theory, (3) Embryolgical theory and (4) Locomotory theory. R.B. Clark (1964) proposed the locomotion theory to explain the origin of metamerism in annelids. According to this theory metamerism evolved in annelids as an adaptation to peristaltic locomotion and for burrowing. Peristaltic locomotion is effected due to shortening and lengthening of body by circular and lognitudinal muscles. As the coelom is filled with coelomic fluid peristaltic locomotion will not be possible unless the coelom is divided by septa, so that high presure produced by contraction of muscles can be confined to a particular region and it does not affect the whole body. Metamerism helps annelids to save energy as well as to control and regulate locomotory movement in different directions. It also offers division of labour. It is noteworthy to mention that metamerism not only occurs in annelids but occurs also in arthropods and in many chordates. Fig. 6: Metameric segmentation

NSOU ? GE-ZO-11 55 6.5 Conclusion Annelids are ringed worms triploblastic and bilaterally symmetrical commonly found in marine, freshwater and terrestrial environments. Well organized body with various organs. Closed circulatory system and nervous system presents a pair of cerebral ganglia. Bisexual or unisexual. Development takes place through the trochophore larval stage. The most interesting feature in this group is metamerism i.e. body consists of a series of ring-like body segments. Though the exact cause of metamerism is not known it is assumed that the same is associated with the locomotion of organism concerned. Thus annelids are adapted in such a way which triggered the appearance of highly developed animal groups even vertabrates. 6.6 Summary i) Annelids are true coelomate animals. ii) The oral end of these animals develops from the blastopore. Therefore, they are protostomes. iii) Elongated body, segmented and each segment is ring-like. iv) Dermo-muscular body wall is contractile. v) Satae or parapodia serve as locomotory organs. vi) Alimentary canal is straight and complete. Extracellular digestion. vii) Closed type vascular system. Blood is red. viii) The coiled tubes i.e. nephridia help in excretion. ix) Nervous system with cerebral ganglia and ventral nerve cord. x) Bi-sexual or unisexual. Cleavage spiral. Indirect development takes place through the trochophore larval stage. xi) Regeneration takes place. xii) Typical homonomous segmentation is absent. 13. The origin of metamerism is not clearly known but locomotion theory suggests that metamerism evolved in annelids as an adaptation to peristalic locomotion and burrowing.

56 GE-ZO-11 ? NSOU 6.7 Glossary Seta : Locomotory organ in earthworm. Ragworms : The worms belong to the family Nereididae of class Polychaeta are commonly called ragworms or clam (Nereis). Schizocoelom : Develops due to mesodermal split. This body cavity is formed blocks of mesoderm around the gut that enlarge and hollow out. Metameric : Consisting of several similar segments or somites. Hermaphrodite : Organism contains both the male and female reproductive organs. Nephridium : Excretory as well as osmaregulatory organ. Statocyst : A small organ helps in balance. Fan worm : Sabella Sea mouse : Aphrodite 6.8 Questions 1. Define protostome. State the locomotory organs of annelids. What do you mean by metameric segmentation? 2. State six salient features of Annelida. Explain why annelids belong to coelomate protostome? 3. Why the blood of earthworm is red? What is nephidium? State its function. State the function of statocyst. 4. Explain the term 'hermaphrodite'. What type of cleavage is seen in Annelida? Which type of digestion takes place on annelids? 5. Define metamerism. Add a note on its origin and significance in annelids. 6.9 Suggested readings 1. K.C. Ghose and B. Manna (2015). A textbook of Zoology. New Central Book Agency, Kolkata. NSOU ? GE-ZO-11 57 2. K.K. Chaki, G. Kundu and S. Sarkar (2014). Introduction to General Zoology, Vol. 1. New Central Book Agency, Kolkata. 3. A.J. Marshall and W.D. Williams (1985). Textbook of Zoology. Vol. 1. Invertebrates. The Macmillan press Ltd. London. 4. J.A. Pechenik (2000). Biology of the invertabrates. 4 th edn. Tata McGraw- Hill edition. The Tata MacGraw-Hill Publishing Company Ltd. New Delhi. 5. D.H. Shain (2009). Annelids in modern Biology. Wiley online library. Wiley-blackwell.

Unit 7 ? Arthropoda : General Characters; Social Life in Insects Structure 7.1 Objectives 7.2 Introduction 7.3 General characters of arthropoda 7.4 Social life in insects 7.5 Conclusion 7.6 Summary 7.7 Glossary 7.8 Model Questions 7.9 Suggested readings 7.1 Objectives By studying this unit, students will be able to have an idea on the characteristics of the diverse animal groups belong to the phylum Arthropoda and to gain knowledge on the social life of some insects. 7.2 Introduction The phylum Arthropoda (Arthro=jointed, pods-feet) contains the animals that have jointed appendages. Todate of the described animal species at least 75% belongs to Arthropoda. 7.3 General characters of arthropoda 1.

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Bilaterally symmetrical, triploblastic and coelomate animals. 2. The body is covered by chitinous exoskeleton. 3. The

three regions, that is, head, throax and abdomen of the body are distinct.

NSOU ? GE-ZO-11 59 4. Exhibits organ system level of organization. 5. Appendages are jointed and locomotion is effected by the help of these appendages. 6. Head bears a pair of compound eyes. 7. Coelom space is filled with blood and thus acts as haemocoel. 8. Open type circulatory system. 9. Excretion is effected through malpighian tubules or green glands or coaxal glands. 10. Nervous system consists of a cerebral ganglionic mass and a ganglionated double ventral nerve cord. 11. Body surface, trachea, gills help in respiration. 12. Hairs, antennae, simple and compound eyes, auditory organ and statocysts act as sensory organs. 13. Unisexual. Fertilization is either external or internal. 14. Development is direct or indirect. In case of indirect development different kinds of larval stages are seen in many group of arthropods. The major groups are : Crustacea : They may be aquatic, terrestrial or parasitic. Head is fused with thorax region and therefore, the said region is known as cephalothorax. Respiration Examples :Prawn (Palaemon carcinus, Macrobrachium rosenbergii), Daphnia (Daphia magna), Crab (Scylla serrata) (Fig: 1). Myriapoda : Elongated, mostly terrestrial arthropods with numerious segments. Head bears antennae, two pairs of jaws and a pair of simple eyes. Legs numerous. Fig. 1: Scylla serrata takes place through gills and body surface. Body is covered either by a single large carapace or carapace covers part of the body. Bear biramous appendages and two pairs of antennae. Excrete through green glands or antennal glands. They bear one pair of compond eyes. Sexes separate. Development passes through larval stages.

60 GE-ZO-11 ? NSOU Fig. 2: Scolopendra Fig. 3: Julus Mouth with upper and lower lips. Upper lip contains epistome and labrum while the lower lip contains a pair of maxilla. One pair mandible locating inside the mouth. Respire by trachea and excrete through Malpighian tubules. Examples :Scolopendra (Scolopendra subspinipes) (Fig : 2), Julus (Julus terrestrics) (Fig : 3) Hexapoda or Insecta : Mostly terrestrial, head bears a pre-segmental acron. Thorax with three segments but abdomen bears 7-11 segments. Three pairs of thoracic appendages and one pair of compound eyes. Respirae by the help of gills and trachea. Malpighian tubules serve as excretory organ. Development is indirect with larval stages. Fig. 4: Mosquito Fig. 5: Honey Bee Fig. 6: Butterfly Examples :Ants (Componotus compressus, Oecophylla smaragdyna), Mosquitoes (Anopheles stephensi, Culex pipiens) (Fig : 4), Honeybee (Apis dorsata) (Fig : 5), Butterfly (Papilo machaon) (Fig : 6), Cockroach (Periplaneta americana). Chelicerata : Mostly terrestrial, body is differentiated into cephalothorax and abdomen which bears 13 segments. Five pairs of anterior appendages of which 1st pair is chelicerae used in feeding. Appendages are uniramous. No mandibles or jaws.

NSOU ? GE-ZO-11 61 Antennae absent. Trachea or gills serve as respiratory organ. Excretion is effected through Malpighian tubules. Examples :Spiders (Aranea diadema, Thiania bhamoensis), King crab or Horse-shoe crab (Limulus polyphemus) (Fig: 7), Mite (Tetranychus urticae). Peripatus (a living fossil) (Peripatus basilensis, P. capensis) (Fig :8) Onychophora (Recently it has been given the status of a seperate phylum) : Small terrestrial arthropods. Body divided into segments. Nephridia help in exertion. Trachea act respiratory organ. Trilobitomorpha : Primitive arthropods which are now extinct. 7.4 Social life in insects In insects social life has evolved in two groups viz. Isoptera (termits) and Hymenoptera (bees, wasps and ants). These insects construct a nest and adapted to live in colonies. Thousands of individuals may be seen in a colony and the division of labour among them is well marked in individual or individuates (castes) which is pronounced through social interactions. In termites :Termites started to live an organized social system about 300 million years ago, much earlier than honey bees and ants. Termite colony is composed of (1) a queen, (2) many workers and soldiers. (Fig : 9) The queen is an egg-laying machine. She lives for 15-20 years. She lives in a royal chamber and workers have to take care of all her daily chores. The workers and soldiers are highly devoted to the colony, working incessantly and tirelessly, demanding Fig. 7: Limulus Fig. 8: Peripatus

62 GE-ZO-11 ? NSOU nothing in return from the society. Soldiers defend their nest and workers chew the wood to feed to the queen and larvae and grow fungus gardens for lean periods. Nasutes are specialized soldiers. They are specialized in chemical warfare. They produce a jet of highly corrosive chemical from their bodies that can dissolve the skin of enemies and can also help in making galleries through the rocks. A termite nest which presents highest form of architecture is known as termitarium. In bees : Honey bees construct hive and the functioning of the hive members is regulated in a disciplined way by (1) a queen, (2) many drones and (3) many workers. In a bee colony only the queen is a fertile female. She keeps the colony in order by secreting a pheromone from her mandibular glands. The queen produces eggs. Drones are haploid fertile males. There may be 2-3 dozen drones in bee-hive. They take part in nuptial flight and finally one drone individual mates with the queen. Thereafter drones are driven out of the colony and finally die in starvation. In a hive workers may be 20,000 to 80,000 in number. They are genetically sterile females. They help to build, maintain and protect the hive. Cleaning and maintaining the hive, feeding the larva with honey and bee bread are their routine work. Also, a worker secretes wax from the abdominal wax glands and builds the honey comb cells. Workers act as foragers and thus collect nectar and pollen and also water for the colony members. They die in course of such services. In wasps : In wasps society there exists a caste system consisting of one or several queens, a few drones (males) and sterile females called workers. The queen, a fertilized female, begins the colony in the Fig. 9: Castes of termites MALE FEMALE QUEEN SOLDIER WORKER REPRODUCTIVE

NSOU ? GE-ZO-11 63 spring by building a small nest and laying eggs that hatch into workers. They construct a paper like nest, which is composed of chewed dry plant materials, woolly wood, that has been mixed with saliva and regurgitated. In ants : Ants are cousins of honey bees and wasps but while bees and wasps are diurnal and sleep in the night ants are busy in working day and night. Ants have the highest developed social system (Fig: 10). A colony may have up to 5,00,000 individuals. The nests are built in various designs and are called formicaria. Different castes are specialized to perform specific functions. The queen lays up to 2-3 million eggs in a year. The males fertilize her. Workers have broad, sharp mandibles for cutting and chewing and the soldiers have large head that bears sharp dagger-like mandibles for fighting. Workers and soldiers are sterile females. Ants construct nest in the ground or on wood or on trees made of earth, carton, wax or silk. They have developed a highly sophisticated chemical language for communication. Pheromones play important role in communication. The queen produces eggs while the other female workers go out for foraging food, carry the same for the queen and her brood, and also help in building, maintaining and defending the anthill. The drone has only function that is, to fertilize the queen. They die shortly after mating. 7.5 Conclusion Arthopods are found almost in all type of habitats and thereby they have undergone distinctly different adaptations, group-wise, by modifying their body organizations morphologically, anatomically, physiologocally and behaviorally to cope up with the conditions to ensure survival and propogation. Interestingly, some of them especially those belong to insect have developed the art of living through Fig. 10: Castes of Ants Queen Male Normal-sized worker Soldier

64 GE-ZO-11 ? NSOU cooperation on way of developing a social life with a view to share the benefit among all the colony members through the execution of assigned functions. 7.6 Summary i) Arthropods are animals with jointed appendages. ii) Bilaterally symmetrical, body is covered by chitinous exoskeleton. iii) Head, thorax and abdomen regions distinct. iv) Head bears a pair of compound eye. v) Coelomic space is filled with blood. vi) Open type circulatory system. vii) Malpighian tubules or green glands or coxal glands help in excretion. viii) Unisexual, fertilization may be internal or external. ix) Gills or trachea or body surface serve as respiratory organ. x) Development may be direct, or iredirect through different larval stages. xi) Termites, honeybees, wasps and ants exhibit social life by developing the strategy of living in colony. 7.7 Glossary Compound eye : An eye consists of numerous small visual units. Green gland : Also known as antennal gland. Acts as excretory organ in crustaceans. Malpighian tubules : A type of excretory and osmoregulatory organ system found in some insects, myriapods, arachnids and tardigardia. Haemocoelomic fluid : Coelomic fluid dissolved with haemoglobin. Gonopore : Genital pore. Hexapoda : Animals with three pairs of thoracie legs, especially the insect. Peripatus : An arthropod belongs to onychophora. It is a living fossil. Nasutes : Specialized soldiers of termite colony. Drones : Haploid fertile male honeybees. Formicaria : Nest of ant.

NSOU ? GE-ZO-11 65 Royal chamber : The chamber where queen of termite lives. Nuptial flight : Flight exhibited by drones of honey bee following queen for mating. Wax gland : Found in the abdomen of worker bee which secretes wax to construct honey comb. 7.8 Questions 1. State any five morphological characters of Arthropoda. Name the excretory organ of cockroach and prawn. 2. Name the major groups of Arthropoda. State the characteristic features of crustaceans. 3. Cite two examples of myriapods with scientific name. An ant is an inset- justify your answer with suitable reasons. 4. Write any five distinctive characters of Chelicerata. Cite examples two such arthropods with scientific name. 5. Discuss the social life of termite. 6. Describe the castes of honeybees and state their role to maintain a social life. 7. Briefly discuss the social life of ant. What meterials are needed to constuct the nest by the wasps? 7.9 Suggested readings 1. K.C. Ghose and B. Manna (2015). A textbook of Zoology. New Central Book Agency, Kolkata. 2. K.K. Chaki, G. Kundu and S. Sarkar (2014). Introduction to General Zoology, Vol. 1. New Central Book Agency, Kolkata. 3. A.J. Marshall and W.D. Williams (1985). Textbook of Zoology. Vol. 1. Invertebrates. The Macmillan press Ltd. London. 4. J.A. Pechenik (2000). Biology of the invertabrates. 4 th edn. Tata McGraw- Hill edition. The Tata MacGraw-Hill Publishing Company Ltd. New Delhi. 5. H.S. Bhamrah and K. Juneja. (2002). An introduction to Arthropoda. Anmol publicetions pvt. Ltd. New Delhi. Unit 8 ? Mollusca : General Characters of Mollusca; Pearl Formation Structure 8.1 Objectives 8.2 Introduction 8.3 General characters of mollusca 8.4 Pearl formation 8.5 Conclusion 8.6 Summary 8.7 Glossary 8.8 Questions 8.9 Suggested readings 8.1 Objectives By studing this unit, students will be able to know the characteristic features of molluscs occurring in land and water and the mechanism of pearl formation by certain groups of aquatic molluscs. 8.2 Introduction Mollusca is one of the most diverse groups of animals having at least 50,000 living species belonging to snails, slugs, octopuses, squids, clamps, scallops, oysters and chitons. It is the second largest phylum of invertebrate animals after the Arthropoda. 8.3 General characters of mollusca 1. Soft, unsegmented (except Monoplacophora), bilaterally symmetrical, coelomate, triploblastic animal. 2. Mostly marine but freshwater and terrestrial are not uncommon.

NSOU ? GE-ZO-11 67 3. Free living but some are parasitic and predacious. 4. Body size varies to a great extent—from giant octopus to small snail. 5. Mantle and radula (except pelecypods) are most notable characters in this animal group. 6. Body in most cases is protected by a calcareous shell which is secreted by the mantle. 7. Tissue-system grade of body organization. 8. Distinct head and ventral muscullar foot. 9. The soft body mass is covered with one-layered usually ciliated epidermis. 10. Except pelecypods and scaphopods head bears mouth, eyes, tentacles and sense organs. 11. The foot is modified in different forms to ensure creeping, burrowing and swimming. 12. Visceral mass contains the vital organs. 13. Body cavity is truly a hemocoel. The coelom is reduced and represented mainly by the pericardial cavity, gonadal cavity and nephridia. 14. Digestive system is well developed and digestive tract is started with mouth and terminated by anus. In gastropods, scaphopods and cephalopods the inestine becomes U-shaped and thus both mouth and anus open at the anterior part while in the remaining groups mouth is anterior and the anus is located at the posterior end. 15. Radula located in the mouth acts as rasping organs. 16. Open circulatory system (except Cephalopoda). 17. Gills or ctenidia help in respiration in aquatic forms while pulmonary sac i.e. so- called lungs help to exchange air in terrestrial forms. 18. Haemocyanins are seen as respiratory pigments in most cases. 19. Paired metanephridia (kidney) act as excretory organs. 20. Nervous system is well developed. It consists of paired cerebral, pleural, pedal and visceral ganglia joined by longitudinal and transverse nerves. 21. Eyes, statocysts and receptors act as sense organs osphradium, generally located adjacent to ctenidium, acts as chemoreceptor or tactile organ.. 22. Some molluscs are unisexual while others are bisexual (hermaphroditic)

68 GE-ZO-11 ? NSOU 23. External as well as internal fertilization are seen in molluscs. 24. Development is direct, or indirect through the trochophore/veliger larva. Examples :Snails [Pila globosa (Fig : 1), Achatina fulica], Mussels (Lamellidens marginalis) Squids (Sepia rostrata, Loligo forbesii (Fig: 2), Octopus vulgaris (Fig : 3) Fig. 1 Pila Fig. 2 Loligo Fig. 3 Octopus 8.4 Pearl formation Molluscs used as food, medicine, decorative and ornamental purposes, also the chank has a role to maintain religion in human society. As ornamental as well as for medicinal purpose, pearl is widely used in human society. It is undoubtedly, intriguing to gain knowledge on the mechanism of pearl formation in molluscs especially in oysters—the pearl oyster. Pearl producing oysters belong to the genus Pinctada. The species Pinctada maxima lives in the Indian ocean and the Pacific from Japan to Australia and produces pearls known as south sea pearls. However, pearls are formed by saltwater, freshwater oysters, mussels, clams, conchs and gastropods. A pear is a resultant reaction to an irritant within a mollusc. Natural pearls form when an irritant, usually a parasite works its way into an oyster, mussel or calm. As a defense mechanism, a fluid is used to coat the irritant, the parasite. Layer upon layer of this coating called 'nacre' is deposited and as a consequencc a lustrous pearl is formed. Pearl culture is nowadays an industry. In this process irritant is a surgically implanted bead or piece of shell called mother of pearl (the foreign body). These seeds or nuclei are most often formed from mussel shells. Quality cultured pearls require a sufficient amount to time—generally at least 3 years for a thick layer of nacre to be deposited, resulting in a beautiful, gem-quality pearl.

NSOU ? GE-ZO-11 69 When a small parasite or foreign body invades in between the mantle and the shell it becomes enclosed in a sac of mantle (Fig : 4) epithelium which produces irritation. The irritation stimulates the mantle epithelium to secrete thin concentric layers of mother of pearl around the foreign body. The amount of deposition is in direct proportion to the degree of irritation. Mantle Foreign body Quter layer Pearl Mother of pearl Shell Layers of nacre Fig. 4: Process of pearl formation in mollusca 8.5 Conclusion Molluscs have undergone through remarkable morphological and anatomical modifications to adjust their mode of living in land, trees, freshwater and salt water under varying enviornmental conditions. Accordingly some species are with a hard shell covering while others are devoid of the same. Some are herbivorous while others are predacious or filter feeders. Thus, they have developed radula, tentacles, suckers, ink gland and in some cases by covering of the shell aperture for feeding. The organ system is highly developed to maintain feeding, respiration, excretion, reproduction etc. Also some of them have developed the art to protect them from the attack of any kind of foreign body by capturing the same by the layer of nacre which ultimately produces the pearl. 8.6 Summary i) Soft, unsegmented, free-living, parasitic or predacious animals. ii) In most cases body is covered by calcareous shell though some could be seen naked either in the land or trees or ponds or sea.

70 GE-ZO-11 ? NSOU iii) Herbivores scrap food by the help of radula while carnivores capture the prey by different devices with the help of tentacles and suckers. iv) In all cases a ventral muscular foot and a mantle covering could easily be revealed through a careful look. v) In most cases eyes, tentacles, head, mouth and sense organs are prominent. vi) Body cavity is truly a hemocoel. The coelom is confined to pericardial cavity, gonadal cavity and nephrida. vii) Well developed digestive system. viii) In most cases circulatory system is open type. ix) Gills or ctenidia and pulmonary sac/lungs help in respiration. x) Haemocyanin acts as respiratory pigment. xi) Metanephrida serve as excretory organs. xii) Well developed nervous system. xiii) Statocyst, eyes and receptors act as sense organs. xiv) Unisexual or besexual. Development may be direct, or indirect through the trochophore or veliger larva. xv) Pearls are product by oysters and also by some gastropods. The commercial pearls are produced by the oysters in culture-farms. 8.7 Glossary Rudula : Food scraping appartus in molluscs Nacre : It is known as mother of pearl which is composed of organic-inorganic composite materials. Osphradium : An olfactory organ found in certain molluscs. It helps to test incoming water for silt and possible food particle. Mantle : It is the dorsal body wall which covers the visceral mass. Metanephridum : An excretory gland which is also known as Bojanus organ in molluscs. Apple snail : It is an amphibious gastropod. It's scientific name is Pila globosa. Mother of pearl : Nacre is called the mother of pearl.

NSOU ? GE-ZO-11 71 8.9 Questions 1. State any five salient features of Mollusca. Name two molluscs of which one respire by the help of lungs while the other depends on ctenidium. 2. What is radula? State its function. Name the mollusc-group where radula is absent. What is osphradium? 3. Name the molluscan animal group where the mouth and anus open at the anterior part. Explain the reason for such a phenomenon. What is haemocyanin? 4. Discuss the components of nervous system and sense organs in molluscs. 5. Name the larval forms of molluscs. What kind of fertilization is in practice in Mollusca? 6. What is pearl? Name a pearl producing oyster of Indian ocean. State the importance of pearl. 7. Discuss the mechanism of pearl formation in a pearl-producing mollusc. 8. Write notes on : (a) Mother of pearl; (b) South sea pearls; (c) Coelom in molluscs; (d) Foot of mulluscs. 8.10 Suggested readings 1. K.C. Ghose and B. Manna (2015). A textbook of Zoology. New Central Book Agency, Kolkata. 2. K.K. Chaki, G. Kundu and S. Sarkar (2014). Introduction to General Zoology, Vol. 1. New Central Book Agency, Kolkata. 3. A.J. Marshall and W.D. Williams (1985). Textbook of Zoology. Vol. 1. Invertebrates. The Macmillan press Ltd. London. 4. J.A. Pechenik (2000). Biology of the invertabrates. 4 th edn. Tata McGraw-Hill edition. The Tata MacGraw-Hill Publishing Company Ltd. New Delhi. 5. G.M. Barkar (eds.) (2001). Biology of terrestrial molluscs. CABI publishing, CAB international, Oxon, U.K. 6. K. Alagarswami and S. Dharmaraj (1984). Manual on pearl culture techiques. CMFRI Speical publication, No. 20. ICAR, Cochin, India. 72 GE-ZO-11 ? NSOU Unit 9 ?Coelomate Deuterostomes : General Characters of Echinodermata; Water Vascular System in Starfish Structure 9.1 Objectives 9.2 Introduction 9.3 General characters of echinodermata 9.4 Water-vascular system in starfish 9.5 Conclusion 9.6 Summary 9.7 Glossary 9.8 Questions 9.9 Suggested readings 9.1 Objectives By studying this unit, students will be able to have an idea regarding characteristic features of the colomate deuterostome animals belong to the phylum Echinodermata. Also, in this group of animals a special type of biological mechanism-the water vascular system is well marked and in this chapter the aim is to study the same in the starfish to ascertain the significance of such a system. 9.2 Introduction Coelomate deuterostomes are advanced group of animals having highly organized biological systems. Coclemate deuterostomes : During the embryonic development, tissues differentiate into germ layers at the gastrulation phase, which later form the organ and specialized tissues of the body. Two or three embryonic germ layers can be developed, based on which animals are also classified and called as diploblasts or triploblasts respectively. NSOU ? GE-ZO-11 73 Deuterostomes are animals in which the blastopore develops into anus (Fig: 1). The mouth forms later. Deuterostomes typically display radial cleavage of the blastula, indeterminate development and enterocoelic formation of the coelom. Paired mesodermal pouches develop from the primitive gut wall, they enlarge and fuse to form the coelom. In cases of radial cleavage the cells divide either parallel to or right angles to the long axis of the early embryo so that the cells produced lie directly above one another. Fig. 1 Deuterostome Enterocoelic is a method of coelom formation within pouches of mesoderm budded off from embryonic gut wall. This way of development is seen in echinoderms, hemichordates, brachiopods and also in some other groups of animal. 9.3 General characters of echinodermata The name Echinodermata [Two greek words : Echinos-spine; dermatos-skin, that means "spiny skin"] was first coined by Kelin (1734) and referenced by Linnaeus (1758). The general characters of echinoderms are: 1. Bodyform varies considerably from star-shaped to spherical, cylindrical. Unsegmented body without head. 2. Most organisms bear spines and pincer-like pedicellariae. Spines help in protection. Pedicellariae keep the body surface clean from all kinds of debris and tiny organisms. 3. Adults show radial and pentamerous symmetry while the larval forms are bilaterally symmetrical. 4. Triploblastic animals having organ system level of organization.

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74 GE-ZO-11 ? NSOU 5. In body wall epidermis is single layered and ciliated. In many species endoskeleton of calcareous plates could be seen in dermis. Spines are supported by the calcareous plates. 6. The body is differentiated into oral (mouth bearing) and aboral surface. 7. On the oral surface there are five grooves called ambulacra, radialing from the mouth to the tip of the arms, with intervening interambulacra. 8. Muscles are smooth and are found beneath the dermis. 9. A true enterocoelic coelom surrounded by ciliated peritoneum. 10. Except Brittle stars digestive system is complete. 11. Presence of water vascular system is the nontable characteristic feature in echinoderms. This is also known as ambulacral system. Madreporite, a perforated calcareous plate is present in this system. Madreporite pores allow water into the system. Tubefeet associated with this system help in locomotion, food-capturing and respiration. Water vascular system is of coelomic origin. 12. Coelomic origin haemal and perihaemal systems serve as an open circulatory system. No respiratory pigment and heart. 13. No specialized excretory organ but the nitrogenous waste, chiefly ammonia is diffused out via gills. 14. A nerve ring and radial nerve cords are the components of nervous system where brain is absent. Sense organs are also poorly developed. 15. All organisms are marine, either pelagic or sessile but prefer to live at the sea bottom. 16. Reproduces both sexually and asexually, but there exists no sexual dimorphism. Usual fertilization is external. Also some are viviparous. 17. Autotomy and regeneration are well marked in echinoderms. 18. Development indirect i.e. adult stage appears through the ciliated larval forms. 19. Echinoderms resemble chordates in early embryoric development. Thus it is assumed that the echinoderms are nearer to the Chordata.

NSOU ? GE-ZO-11 75 Examples :Starfish (Asterias rubens) (Fig: 2), Brittlestar (Ophiura ophiura), Sea urchin (Echinometra viridis, Echinus sp.), Sea cucumber (Cucumaria frondosa) (Fig : 3), Sea lillies (Cenometra bella, Antedon sp.) (Fig: 4) 9.4 Water vascular system in starfish Water vascular system (Fig : 5) is a hydraulic system used by echinoderms to accomplish various functions. This system is well developed in starfish and be treated as typical one. This system is also known as Ambulacral system. The system is nothing but a net-work of canals which remain filled with sea water. The entire tube is lined by ciliated epithulium. The system is composed of (1) Madreporite, (2) Stone canal, (3) Ring canal, (4) Radial canals, (5) Polian vesicles and Tiedmann's bodies, (6) Lateral canals and (7) Tube feet (Fig :5) Fig. 4 Sea lily Fig. 2 Starfish Fig. 3 Sea Cucumber

76 GE-ZO-11 ? NSOU 1. Madreporite : It is located on the aboral surface of the central disc of star fish. It is calcareous in nature and plate-like in structure. On the surface of madreporite grooves furrows are present. Each furrow is provided with a number of pores. These pores lead into small canal which opens into a stone canal. 2. Stone canal : This canal is '

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S' shaped. The canal extends downwards (orally) and opens into a ring canal, around the mouth. The canal wall is

supported by a number of calcareous rings, thereby it is named as stone canal. A ridge is projected from the wall of the stone canal. The ridge is bifurcated into two lamellae. The lamellae become spirally rolled and occupied considerable portion of the lumen of the stone canal. Sometimes the lumen of the stone canal looks very much complicated due to extensive development of the lamellae. The stone canal serves as pump to drive the circulation of sea water. 3. Ring canal : It is located around the mouth

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and directly above (aboral) to the hyponeural ring sinus. It

is wide but pentagonal ring like canal. 4. Radial canal : The ring canal gives off five radial canals along the ambulacral grooves of the arms. This canal runs
up to the tip of the arms and ends as the lumen of terminal tentacle. 5.
Polian vesicles and Tiedmann's bodies : In certain star fishes there occur pear-shaped sacs called polian vesicles which are connected with ring canal Fig. 5 Water vascular system in star fish Lateral canal Tiedmann's body Polian vesicle NSOU ? GE-ZO-11 77 inter-radially. Tiedmann's bodies are small spherical yellowish, glandular bodies emerged from the neck of each polian vesicle, attached to the inner wall of the ring canal. The polian vesicles are absent in Asterias sp. Thus, the ring canal gives of inter-radially nine such Tiedmann's bodies. The function of the Tiedmann's bodies are not clearly known. It is assumed that, these help

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to filter fluid from the vascular system into the body cavity. 6.
Lateral (podial) canals : These paired but alternately arranged small side branches projected from the radial

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canals. Each lateral canal is attached to the base of the tube-foot and contains a valve

which prevents the back flow of water from the tube-foot to the radial canal. The flow of fluid from lateral canal to ampulla and podium of tube foot is controlled by the valve. 7. Tube feet : There are numerous tube feet arranged in two rows on either side of the ambulacral groove. A

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tube feet is a hollow, elastic, thin walled, closed cylinder or sac-like ampulla, a middle tubular podium and a lower disc like sucker. The ampulla lies within the arm, projecting into the coelom above the ambulacral pore—

a gap between the adjacent ambulacral ossicles for the passage of the podium. Tube feet help in locomotion and respiration. Function of water vascular system: water vascular system helps starfishes in (i) locomotion, (ii) food-capturing and (iii) attachment to the rocks. 9.5 Conclusion In deuterostome animals the first opening, during the development process of the embryo, becomes the anus. Deuterostome animals are enterocoelic. Echinoderms are marine animals with different shapes and sizes but without head. Many organ- systems are absent in echinoderms and to get the benefit of the organs which are absent in their body they have developed the unique device- the water-vascular system. Through this system water from the surroundings is taken in through the large pore and then passes through a canal system which is ramified throughout the body to suppy oxygen, food and to discharge the carbondioxide and nitrogenous waste from the body. Also, it helps them in locomotion.
78 GE-ZO-11 ? NSOU 9.6 Summary i) Star-shaped, sphrical or cylindrical unsegmented body without head but most echinoderms are with spines. ii) Adult forms are pentamerous and radially symmetrical while larval forms are bilaterally symmetrical. iii) In many cases endoskeleton with calcareous plates may be seen. iv) Enterocoelic coelom surrounded by ciliated peritoneum. v) Presence of water vascular system. vi) Tube feet help in locomotion, food-capturing and respiration also while associated with the water vascular system. vii) Open circulatory system but no respiratory pigment and heart. viii) Nitrogenous waste diffused out through the gills. ix) Brain is absent, sense organs are poorly developed. x) Marine, sessile or pelagic. xi) Reproduces both sexually and asexually but fertilization is external. xii) Autotomy and regeneration are well marked. xiii) Indirect development is effected through ciliated larval forms. xiv)Water vascular system is a hydraulic system used by echinoderms to accomplish different functions. 9.7 Glossary Deuterostomes : Animals in which the blastopore develops into anus. Pedicellariae : Pincer-like outer extension of the body of echinoderm which helps to keep the body surface clean. Ambulacral system : The other name of water vascular system. Madreporite : A perforated calcareous plate associated with the water vascular system which allows water into the body. Tube feet : Associated with the water vascular system and help in locomotion, food capturing and respiration. Autotomy : The casting off a part of the body. Stone canal : One type of canal which is associated with the water vascular system. It is "S" shaped and opens into a ring canal.

NSOU ? GE-ZO-11 79 Radial canals : Canal arising from the ring canal extends up to the tip of the arm. These are five in number. Tiedmann's body : The sacs associated with the ring cannal of water vascular system is known as Tiedmann's body. 9.8 Questions 1. Explain the term 'deuterostome'. Explain why echinoderms are coelomate deuterostome. 2. Who first coined the term 'echinodermata'? Mention any five salient features of echinoderms. Cite two examples. 3. What are spines and pedicellariae. State their functions. Add a note on the nature of exoskeleton of echinoderms. 4. How does echinoderm get rid or nitrogenous wastes? Where we can get the echinoderms in sea water. What is Tiedmann's body? 5. What are autotomy and regeneration? What do you mean by oviparous? Name the scientific name of a starfish and a brittle star. 6. In brief describe the water vescular system in starfish and state its functions. 7. Write notes on : (a) Stone canal (b) Ring canal (c) Podial canal (d) Tube feet 9.9 Suggested readings 1. K.C. Ghose and B. Manna (2015). A textbook of Zoology. New Central Book Agency, Kolkata. 2. K.K. Chaki, G. Kundu and S. Sarkar (2014). Introduction to General Zoology, Vol. 1. New Central Book Agency, Kolkata. 3. A.J. Marshall and W.D. Williams (1985). Textbook of Zoology. Vol. 1. Invertebrates. The Macmillan press Ltd. London. 4. J.A. Pechenik (2000). Biology of the invertabrates. 4 th edn. Tata McGraw- Hill edition. The Tata MacGraw-Hill Publishing Company Ltd. New Delhi. 5. Joanna Brundle (2000). Echinoderms. Kidttaven Publishing, New York.

80 GE-ZO-11 ? NSOU Unit 10 ? Protochordata : Salient Features Structure 10.1 Objectives 10.2 Introduction 10.3 Protochordata : salient features 10.4 Conclusion 10.5 Summary 10.6 Glossary 10.7 Question 10.8 Suggested readings 10.1 Objectives By studying this unit, students will be able to gain knowledge regarding emergence of some chordate features in the protochordate animal groups. 10.2 Introduction Protochordates are also known as lower chordates. They have many similarities with higher invertebrates and vertebrates. As these animals lack a cranium they are also known as Acraniata. Traditionally Protochordates consist of three sub-phyla in respect to the property of notochord. They are Hemichordata, Urochordata and Cephalochordata. But in modern concept Hemichordates are included among the non-chordates as a seperate phylum. Neverthless hemichordates are close relatives of the chordates. 10.3 Protochordata : salient features 1. Bilaterally symmetrical, coelomate triploblastic animals. 2. Presence of a single dorsal hollow tubular nerve cord, paired pharyngeal gill slits and an elastic, solid, rod-like structure the notochord either throughout the life or only during larval stage at certain part of the body. 3. Well developed organ system level of organization.

NSOU ? GE-ZO-11 81 10.3.1 Characteristic features of Hemichordata (i) Marine, solitary or colonial, filter feeder. (ii) Unsegmented, cylindrical stout body. (iii) Three distinct regions in the body viz.; proboscis, collor and trunk are well marked. (iv) Collor bears arms and tentacles. (v) Preoral extension of buccal cavity known as buccal diverticulum or stomochord be mistaken as notochord. (vi) Complete digestive system. (vii) Body surface and gills help in respiration. (viii) A heart with two longitudinal vessels Fig. 1 Acorn worm are the main components of circulatory system. (ix) Blood has no corpuscles and is colorless. (x) Excretory system is confined to the proboscis gland or glomerulus. (xi) Sexes separate (xii)Fertilization is either external or internal. Examples :Acorn worm (Saccoglossus kowalevskii, Balanoglossus aurantiacus) (Fig: 1), Planctosphaera pelagica 10.3.2 Characteristic features of Urochordata (Tunicata) (i) Marine, sessile and filter feeders. (ii) Body is surrounded by a leathery sheath called tunic and composed of tunic in protein and cellulose like polysaecharide. Thus, the name Tunicata is applied to this group. (iii) Notochord found in the tail region in larval stage and disappears in the adult. This phenomenon is related with the retrogressive metamorphosis. (iv) Neural tube of the larva is replaced by a dorsal ganglion in the adult stage. (v) Pharyngeal gill slits present. (vi) Circulatory system is open-type. (vii) No excretory organ. (viii) Reproduces both asexually (through budding) and sexually.

82 GE-ZO-11 ? NSOU Examples :Herdmania armata, Salpa fusiformis (Fig :2), Doliolum denticulatum (Fig: 3) 10.3.3 Characteristic features of Cephalochordata (i) Marine, mostly sedentary and burried with only anterior body end projecting above bottom sand. (ii) Body 5-8 cm long, slender lancet-shaped and transparent. (iii) No head but trunk and tail distinct. (iv) Paired appendages lacking, median fins present. (v) No exoskeleton, epidermis single-layered, muscles dorsolateral, segmented into myotomes. (vi) Enterocoelous coelom is confined to the pharyngeal region through the development of atrial cavity. Fig. 2 Salpa sp. Fig. 3 Doliolum sp. Fig. 4 Branchiostoma sp. (vii) Notochord rod-like, persistent, extending from rostrum to tail, hence it named as cephalochordata. (viii) Filter feeders, digestive tract complete, pharynx with gill-slits. (ix) '>' shaped myotomes present. (x) Well developed, closed circulatory system without heart and respiratory pigment. Hepatic portal system developed. (xi) Protonephrida with solenocytes help in excretion.

NSOU ? GE-ZO-11 83 (xii) Dorsal tubular nerve cord without ganglia and brain. (xiii) Sexes separate, numerous gonads but no gonoducts. No asexual reproduction. (xiv) External fertilization, indirect development through free-swimming larva. Examples :Branchiostoma belcheri [common name=Amphioxus] (Fig: 4), Branchiostoma lanceolatum, Asymmeton lucayanum. 10.4 Conclusion Chordates are characterized by having a notochord. But such a structure was developed through certain steps in the lower chordates where the notochord is confined to larval stages or at certain regions of the body in adult forms. 10.5 Summary i) Protochordates are differentiated into three groups viz., Hemichordates, Urochordates and Cephalochordates depending upon the property of notochord but all animals bear pharyngeal gill slits and dorsal hollow tubular nerve cord. ii) Marine, hemichordate animals having three distinct regions viz.; proboscis, collar and trunk in the body. iii) Circulatory system consists of a heart with two longitudinal vessels. iv) Blood is colourless and without corpuscles. v) Excretory system is confined to glomerulus. vi) Sexes may be united and separated. vii) In Urochordata notochord is confined to the tail region, in Cephalochordata notochord is extended from rostrum to tail is a primitive character. 10.6 Glossary Notochord : A cartilaginus skeleton rod found in all the embryonic and some adult chrodate animals.

84 GE-ZO-11 ? NSOU Protochordates : A group of invertebrate chordate animals closely related to vertebrates. Hemichordata : Absence to true notochord in these animals and usually considered as sister group of Echinodermata but very much related with the Chordata. Thereby they are known as half-chordata. Urochordata : Protochordates where notochord is found in the tail region in the larval stage but disappears in the adult form. Cephalochordata : Protochordates where notochord is extended from the rostrum to tail. 10.7 Questions 1. What are protochordates? State the characteristic features of Protochordata. 2. Mention the salient features of Hemichordate with examples. 3. Give a comparative account of Urochordata and Cephalochordata. 4. Write notes on : (a) Notechord; (b) Solenocytes; (c) Acraniata; (d) Metamorphosis in Tunicata 10.8 Suggested readings 1. K.C. Ghose and B. Manna (2015). A textbook of Zoology. New Central Book Agency, Kolkata. 2. K.K. Chaki, G. Kundu and S. Sarkar (2014). Introduction to General Zoology, Vol. 1. New Central Book Agency, Kolkata. 3. A.J. Marshall and W.D. Williams (1985). Textbook of Zoology. Vol. 1. Invertebrates. The Macmillan press Ltd. London. 4. J.A. Pechenik (2000). Biology of the invertabrates. 4 th edn. Tata McGraw- Hill edition. The Tata MacGraw-Hill Publishing Company Ltd. New Delhi. 5. E.J.W. Barrington (1975) Protochordates. Academic Press-Inc. (Sell on Amazon) 6. V.R. Misra and R. Gupta (1960). An Introduction to Protochordata. Indian Book Depot, Delhi.

Unit 11 ? Pisces : Osmoregulation, Migration of Fishes Structure 11.1 Objectives 11.2 Introduction 11.3 Pisces : osmoregulation 11.4 Migration of fishes 11.5 Conclusion 11.6 Summary 11.7 Glossary 11.8 Questions 11.9 Suggested readings 11.1 Objectives Fishes are adapted to live in freshwater, saltwaters as well as in esturaies. As the quality of water varies with the type of water it is intriguing to have an idea regarding the homeostasis in these aquatic organisms. Also they need different qualities water with a view to ensure reproduction and for the growth of young individuals the strategy of migration is well established in some fishes. The aim of the study is to gain knowledge on these aspects. 11.2 Introduction Pisces, the first true jawed vertebrate group includes all the fishes, having paired and unpaired fins with finrays for swimming and gills for respiration in aquatic medium. Ichthyology is the branch of zoological science which deals fishes. Placodermi, the first jawed vertebrate appeared in mid-Silurian period though fishes flourished in Devonian period. Therefore, Devonian period is called the golden age of fishes. Fishes are adapted to survive in marine, fresh and estuarine waters.

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86 GE-ZO-11 ? NSOU 11.3 Pisces : Osmoregulation Osmoregulation is a process of regulation of water and electrolytic balance in the body of an organism with a view to maintain the homeostasis. Fresh water fishes are hypertonic to their surrounding enviornment. This means that the concentration of salt is higher in their blood than their surrounding water. They absorb a controlled amount of water through the mouth and the gill membranes. Beacuse of hyperosmotic body fluid they are subjected to swelling by movement of water into their body owing to osmotic gradient. As the surrounding medium is with low concentration of salt, fishes are to face the loss of body salts almost continuously. Thus they have developed the art regarding net gain of water and net loss of salts. Net intake of water is regulated by kidney by developing the mechanism to produce a dilute, more copious urine. In course of urine formation useful salts are reabsorbed in tubules of kidney and thereafter refined in the blood. Gills of the fishes play important role in extracting Na + and Cl - from surrounding water. Thus NaCl actively transported in the gills against a concentration gradient. Also depending upon the permeability and impermeability nature of the integument salt loss and water uptake are regulated by the fishes by not drinking the water. (Fig: 1) Fig. 1 Rohu fish Fig. 2 Marine Cat Fish In marine condition concentration of body fluid and marine water is almost same (isotonic). Thus, these fishes (Fig: 2) hardly face the osmoregulation process. Elasmobranch fishes (such as sharks, rays, skates) coelacanth, Latimaria have iso-osomotic to sea water having capacity to maintain very lower electrolyte concentration. Kidneys of coelacanth and elasmobranchs excrete excess of inorganic salts such as NaCl. Also rectal gland located at the end of alimentary canal takes part in excretion of NaCl.
NSOU ? GE-ZO-11 87 Marine bony fishes having hypotonic body fluid in respect to sea water have developed the tendency to loss water through the gills and to compensate the same by drinking sea water. (Fig: 3) The ingested NaCl and KCl enter the blood stream by absorption across the intestinal epithelium. However, Ca ++ , Mg ++ and SO 4 ++ when left in the gut are excreted out. Excess salts mainly sodium and chloride when absorbed are eliminated into the sea water by the gills via blood stream and salts if excreted in excess may be reabsorbed by the gills. Mg ++ and SO 4 ++ are excreted by the kidney. 11.4 Migration of fishes Simply, migration means movement (may be seasonal) of animals from one region to another. Migration of fishes is a regular phenomenon. This kind of behaviour may be exhibited in conncetion with the assurance of getting the food resources or/and to ensure reproduction by the fishes. Fish migration are of following types : 1. Diadromous migration : This sort of migration of fish takes place between sea and freshwater. Such fish species are adapted to maintain the osmotic balance in both the habitats. This migration is of two types; Fresh Water Sea Water Fig. 3 Mechanism of osmoregulation in freshwater and marine teleost fishes (Evans, 2008)
88 GE-ZO-11 ? NSOU (a) Anadromous migration : This type of migration is exhibited by the marine fishes from sea to river for spawning. Therefore this migration is confined to breeding season. Examples :Hilsa, Salmon, Sea trout etc. (b) Catadromous migration : This sort of migration is exhibited by the freshwater fishes. They migrate from river to sea during breeding season for spawning. Examples :Eel. 2. Potamodromous migration : This kind of migration takes place from one fresh water habitat to another for feeding or spawning. Examples :Carps, Catfish 3. Oceanodromous migration : In this case fish migration is confined to the same sea but from one area to another in search of suitable feeding and spawning ground. Examples :Mackerel, Thummus, Tuna. 4. Latitudinal migration : This type of migration is also known as climatic migration. Becasue, the fishes migrate from south to north to south in respect to climate change. Examples :Sword fish migrate to north in spring and to south in autumn. 5. Vertical migration : This type of migration is exhibited by certain fish species daily from deep to the surface and vice-versa for food, protection and spawning. Examples :Sword fish usally move vertically downward to greater depth for food. 6. Shoreward migration : In this case the fish migrate from water to land for short period. Thus it is a temporary migration. Examples :Eel migrate from one pond to another pond via moist meadow grass. Significance of fish migration : (i) To get suitable feeding and spawning ground. (ii) To protect the members from predators and hazardous climatic conditions. (iii) To increase genetic diversity with a view to ensure survival and existence through the development of adaptive characters.

NSOU ? GE-ZO-11 89 11.5 Conclusion In freshwater fishes concentration of salt is higher in their blood than their surrounding water but in marine fishes the concentration of salt in the body fluid as well as in the surrounding water is almost same. Therefore, osmoregulation in freshwater fishes is a complicated process in respect to those adapted to lead a marine life. Various types of migration are recorded in fishes and the main purpose of migration of fishes is spawning. 11.6 Summary i) Fishes are jawed vertebrate with paired and unpaired fins with fin-rays. ii) Fishes are found in different habitats having variation in ionic concentrations in respect to external and internal environments. iii) Electrolytic balance in the body of the fishes is essential to maintain the homeostasis. iv) Freshwater fishes are hypertonic i.e. the concerntration of salt in their body is higher than the surrounding water. v) In marine fishes ionic concentration in the body fluid is almost equal to the surrounding water body i.e. these fishes are isotonic. vi) Fishes migrate from saltwater to freshwater or vice-versa to ensure spawning, protection from adverse condition as well as to maintain the genetic diversity. vii) Migration may be diadromous (between sea and fresh water) anadromous (from river to sea), potamodromous (from any freshwater body to another), oceanodromous (from one area to other area in the same sea), latitudinal (from north to south or from south to north in respect to climate change), vertical (from deep to surface and vice-versa daily) and shoreward (from water to land temporarily). 11.7 Glossary Osmoregulation : The process of maintaining constant osmotic pressure in the fluid of an organism by controlling the water and salt regulations.

90 GE-ZO-11 ? NSOU Migration : Movement of organisms from one place to another for a definite purpose. Hypotonic : Having lower osmotic pressure in respect to a particular fluid. Hypertonic : A greater concentration of solutes on the outside of a cell (organism) when compared with the inside of the same. Anadromous : Migration of fish from sea to river (salmon fish exhibits this kind of migration for spawning). Catadromous : Migration of fish from river to sea (eel exhibits this type of migration for spawning). 11.8 Questions 1. Define osmoregulation. Explain the mechanism of osmoregulation in freshwater fishes. 2. Describe the process of osmoregulation in marine fishes. 3. Define migration. State the different types of migration exhibited by fishes. 4. What kind of migration is exhibited byHilsa and eel? State the significance of fish migration. 5. Write notes on : (a) Potamodromous migration; (b) Latitudinal migration; (c) Vertical migration; (d) Diadromous migration 11.9 Suggested readings 1. Baldisserotto, B. Mancera, J. M. and B. G. Kapoor (2007). Fish osmoregulation. CRC Press, Taylor and Francis group. Boca Ration, FL. 2. Morais, P. and Daverat, F. (2016). An introduction of fish migration. CRC Press, Taylor and Francis group, Boca Ration, FL.

Unit 12 ?Amphibia : General Characters, Adaptations for Terrestrial Life, Parental Care in Amphibia Structure 12.1 Objectives 12.2 Introduction 12.3 General charaters of amphibia 12.4 Adaptations for terrestrial life in amphibia 12.5 Parental care in amphibia 12.6 Conclusion 12.7 Summary 12.8 Glossary 12.9 Questions 12.10 Suggested readings 12.1 Objectives By studying this unit, students will be able to gain knowledge on the characters of the first tetrapods appeared on the land, the adaptive features in these animals life, the parental care in order to lead a terrestrial mode of life by these animals. 12.2 Introduction Of the vertebrates, animal belong to the class Amphibia first invaded the land. But they were unable to adapt themselves to lead a terrestrial life completely. Therefore, they had to go back, for certain purposes, to water to ensure their survival and propagation. Actually they depend on water for reproduction especially to deposit eggs and to ensure the development to the larval form the tadpoles. Tadpoles respire by the help of gills just like fishes and equally apt to swim by the help of the tail. Adult stage is with limbs and thus they are able to move freely on land and also they respire by the help of lungs while in land and are equally capable to use the skin

92 GE-ZO-11 ? NSOU which is naked and moist for exhange of air. Such a dual mode of life is termed by amphibious (amphi=two, bios=life) to these animals. 12.3 General characters of amphibia 1. Tetrapod, aquatic or semiaquatic (freshwater) cold blooded animals. 2. Distinct head, elongated trunk; neck and tail may be present or absent. 3. Naked, moist, glandular skin with pigment. 4. Limbs 2 pairs but certain species are limbless. Fore limb with 4 fingers and hind limb with 5 fingers but clawless. 5. Median fins when present are without fin-rays. 6. Mostly endoskeleton is bony. Notochord is replaced by the vertebral column. Skull with two occipital condyles. 7. Small homodont teeth may be seen either in the upper or in both the jaws. 8. Protrusible tongue. 9. Well developed alimentary canal but terminates into colaca. 10. Lungs, gills, skin and inner lining of the buccal cavity take part in respiration depending upon the habitats. 11. Heart consists of three chambers (2 auricles and 1 ventricle). Sinus venosus present. 12. One to three pairs aortic arches. 13. Heptic portal and renal portal systems are well developed. 14. Red blood orpuscles are large in size, oval in shape and with a nucleus. 15. Poikilothermous i.e. variable body temperature. 16. Mesonephric kidney. 17. Large urinary bladder and urinary ducts open into cloaca. 18. Uricotelic organisms i.e. nitrogenous wastes mainly of uric acid. 19. Brain is located inside the cranium; ten pairs of cranial nerves. 20. Nostrils have direct connection with the buccal cavity. 21. Middle ear with a single rod-like ossicle. 22. Lateral line system is seen in larval as well as in aquatic adults. 23. Unisexual, no copulatory organ in male. 24. Gonoducts open into cloaca. 25. In most cases fertilization is external and females are oviparous.

NSOU ? GE-ZO-11 93 26. Indirect development, cleavage unequal, extra embryonic membrane absent. 27. Larva i.e. tadpole metamorphoses into adult. Examples :[Toad Dyttaphrynus (=Bufo) melanostictus] (Fig: 1), Frog (Rana tigerina) (Fig: 2), Indian Salamander (Tylototriton verrucosus) (Fig: 3), Ichthyophis sp. 12.4 Adaptation for terrestrial life of amphibia Transition of vertebrates from aquatic environment to terrestrial environment compelled amphibians to solve the following problems on way of effective adaptations, such as: (i) To avoid dehydration they have developed a thicker, impermeable skin which protects body from the loss of excessive water. (ii) They have also developed the skin semipermeable in nature and thereby they have developed the art to respire through the skin under certain circumstance in land habitat. (iii) To minimize the loss of body water, they have modified the mechanism of excretion by secreting nitrogenous wastes as urea and uric acid, as they need less water to dissolve instead of to release the excretory waste i.e. ammonia which is dissolved in water. (iv) To protect them from the harmful solar radiation they have developed pigments in the skin to filter the harmful radiation. (v) They failed to adapt fertilization in terrestrial environment and therefore, to ensure external fertilization both male and female are accustomed to go to the water to maintain their race. Fig. 1 Dyttaphrynus melanostictus Fig. 2 Rana tigerina Fig. 3 Tylototriton verrucosus

94 GE-ZO-11 ? NSOU 12.5 Parental care in amphibia Care to the brood i.e. eggs or young by the parents is known as parental care. Amphibians (anurans, urodelans and apodams) usually lay few eggs and thereby they are cautious to protect their eggs and developing young ones from any sort of adverse situations- be it natural enemies or the hazardous conditions of the habitats. The sole aim behind such care is only to ensure the survival and propagation of the race. In Amphibians parental care is effected by two ways : (1) by providing nest, nursery or shelter and (2) by direct caring i.e. nursing. Toads, frogs are habituated to construct nest where they deposit eggs and the young ones find the space for development. The tree frog, Hyla faber in Brazil, protects its progeny by building a basin- shaped nest in shallow water on the border of the pond (Fig: 4). The mud hole nest is protected from the water by constructing circular wall above the water surface. The nest-hole is made smooth by the help of limbs and belly. The eggs and early larval stages are thus protected from predators and following heavy rain the larva moves to the water body by protecting itself from the predators. Fig. 4 Parental care in amphibians. A. Ichthyophis coiling round the eggs. B. Phyllobates transport tadpoles on back. C. Desmognathus fuscus with eggs. The Japanese tree frog Rhacophorus schlegelii construct foam nest in sloping burrow near water (Fig: 5). The parents bury themselves in the damp earth on the edge of ditch or watery rice fields. The hole is made a few centimetres above the

NSOU ? GE-ZO-11 95 Fig. 5 Parental care in Amphibia. Protection by nests, nurseries of shelters. A-A tree frog guarding eggs glued to a leaf overthanging water. B-Form nest of Rhacophorus schlegeli in a sloping burrow near water. C-Form nest floating on water. D-Mud nest of Hyla faber. water level. After entering into the hole-chamber the entry gallery gets obliterated. Then oviposition starts. The female produces a secretion from cloaca which is beaten by the limbs into a froth. The eggs are deposited into that froth. The male impregnates these eggs and then both the parents make an exit gallery towards the water body, obliquely downwards to the water. Later, the larvae use the said exit gallery to reach the water to complete development. The froth liquifies and these liquids act as an efficient vehicle to transport the larvae down the tunnel into the water. ? The south American tree frog Leptodactylus mystacinus, prior to egg deposition produces a frothy mass of mucus inside a hole near water. The eggs hatch there and in due course of time the tadpoles make their way to water. ? In some anurans (e.g. Rhacophorus maculatus) female discharges large amount of mucus and beat it into a foam and then deposits eggs there. The tadpoles in due course of time drop into water. ? Tree frogs like Rhacophorus malabaricus in India, Phyllomedusa in South America and Chiromantis in tropical Africa glue eggs to the leaf of the tree hanging close to the water body. Thereby, after hatching the tadpoles drop into the water. Parents in this case guard the nest throughout. The tree frogs Hyla resinfictnix use bees wax for the construction of shallow cavity in the tree. When the cavity is filled with rain water they deposit eggs there. The tadpoles develop and move away in due time. 96 GE-ZO-11 ? NSOU ? Autodax (an urodele) deposit10-20 eggs in a dry hole in the ground or tree. Both the parents remain inside the egg-nest hole, to provide required moisture, for longtime untill the tadpoles come out. ? Phrynixalus biroi produce large-sized eggs. These eggs are enclosed in sausage-shaped transparent membranous bag which is secreted by the female. The said bag is released in the mountain stream. The complete development takes place inside the bag and little frogs come out in due time. ? Salamandrella keyserlingi deposits small egg in a gelatinous bag which is attached to an aquatic plant just below the water level. ? Some tropical American Hylodes deposit their large eggs under stones, moss or plant leaves. Because of plenty of yolk in the egg young frogs come out following complete development. Direct nursing by the parents : ? South American frogs Phyllobates, Dendrobates and the tropical African frogs Arthroleptis and Pelobates deposit their eggs on the ground. After hatching the tadpoles adhere by their sucker like lips and flattened abdomen to the back of one of their parents. They are, thus carried by the parents to the safe water body. ? The male Mantophryne robusta sits on the egg-mass strung together in an elastic gelatinous envelope for the entire development period until the larvae move to the water body. ? In Europe, the male Obstetric toad (Alytes obstetricans) carries the eggs round his body and hind legs adhering the eggs in a gelatinous material untill the tadpoles are released. ? The Sri Lankan female tree frog (Thacophorus reticulatus) carries the eggs glued to her belly. ? In urodelan species Desmognathus fuscus the eggs are laid in the form of rosary-like strings which is bounded round the body. The female nourishes them at any comparatively dry spot. ? Brazillan female tree-frog Hyla goeldii carries eggs on her back until the todpoles are released. The eggs remain exposed throughout. ? In Nototrema though eggs are placed on the back in a single large brood pouch, the same remain covered by skin. The tadpoles come out through an opening at the posterior end close to cloacal aperture.

NSOU ? GE-ZO-11 97 ? The Surinam toad, Pipa americana, Pipa dorsigera the male places the eggs on the back of the female in cell-like pouches. These eggs hatch and the larvae are capable of metabolic exchanges between the maternal and embryonic tissues in the manner of a primitive placenta (a phenomenon of pseudoplacentation). The tadpoles emerged out about after eight days after egg-deposition. ? The small South American male frog Rhinoderma darwini keeps the eggs in vocal sacs to ensure safe development of the tadpoles (Fig: 6). In contrast, male Arthroleptis frog keeps larva in his mouth. Fig. 6 Example of different forms of amphibian parental care. (a) attendance of eggs, (b) transport of tadpoles, (c) feeding to tadpoles, (d) brooding of eggs, (e) viviparity, or live-birth ? The female west African tree-frog, Hylatobates breviceps bears the eggs in her mouth. ? In Australian frog Rheobatrachus silus eggs are kept inside the stomach and the tadpoles, following completion of development, expelled through mouth. ? The female Plethodon (urodelan amphibia) deposits eggs in small packages (about 5) bencath the stones or in hollow of rotten log. The mother protects them coiling around. But in Megalobatrachus maximus the male coils the eggs. ? Caecilian Ichthyophis and Hypogeophis deposit eggs in burrows in moist soil and coil round the eggs until tadpoles are released. ? The small East African toads, Pseudophryne vivipara and Nectophryne tornieri are known to be vivparous but not yet confirmed and the Caecilian amphibians viz. Typholnectes, Geotrypetes, Schistometopum and Gymnopis

98 GE-ZO-11 ? NSOU are ovoviviparous. Thereby, they have shown the strategy how to aviod the risk or uncertainty of loss of eggs or larval stage. ? In Salamandra atra and S. maculosa a clear case of viviparity is observed. Two eggs are laid in the uterine cavity at a time where entire development is completed. The larvae remain attached with the uterine wall by a membrane which physiologically acts like primitive placenta. 12.6 Conclusion Amphibia being the first animal group to lead a terrestrial life, of couse, depends on water to perform various activities. Accordingly they have modified their body organization to a great extent to lead the life successfully in land as well as by developing remarkable strategies to ensure reproduction on way of adequate caring to the eggs and young ones by both the parents. 12.7 Summary i) Aquatic, semiaquatic (freshwater) cold- blooded tetrapods, though some are limbless. ii) Body is covered by naked, moist, glandular skin with pigments. iii) 4-5 clawed toes. iv) Median fins when present are without fin-rays. v) Endoskelton mostly bony and skull with two occipital condyles. vi) Heterodont teeth, protrusible tongue. vii) Lungs, gills and skin and inner lining of the mouth cavity act as respiratory organs. viii)Heart 3-chambered, 1-3 pairs of aortic arches. Hepatic portal and renal portal systems are well developed. ix) Mesonephric kidney and large urinary bladder opens into cloaca, uricotelic. x) Brain is located inside the cranium, ten pairs of cranial nerves. xi) Middle ear with a single rod-like ossicle, the columella. xii) Unisexual, no copulatory organ in male. xiii) Mostly fertilization is external and females are oviparous. NSOU ? GE-ZO-11 99 xiv) Indirect development, larva or tadpole metamorphoses into adult. xv) Highly adapted to prevent the loss of body water. Most skin as well as lungs help in respiration in land. Nitrogenous wastes are urea and uric acid as they need minimum water to be dissolved. xvi) To ensure external fertilization both male and female depend on water body. xvii) Various stategies have been developed to deposit eggs and/or to look after the young ones. Thus parental care is highly developed. 12.8 Glossary Amphibia : Animals that spend part of their lives in water and part on land. Cold-blooded : Animals whose body temperature varies with that of enviornment. Tetrapod : Four-footed animals. Cranial nerves : Nerves that emerge directly from the brain. Oviparous : Animals produce eggs or egg-laying animals. Adaptation : The evolutionary process whereby an organism becomes better able to live in its habitats by structural and physiological modification. Parental care : A behavioural and evolutionary strategy adopted by some animals, involving a parental investment being made to the evolutionary fitness of offspring. Anura : Living order of class Amphibia characterised by short and broad body with larger hind limbs than fore limbs e.g. Toad, Frog, ect. Urodela : Living order of class Amphibia characterised by lizard like body with equally developed both the limbs. e.g. Salamander. Apoda : Living order of class Amphibia characterised by eel-like body with no limbs. e.g. Ichthyophis. 12.9 Questions 1. What do you mean by tetrapods. Explain why animals belong to the class Amphibia are called tetrapods. What are the respiratory organs of Amphibians? 2. Mention any six salient features of the class Amphibia. Mention one similarity and one dissimilarity between a fish and a tadpole.

100 GE-ZO-11 ? NSOU 3. Discuss the adaptations in Amphibia to lead a terrestrial life. 4. How many cranial nerves and occipital condyles are there in an animal belongs to the class Amphibia? How many chambers are there in an amphibian heart? State the characteristics of middle ear in amphian animal. 5. Define parental care. Give an account of different types of parental care in Amphibia studied by you. 6. Write notes on : (a) Cloaca (b) poikilotherm (c) Parental care in Autodax (urodela), (d) Foam nest. 12.10 Suggested readings 1. T. J. Parker and W. A. Haswell (1985). Textbook of Zoology, Verteblate. Vol. 2. The Macmillan Press Ltd. London 2. D. R. Khanna and P. R. Yadav (2005). Biology of Amphibian, Discovery Publishing Pvt. Ltd. New Delhi. 3. B. S. Media (2017). Parental care in the members of class Amphibian. Bioscience. New Delhi. 4. K. C. Ghose and B. Manna (2011). A Textbook of Zoology, New Central Book Agency, Kolkata. 5. K. K. Chaki, G. Kundu and S. Sarkar (2008). NCBA, Kolkata.

Unit 13 ? Amniotes : Origin of Reptiles, Terrestrial Adaptation in Reptiles Structure 13.1 Objectives 13.2 Introduction 13.3 Amniotes 13.4 Origin of reptiles 13.5 Terrestrial adaptation in reptiles 13.6 Conclusion 13.7 Summary 13.8 Glossary 13.9 Questions 13.10 Suggested readings 13.1 Objectives By studying this unit, students will be able to gain an idea about amniote animals and to study on the origin of Reptiles as well as to know the adaptive characters of reptiles in respect to lead a terrestrial life. 13.2 Introduction Emergence of reptiles is a landmark in vertebrate evolution. Because, to lead absolutely a terrestrial life these animals had to develop the system to maintain their life on the land ecosystem as well as to ensure the protection of their embryos from any kind of adverse effect. 13.3 Amniotes Amnitoes (from Greek amnion, "membrane surrounding the fetus") are a clade of tetrapod vertebrates—the reptiles, birds and mammals. As the embryo needs

102 GE-ZO-11 ? NSOU water or fluid medium to grow as was the cases noted in fishes and amphibians, the amniotic animals have developed the device to retain water/fluid within a sac which is bounded by the membrane called amnion which encloses the embryo. Therefore, the term 'amniote' is applied to recognize these animals. But, amnion membrane is covered by allantois membrane which is covered by chorion membrane (Fig: 1). Thus, these three extra embryonic membranes protect the embryo. But, in cases of reptiles, birds and some egg-laying mammals the egg is further protected by a strong outer covering- the shell which may be soft, leathery or hard. Fig. 1 Amnion membrane 13.4 Origin of reptiles Reptiles originated from amphibians in the swamps of th Carboniferous period, about 320-310 million years ago. The labyrinthodont amphibians (Fig: 2) were the source of reptilian evolution. The cotylosaurs (Fig: 3) were the earliest group of true reptiles. The first evolved reptile Seymouria (Fig: 4) was lizard-like animal with pentadactyle limbs and a short

NSOU ? GE-ZO-11 103 tail, homodont labyrinthine teeth on the jaw bones as well as on vomer and palatine bones. Also presence of lateral line justifying its amphibian habit. Being monocondylic Fig. 2 Labyrinthodontia Fig. 3 Cotylosaurs Fig. 4 Seymouria Fig. 5 Limnoscelis it had no problem to move its head. Thus Seymouria indicates gradual transition from labyrinthodont amphibians to reptiles. Also the fossil Limnoscelis (Fig: 5), a captorhinomorph cotylosaur, found in Mexico supports the above view because of presence of large premaxillary teeth and long tail in its body. However, there exists dispute regarding Seymouria origin of reptiles. Becasue, records suggest that, there were some other reptilian organism, probably for 50 millon years, while Seymouria started roaming on the earth in Pre-Permian period i.e. after carboniferous period. As Seymouria exhibited both amphibian and reptilian features the same was considered as a perfect intermediate form between amphibia and reptilia. Thus the true taoxonomic position of the said organism remained uncertain. But later on Romer considered it as a reptile under the order Cotylosauria while others clasified it as an Amphibia under the order Seymouriamorpha. Under such a situation Seymouria is considered as a connecting link between Labyrinthodontia and Cotylosauria. Limnoscelis was a genuine reptile. Becasue Romer (1946) following critical studies suggested that Limnoscelis is the primitive reptile. Like Seymouria it was aquatic in habit, with anapsid skull compressed from side to side and dorsoventrally

104 GE-ZO-11 ? NSOU flattened. The otic notch disappeared. Premaxillary teeth were elongated and overhung the front teeth in the lower jaw. Diadectes (Fig: 6) was contemporary to Limnoscelis but had a different evolutionary line. It retains the otic notch at the back of skull. The front teeth were Fig. 6 Diadeces Fig. 7 Pareiasaurus chisel-shaped and back teeth had broad ridge crowns. The true large reptile the Pareiasaurus (Fig: 7) appeared in the late Permian had close relation to Diadectes. Spiny armour of bony plates along back, spiny excrescences on the head developed in this group perhaps to protect them from predators. 13.5 Terrestrial adaptations of reptiles To ensure a successful terrestrial life reptiles have exhibited the following adaptations: 1. Modification of skin : In reptiles the skin is dry and cornified. It contains keratin, a water resistant substance. This protects them from dehydration. Also they have developed scales which help to protect the skin from any kind of damage. However, in turtles the scales fused to form a shell. This kind of skin have enabled reptiles to go to the water body in search of resources or to spent a substantial part of life in water; on way of engulfing air, they come to the surface water off and on. 2. Limbs and their modification : Though reptiles belonged to tetrapoda (having four limbs) many lizards and snakes are limbless. Limbs help them not only to move on the land but also to protect them from the attack of enemies. Because, these limbs are provided with strong and pointed claws

NSOU ? GE-ZO-11 105 that act as weapons. Moreover, such type of limbs are effective to capture the prey as many of them are carnivorous. 3. Camouflaging : Certain reptiles especially the lizards have developed camouflaging nature to protect them from the enemies as well as to ensure trapping the prey animals. Besides, certain snake species have also developed the art of death feining strategy to capture the prey. 4. For aerial respiration : Instead of many respiratory devices as were exhibited by amphibians reptiles have developed the mechanism to depend absolutely on lung by exhanging air in the terrestrial envionment. 5. Basking : Being cold-blooded reptiles body temperature depends on thier surrounding enviornment. But they need required body temperature to make them effective to capture the prey animals. Therefore, they bask on rocks or on any other suitable platform to warm the blood. 6. Water conservation : In land access to drinking water is limited. Therefore, kidneys in reptile have adapted to produce less urine in a concentrated form with a view to conserve water in the body. The final excretory product is a chalky white mass of urates and it is almost dry due to reabsorption of water by cloaca. 7. To ensure reproductive success : Reptiles lay eggs on the land which are subjected to dessication and thereby unusual mortality of eggs could not be ruled out. To protect the eggs rather embryo they have developed a protective covering—the shell. It may be soft, leathery or hard. Even having the shell covering they are careful in selecting the nesting site in moist areas to save the eggs from dessication. Also some of them did not rely on these sorts of protection of the eggs and thus, they (especially the snakes) adapted for ovoviviparity where eggs are retained inside the body to hatch internally and the babies are released from the body in due time. 13.6 Conclusion Vertebrates like reptiles, birds and mammals bear a membrane to protect the embryo in a fluid-filled medium. The said membrane is known as amnion membrane. Reptiles have evoled from the labyrinthodont amphibians. After emergence reptiles

106 GE-ZO-11 ? NSOU have undergone through a number of adaptive changes by modifying the armature of skin, limbs, body colouration, respiratory organs, basking, water conservation and egg-laying process to ensure reproductive success and survival. 13.7 Summary i) In amniotes embryo remains protected by the three membranes viz. amnion, chorion and allantois. ii) Reptiles originated during late Carboniferous period from the labyrinthodont amphibians. iii) The cotylosaurs were the first group of true reptiles. iv) The first evolved reptile Seymouria was a lizard-like animal with homodont labyrinth teeth. v) According to some authority Limnoscelis was a genuine reptile while Seymouria is a connecting link between Labyrinthodontia and Cotylosauria. vi) The skin is keratinized to resist body dehydration. vii) Being tetrapod many reptiles are limbless while in others limbs are provided with strong and pointed claws. viii) Exclusively respires through lungs. ix) They have developed the art of basking to adjust themselves with the surroundings. x) Release concentrated urine with a view to conserve body water. xi) To save eggs from dessication under land environment they have developed the art of deposition of eggs with shell covering. 13.8 Glossary Amniotes : A clade of tetrapod vertebrates comprising the reptiles, birds and mammals which developed amnion to protect the embryo. Labyrinthodont : A group of amphibian animals from which reptiles have evolved. Pareiasaurus : The true large reptile which emerged in the late Permian. Skin of reptiles : Dry and cornified.

NSOU ? GE-ZO-11 107 Camouflage: A strategy to hide oneself in its surroundings. Basking : To lie in or be exposed to pleasant warmth (especially to the sushine). 13.9 Questions 1. What are amniotes? Name two other membranes which are found covering the amnion membrane. What is labyrinthodont? 2. Write in brief the origin of reptiles. 3. Mention any two kinds of adaptation in reptiles to lead a terrestrial life. Add a note on Limnoscelis. 4. Describe in brief the terrestrial adaptations in reptiles. 5. Write notes on : (a) Basking; (b) Camouflaging; (c) Diadectes; (d) Seymouria. 13.10 Suggested readings 1. T. J. Parker and W. A. Haswell (1985). Textbook of Zoology, Verteblate. Vol. 2. The Macmillan Press Ltd. London 2. K. C. Ghose and B. Manna (2011). A Textbook of Zoology, New Central Book Agency, Kolkata. 3. K. K. Chaki, G. Kundu and S. Sarkar (2008). NCBA, Kolkata. 4. H. D. Sues (2019). The rise of reptiles. Johns Hopkins University Press. Baltimore.

108 GE-ZO-11 ? NSOU Unit 14 ?Aves : The Origin of Birds, Flight Adaptations Structure 14.1 Objectives 14.2 Introduction 14.3 Origin of birds 14.4 Flight adaptation 14.5 Conclusion 14.6 Summary 14.7 Glossary 14.8 Model Questions 14.9 References 14.1 Objectives By studying the unit students will be able to gain knowledge on birds in respect to their origin and adaptation for flight. 14.2 Introduction The class Aves represents the birds. A bird is characterized with spindle shaped body having four distinct regions viz. head, neck, trunk and tail. Forelimbs modified for flying, feathers (the unique feature of birds) covering the body are of various types and the legs with scales. 14.3 Origin of birds Birds orginated from reptiles. But from which group of reptiles is an open question. On the basis of available evidences and information it is nowadays consensus that birds are a group of maniraptoran theropod dinosaurs that originated during Mesozoic era.

NSOU ? GE-ZO-11 109 Maniraptora is a clade of coelurosaurian dinosaurs which includes the birds and the non-avian dinosaurs. They were very close to each other Maniraptorans (Deinonychus, Archaeopteryx, Patagonykus, and Erliansaurus) first appeared in the fossil record during the Jurassic period and are regarded as ancestral to living birds. The hunt for the ancestors of living birds began with a specimen of Archaeopteryx (Fig: 1), the first known bird, discovered in early 1860's. It had feathers along the arms and tail just like birds but unlike living birds it had teeth and a long bony tail. Fig. 1 Archaeopteryx Furthermore, many of the bones in Archaeopteryx's fore-arms, shoulder girdles, pelvis and feet were distinct i.e. not fused and are also not reduced as they are seen in modern birds. Based on these features Archaeopteryx was recognized as an intermediate form between birds and reptiles, but which reptiles? Today there are 8 preserved fossils of Archaeopteryx in various museums of the world. But the amazing aspect of Archaeopteryx lies with its superficial resemblances both a bird and a reptile. But as a fact, except for the feathers and the bird-like feet, the presence of a wishbone (furcula) its real appearance as bird is questionable. Moreover, teeth in jaws and the ankle bone fused to the shinbone confirmed the presence of dinosaur's and bird's features in Archaeopteryx. So, question still in the air—from where did birds evolve? Thus, three hypotheses on the origin of bird were proposed. 1. Theropod dinosaur hypothesis : This hypothesis (first one) advocated that theropods were meat eating dinosaurs such as Allosaurus and the birds were evolved from them. 2. Crocodiles hypothesis : According to this hypothesis because of presence of an endolymphatic duct which is present in crocodiles, the birds were emerged from crocodiles. But further research suggested that, there exists tremendous amount of variation in the duct even among the lizards and other reptiles. Therefore, nowadays, no much attention is given to this hypothesis. 3. Neither crocodiles or dinosaurs hypothesis. As several dinosaurs were very much specialized, the possibility of origin of bird form the crocodile line or dinosaur line is confusing.

110 GE-ZO-11 ? NSOU Today it is clear that birds are related to dinosaurs in many ways. But using key characters we can use cladistics to understand the better relationships. For instance, we can look at the feathers they share in common with animals such as reptiles and ancient dinosaurs in order to figure out where they may have evolved. They can thus, be linked generally to Ornithodira and more specifically to Maniraptorans. In a cladogram of diapsids which include snakes, lizards, crocodiles (archosaurs) and dinosaurs and birds it seems to be easier to get a better picture as to where birds fit in. Dinosaur cladogram : Looking in particular at the Ornithodira, Dinosaurs, Saurischian dinosaurs, Theropods tetanurae, Coelurosaurs and others we can get the following facts. Ornithodira : Advanced mtatarsal angie. Dinosauria : 3+ sacral vertebrae, reduced fibula. Ornithischia : 5+ sacral vertebrae, opisthopubic pelvis, pre-dentary bone in lower jaw. Sauropodomorpha : 10+ sacral vertebrae, ankles have an ascending process. Theropoda : Elongate narrow metatarsus, hollow bones, metatarsal 5 reduced. Tetanurae : 'Allosaurus etc.' tooth row (upper) does not extend back beyond the orbit also, with an antorbital fanestra. Maniraptora : With a semi-opisthopedic pelvis, this indicates that the pubis bone of the pelvis is rotating backwards and has a foot. It is regarded as feathered dinosaurs. Avialae : Presence of feathers. Summarization of the set of derived characters that link them to Dinosaurs. ? Pelvis ? Clavicles ? Wrist Once the idea that birds came from dinosaurs, then there was scurry ? To find fossil evidence that could link birds back to their dino-roots. NSOU ? GE-ZO-11 111 ? Several different dino-birds, fossils were discovered in the last century. One was Caudipteryx. Caudipteryx : It was a dinosaur-like fossil but had feathers. However, the wings were to small to allow them to fly. But presence of wing was a significant character. Microraptor : It had four wings and possessed long feathers on both it arms and legs but was closely related to dinosaurs and birds; it was very small and appeared to be arboreal. This tiny fossil was about to fly. But presence of wing was a significant character. This tiny fossil was about 10 cm long. If it lived in the trees could have glided from tree to tree. Thus, it is most likely that birds originated from dinosaurs through Archaeopteryx which were not only with the feathers or wings but also have the gliding ability from tree to tree—an attempt to ensure flying in the air. From the following Fig : 2 the possible pathway of the origin of bird could be visualized at a glance. Thus birds are often called "glorified reptiles". Fig. 2 Origin of birds within Theropod dinosaurs by Prum, 2003 Evolution of four feathered wings and gliding Evolution of powered flight and loss of hind wings

112 GE-ZO-11 ? NSOU 14.4 Flight adaptation Birds are efficient flyers. To gain the said ability they exhibit a number of adaptive features both externally and internally of their body configuration. Such adaptations are as follows. 1. Body shape stream-lined. This helps birds to reduce air resistance. 2. Feathers—the exoskelton are developed to protect the body from a number of environmental factors especially the water. This is why they can fly in rains also. Flight feathers are effective in generating both thrust and lift and thereby enabling the birds to fly. It also increases the surface area of the wings. 3. Modifications of fore-limbs into wings : The fore-limbs are transferred into potential propelling organs, the wings. The feathers of the wings form a broad surface for striking the air. The flight feathers of the wing also form a broad surface for supporting the bird in the air. The wings of the bird are not flat but are concave below and convex above. The air that passes over the top of the wing and below the wing regulates the speed for flying and pressure to drop. This acts effective sucks the wings up. 4. Tail feathers : Tail feathers form a steering apparatus. They are used jointly as a radder and help in balance and twisting and turning during flight. Also, they act as a brake for landing. 5. They have acute vision. This enables birds to flight to distant places safely. 6. Well developed flight muscles. Pectoralis major is the breast muscle that powers the upstroke for flight. Pectoralis minor muscle is found just beneath the pectoralis major. The action of the muscle is stabilization, depression, abduction or protraction, upward tilt and downward rotation of the spcapula. 7. Long bones are pneumatic having air cavities, skull bones are thin and papery. These make the bird's skeleton light. 8. No gall bladder, no urinary bladder and the rectum is reduced to a great because of minimum undigested waste. Therefore, birds adapted in an efficient way to reduce the body weight to be the good flyers.

NSOU ? GE-ZO-11 113 9. The lungs are highly adapted to supply required energy to maintain flying for a long time. There is a great interconnection with the organs which generates the required energy. In birds development of thin-walled bladder- like air-sacs is unique and the major air-sacs directly originate from lungs. The air that is taken in passes to the air sacs on the posterior side then reaches the lungs. Birds lack alveoli, instead many small sacs called parabronchia are present that are connected to the capillaries. 10. In most of the female birds liver is pushed towards right side in order to balance the weight of the body. 11. Ovaries and tests are reduced in size to a great extent and in some birds only one ovary i.e. left one is functional. Right oviduct is vestigial in many birds. 12. Birds can rotate their heads to 180° for a wide range of vision all around. 14.5 Conclusion Class Aves represents different kinds of birds. Birds originated from reptiles. Though controversy exists it is assumed that the birds are a group of maniraptoran therepod dinosaurs that originated during Mesozoic Era. The first fossil bird Archaeopteryx discovered in early 1860's provided the key to trace the origin of modern birds. Birds are efficient flyers. To enable them to be the efficient flyers, they have shaped their body stream-lined, developod wings and feathers with effective flight muscles, to develop pneumatic bones, air sacs, reduction or abolition of certain organs to make the body light. 14.6 Summary i) Aves is class which represents all kinds of birds. ii) It is assumed that the birds evolved from the maniraptoran therepod dinosaur during Mesozoic era. iii) The fossil records of Archaeopteryx and some other maniraptorans enable the scientists to trace the origin of birds.

114 GE-ZO-11 ? NSOU iv) Finally, the theories (a) the theropod dinosaur hypothesis (b) crocodiles hypothesis and (c) neither crocodile nor dinosaurs hypothesis are now considered unncessary for discussion on origin of birds. v) Dinosaur cladogram revealed the progresive evolutionary path of birds. vi) To be an efficient flier birds have not only change the shape of their body but also modified the fore-limits into wings. They have developed feather and strong muscles for flying in the air at length. The bones are filled with air, the air-sacs contain adequate oxygen and the organs in some cases converted or deleted to make the body lighter. 14.7 Glossary Maniraptora : Maniraptora is a clade coelurosaurian dinosaurs which includes the birds and the non-avian dinosaurs. Archaeopteryx : A fossil of the first bird specimen discovered in eary 1860's. Ornithodira : Advance metatarsal angle. Tail feathers : Streering apparatus of birds. Air-sacs : Extension of a bird's lung cavity into a bone or other parts of the body. Pneumatic bone : Bones contain air inside. 14.8 Questions 1. State any two characteristic features of Aves. Archaeopteryx was a bird— explain why? 2. Give a schematic representation of the origin of birds. 3. Explain the hypotheses proposed on the origin of birds. Add a note on Maniraptorans. 4. Discuss the dinosaur cladogram to trace the origin of birds. 5. Give an account of the flight adaptations in birds. 6. Mention the organs in birds which ensure flight adaptations. State the functions of tail feathers in birds. 7. Write notes on : (a) Microraptor (b) Air-sacs (c) Flight muscles (d) Ornithischia

NSOU ? GE-ZO-11 115 14.9 Suggested readings 1. T. J. Parker and W. A. Haswell (1985). Textbook of Zoology, Verteblate. Vol. 2. The Macmillan Press Ltd. London 2. K. C. Ghose and B. Manna (2011). A Textbook of Zoology, New Central Book Agency, Kolkata. 3. K. K. Chaki, G. Kundu and S. Sarkar (2008). A Textbook of Zoology, Vol. 2 NCBA, Kolkata. 4. A. David (2015). The Life of Birds. Amazon Warehouse

116 GE-ZO-11 ? NSOU Unit 15 ? Mammalia : Early Evolution of Mammals; Primates; Dentition in Mammals Structure 15.1 Objectives 15.2 Introduction 15.3 Early evolution of mammals 15.4 Primates 15.5 Dentition in mammals 15.6 Conclusion 15.7 Glossary 15.8 Summary 15.9 Questions 15.10 Suggested readings 15.1 Objectives By studying this unit students will be able to gain knowledge on the early evolution of mammals and the primate gruop of mammals. To have an idea regarding dentition in mammals. 15.2 Introduction Mammals are recognised on the basis of four main characteristic features viz. presence of mammary glands, presence of hair, presence of external pinna and the three bones in the middle ear. 15.3 Early evolution of mammals Mammals evolved from a group of reptiles called synapsids. These reptiles arose during the Pennsylvanian sub period (310-275 million years ago) of the late Carboniferous period. By the mid-Triassic many mammal-looking synastids were

NSOU ? GE-ZO-11 117 came into the existence. The lineage leading to present day's mammals split up in the Jurassic period. Thus Dryolestes, the advanced form of synapsids emerged. Dryolestes exhibit a close relation with the extant placemental and marsupials than to monotremes. With the progress of time eutherian and metatherian lineages separated. Metatherians are closely related to the marsupials and the eutherians have close affinity to the placentals. Paleogene extinction event occurred at the end of Cretaceous period when non- avian dinosaurs were completely disappeared and mammalian groups—placental and marsupials were diversified into various new forms occupying different ecological niches throughout the Paleogene and Neogene. The modern orders of mammals appeared by the end of these events. Mammals are the only living synapsid. They have undergone various changes during Permian and Triassic periods. They were carnivores and herbivores. But a group of sauropsids, the archosours, became then dominant. At this time the mammaliaforms appeared. They had superior sense of smell, backed up by a large brain enabled them to get access into suitable nocturnal niches to aviod exposure to archosaur predation. This sort of adaptive behaviour may have contributed greatly to the development of mammalian traits such as endothermy and hair. Later, in the Mesozoic with the disappearance of Rauisuchians (a group of mostly large triassic Archosaurs), the dominant carnivores, mammals spread to other niches even to the water body. Earliest crown mammals : The crown groups of mammals or the "true mammals" are the extant mammals and their relatives back to their last common ancestors. The family tree of early crown mammals could be revealed from the following cladogram (Luo, 2007) : Crown group mammals Australosphenida Ausktribosphenidae† Monotremes Eutriconodonta † Allotheria Multituberculates † Trechnotheria Cladotheria Spalacotheroidea † Dryolestoidea † Theria Metatheria Marsupials Etheria Placentals Fig : Cladogram after Z.–X Luo (2007); (+= Extinct)

118 GE-ZO-11 ? NSOU 15.4 Primates Primates are a group of eutherian mammals confined to the order Primates. They emerged 85-55 million years ago from small terrestrial mammals who were adapted to live in trees of tropical forest. The characteristic features of primates are : 1. Prehensile hands and feet : Almost all living primates have prehensile hands and feet and most have five digits on their appendages, including opposable thumbs. 2. Shoulders and hips : Flexible and rotating shoulder and hip joints. 3. Brain : The olfactory region is reduced to a great extent in most species (in humans also), the cerebrum is expanded with a view to develop increasing reliance on sight and stereoscopic vision with colour vision along with binocular vision. 4. Nail and claw : Each digit has a flat nail instead of a claw. 5. Possess a clavicle or collar bone. 6. Exhibit the tendency to be erect. This trait is visible when even quadrupedal primates sit or stand. Also a good number of species sometimes exhibit bipedalism or standing on hind legs like humans. All primates exhibit adaptations for climbing trees and have evolved into two main groups and subsequently into some sub-groups. Ceboids (New World Monkeys) PRIMATES Order Suborder Infraorder Lemurs Lorises Tarsiers Cercopithecoids (Old World Monkeys) Hominoids (Apes and Man) Prosimians Anthropoids Lemuriformes Tarsiiformes Platyrrhines (New World) Catarrhines (Old World)

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NSOU ? GE-ZO-11 119 ? Prosimians : Prosimians are primitive primates. All living and extinct strepsirrhines (lemurs, lorisoids and adapiforms) as well as the haplorhine tarsiers and their extinct relatives, the omomyiforms i.e. all primates excluding the simians are prosimians. They exhibit more privitive or ancentral characters in respect to simian group. Thus, lemurs, lorises and tarsiers are the example of prosimians Lemur (Fig: 1) are mostly found in Madagascar and neghbouring islands. They mostly live in trees and are active mostly in night. Loris (Fig: 2) are nocturnal and arboreal. They are found in propical and woodland forests of India, Sri Lanka and part of South-east Asia. Tarsiers (Fig: 3) are small leaping primates found only in the islands of South-east Asia, including the Philippines. They are intermediate form (about 9- 16 cm in length excepting the tail) between lemurs and monkeys. They are nocturnal and are with well developed sense of smell. But like monkeys and apes and humans they have a nose that is dry and hair covered. The eyes and placenta are also simiiform in structures. Fig. 1 Lemur Fig. 2 Loris Fig. 3 Tarsiers Fig. 4 Spider Monkey ? Anthropoids (Smimians) : Simians or Anthropoids or higher primates are familiar to us as the old world monkeys and apes, including humans—as Catarrhines

120 GE-ZO-11 ? NSOU and the new world monkeys or Platyrrhines. Simians are usually larger than Prosomians. Ceboids the new world monkeys believed to have evolved from prosimians isolated in South America. Examples : Marmosest, Capuchins, Tamarins and Spider Monkeys (Fig: 4) The Catarrhines or the old world anthropoids are the sister group to new world monkeys categorized into two groups vis. Cercopithecidae and Hominidae. ? Cercopithecidae : Is a family of primates which is represented by old world monkeys. It is the largest primate family and includes. The langurs, the baboons (Fig: 5) and macaques. ? Hominoids : Are the members of the primate family hominoidae which includes apes and man. Men and apes had common ancestor. Apes are capable of communi-cation by vocal means. Gibbon, Orang-utang Chimpanzee and Gorilla are examples of apes. Fig. 5 Baboon ? Gibbons (Hylobates) (Fig: 6) : Are most gentle smallest (90-95 cm in height and 15-25 lbs in weight) and cleanest apes with remarkable vocal power. Gibbons belong to the family hylobatidae. They are distributed into 18 species under 4 extant genera. They live in tropical and sub tropical rain forests from eastern Bangladesh to Northeast India to southern China and Indonesia. They are the only apes which can walk errect. Fig. 6 Gibbon Fig. 7 Orang-utang ? Orang-utangs (Fig: 7) : Are great apes (135 cm in height and about 150 lbs in weight). They are distributed into 3 extant species. Being natives of Indonesia and

NSOU ? GE-ZO-11 121 Malayesia they are now found in the rainforests of Borneo and Sumatra. They are very intelligent and are habituated to use different kinds of sophiisticated tools and construct eleborate sleeping nests in the tree. The learning ability of Orang-utang is very high. ? Cimpanzee (Fig: 8) : Also known as chimp is a type of great ape which is confined to the forest and savanah of tropical Africa. Chimps are highly intelligent and are closest relatives of men. ? Gorilla (Fig: 9) : Is ground—dwelling predominantly herbivorous ape inhabits Fig. 8 Chimpanzee Fig. 9 Gorilla Fig. 10 Homo sapiens the forest of central and sub Saharan Africa. There are two speices of the genus Gorilla. These species again subdivided into 4-5 sub species. It is the largest living primate. Apes, irrespective of the types exhibit a social bonding through the development of a social culture. ? Man (Homo sapiens) (Fig: 10) : Homo sapiens are the dominant primate group of the world. They are most intelligent, social and cultural entities of the world. The facial gestures are quit good-looking. They are well-adapted to a bipedal mode of walking. They have opposable thumbs. The most significant is that they have a language and speech.

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122 GE-ZO-11 ? NSOU 15.5 Dentition in mammals The arrangement of teeth in the upper and lower jaws, specifically on premaxilla, maxilla and dentary bones is called dentition (Fig: 11). Teeth are present in mammals though a secondary toothless condition is found in some mammals. In some monotremes like echidna—the spiny ant-eaters teeth are completely absent. In Platypus embryonic teeth are replaced in the adult by horny epidermal plates but no true teeth are present. The great ant eater of South America (Myrmecophaga-an edenttate) also lacks teeth. The whale-bone whale and many edentates lack teeth in the adult condition. In mammals, morphologically teeth may be of two types. 1. Homodont : All teeth are similar in shape. This type of teeth are found only in certain cetaceans. But in toothed whales, dolphins, porpoises and armadillos, teeth become secondary uniform as homodont. 2. Heterodont : Characteristically mammalian teeth are heterodont. That is, the teeth are dissimilar in shape, size and functions. Heterodont dentition commonly includes four kinds of teeth viz, incisors, canines, premolars and molars. Incisors help in nipping, canines perform the functions of grasping the prey and tearing the food, pre-molar and molars help in grinding and shearing the food with the help of tooth row in both upper and lower jaws. Depending upon the number of cusps the teeth are four types. Cusp is a pointed projection or elevated feature. In mammals it is usually refer to as raised points on the crown of the teeth. (a) Monocuspid : One cusp is present. e.g. canine tooth (b) Bicuspid : Two curps are present. e.g. premolar teeth in human (c) Tricuspid : Three cusps are present. e.g. molar teeth (d) Polycuspid : More than three cusps are present. e.g. molar teeth Fig. 11 Denitition of man

NSOU ? GE-ZO-11 123 On the basis of the shape of the cusps the cheek teeth are of following types : (a) Bunodont : The cusps in the check teeth remain separate and rounded. That is many cusps in the teeth. This type of teeth are found in man and also in some carnivorous mammals. The function of these teeth is to grind food. (b) Lophodont : In this case the cusps are joined to form ridges or lophs. This type of teeth are found in elephants. These teeth are used to grind all sorts of plants and also grasses. (c) Secodont : In this type the cheek teeth are with sharp cutting crowns. This kind of teeth are found in land carnivores. These teeth help in cutting and shearing the flesh. (d) Selenodont : Cheek teeth with crescent-shaped cusps are known as selenodont. These are found in runminants cattle, camel and horses. They help in grinding the plant matter. (e) Brachydont : Tooth with a low crown and comparatively long root is termed as brachydont. This kind of teeth are found in man. (f) Hypsodont : Here the crown is high but the root of the tooth is short and open. These type of teeth are found in horse and incisors of elephant are of this type. Teeth have evolved from denticles which are released from armour near the margins of mouth as ossification in the integument. A typical mammalian tooth can be distinguished mainly into two regions—crown and root. The crown is the exposed part of the tooth and situated above the root. The root is the hidden part in the gum which anchored in the socket or alveolus of the jaw bone. The tooth enclosed a pulp cavity that contains blood vessels, nerves and connective tissues. The junction of the root and crown is called neck. In typical tooth there are three kinds of tissues—enamel, dentine and cement. The bulk of the tooth is formed by a hard calcium rich dentine. The dentine is covered by a coat of hard shiny enamel in the region of crown. The root of the tooth is covered by a thin layer of cement and a vascular periodental membrane. According to the mode of attachment of teeth, thecodont type dentition is the rule among mammals. In this condition the teeth are lodged in bony sockets or alveoli of

124 GE-ZO-11 ? NSOU the jaw bone and capillaries and nerves enter the pulp cavity through the open tips of the hollow roots. According to the succession or replacement, the teeth of mammals can be grouped into monophyodont (when one set of teeth only develops in life time. e.g. Marsupials, squirrels etc.) and diphyodont (when milk teeth are replaced by permanent teeth. e.g. Man) Dental formula in some mammals : Dental formula in mammals varies with the groups. In primitive eutherian mammal the formula is 3 1 4 3 I –, C –, Pm –, m – = 22×2=44 3 1 4 3 [I = Inisors, C = Canines, Pm = Pre-moatrs, m = molars] 3,1,2,4 In kangaroo (macropus) : ——— = 34 1,0,2,4 3,1,4,3 In horse and pig : ——— = 44 3,1,4,3 2,1,0,4 in bat : ——— = 32 3,1,0,5 3,1,3,1 8 in cat : ——— = – = 30 3,1,2,1 7 3,1,4,2 10 In dog and bear : ——— = –– = 42 3,1,4,3 11 3,1,4,1 9 In seals : ——— = – = 34 2,1,4,1 8 1,0,0,3 In rat : ——— = 16 1,0,0,3 2,0,3,3 8 In rabbit : ——— = – = 30 2,0,2,3 7 2,1,2,3 In man : ——— = 34 (Fig : 11) 2,1,2,3

NSOU ? GE-ZO-11 125 15.6 Conclusion Mammals evolved from a group of reptiles called synapsids. During mid-Triassic many mammal-looking synapsids came into the existence. However, the lineage leading to present day's mammals split up in the Jurassic period. Mammals being the only living synapsids have undergone various changes during Permian and Triassic periods. Cladogram suggests that from the crown group mammals Monotremes as well as eutherian mammals were evolved in due course of time. Primates are a group of eutherian mammals emerged 85-55 million years ago in the tropical forests. They are characterized by prehensile hands and feet, movable shoulders and hips, brain, nail instead of claws. In due course of time through successive evolutionary stages hominids (apes and man) appeared. Mammals may be homodont or heterodont. Also depending on the number of cusps the teeth may be monocuspid, bicuspid, tricuspid and polycuspid. Also on the basis of the shape of the cusps teeth are again divided into a number of groups. Usually incisors, canines, pre-molar and molars are found in mammals but the number of such teeth varies in groups or species. Thus, a dental formula for different species of mammals is well established. 15.7 Glossary Synapsids : A group of reptiles from where mammals emerged. Marsupials : Any member of the mammalian infraclass Marsupialia. The female members posses marsupium where immature young are developed. Monotremata : Most primitve order of mammals characterized by certain reptilian features. They are egg-laying mammals. Theria : A subclass of mammals which includes examples that give birth to live young without using a shelled egg. Eutheria : One of the two mammalian clades with extant members that diverged in the early Cretaceous perhaps the late Jurassic. Mature youngs are born in these members. Thecodont : The arrangement of teeth in which the base of the tooth is completely enclosed in a deep socket of bone. Heterodont : Animal which possesses more than a single tooth morphology. In vertebrates especially in mammals there are incisors, canines, pre-molars and molars.
126 GE-ZO-11 ? NSOU Bunodont : The cusp in the cheek teeth remain separate and rounded. That is many cusp in the teeth. Found in man and also in some carnivorous animals. Prosimians : Primitive primates. Hominids : Members of the primate family Hominidae which includes apes and man. Paleogene : It includes Paleocene epoch, Eocene epoch and the Oligocene epoch. Neogene : It includes Miocene and late Pliocene epoch. 15.8 Summary i) Mammals are identified on the basis of the presence of hair, mammary gland and the three bones in the middle ear. ii) Mammals evolved from a group of reptiles called synapsids. iii) Dryolestes exhibit a close relation with the extant placemental and marsupials than to monotremes. iv) Mammals are the only living synapsids. They have undergone various changes during Permian and Triassic periods. v) Eutherian mammals are placemental mammals. vi) Primates have prehensile hands and feet. vii) Lemurs, lorises and tarsiers are prosimian primates. viii) Monkey, apes and man are simian primates. ix) Gorilla is the largest living primate. x) Of the primates man has a language and speech. xi) Various types of teeth are found in mammals. xii) Dental formula in mammals varies with the groups. 15.9 Questions 1. How could you identity an animal as a mammal? In which geological period and from which group of reptiles mammals were evolved? What is Dryolestes? NSOU ? GE-ZO-11 127 2. Present the cladogam as per Luo (2017) showing the family tree of early crown mammals. 3. State the characteristic features of Primates with examples. 4. Distinguish between prosimians and simians with examples. 5. What are hominids? Give an account of hominids with examples. 6. Mention the salient features of Homo sapiens. What do you mean by homodont and heterodont? Write down the dental formula of (a) pig and (b) man. 7. Give a comparative account of lemurs, lorises and tarsiers. Add a note on gibbon. 8. Write notes on : (a) Metatherian mammals; (b) Monotremes; (c) Brain of primates; (d) Chimpanzee. 15.10 Suggested readings 1. T. J. Parker and W. A. Haswell (1985). Textbook of Zoology, Verteblate. Vol. 2. The Macmillan Press Ltd. London 2. K. C. Ghose and B. Manna (2011). A Textbook of Zoology, New Central Book Agency, Kolkata. 3. K. K. Chaki, G. Kundu and S. Sarkar (2008). A Textbook of Zoology, Vol. 2 NCBA, Kolkata. 4. J. Stainforth Kemp and T. Kemp (2005). The Origin and Evolution of Mammals. Oxford University Press. Oxford OX26DP. 5. J. Ottaviani and M. Wicks (2020). Primates. The New York Times Company, New York.
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cells (Fig. 1) line the interior body wall of sponges. Choanocyte cell has a central flagellum which is surrounded by a collar of microvilli.

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Spongocoel is bordered by oval flagellated chambers, opening into it by apopyles.

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Sycon type of canal system. (c) Leucon type of canal system. (d) Rhagon type of canal system. 7.

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brain) and double ventral nerve cord having segmentally arranged ganglia and lateral nerves in each segment. 15. Tactile organs, buccal receptors, statocysts, photoreceptor cells and sometimes eyes with lenses

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Bilaterally symmetrical, triploblastic and coelomate animals. 2. The body is covered by chitinous exoskeleton. 3. The

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S' shaped. The canal extends downwards (orally) and opens into a ring canal, around the mouth. The canal wall is

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and directly above (aboral) to the hyponeural ring sinus. It

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canals. Each lateral canal is attached to the base of the tube-foot and contains a valve

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9/9	SUBMITTED TEXT	34 WORDS	90%	MATCHING TEXT	34 WORDS

tube feet is a hollow, elastic, thin walled, closed cylinder or sac-like ampulla, a middle tubular podium and a lower disc like sucker. The ampulla lies within the arm, projecting into the coelom above the ambulacral pore—

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PREFACE In a bid to standardize higher education in the country, the University Grants Commission (UGC) has introduced Choice Based Credit System (CBCS) based on five types of courses viz. core, generic, discipline specific elective, ability and skill enhancement for graduate students of all programmes at Honours level. This brings in the semester pattern which finds efficacy in sync with credit system, credit transfer, comprehensive continuous assessments and a graded pattern of evaluation. The objective is to offer learners ample flexibility to choose from a wide gamut of courses, as also to provide them lateral mobility between various educational institutions in the country where they can carry their acquired credits. I am happy to note that the university has been recently accredited by National Assessment and Accreditation Council of India (NAAC) with grade "A". UGC (Open and Distance Learning Programmes and Online Programmes) Regulations, 2020 have mandated compliance with CBCS for U.G. programmes for all the HEIs in this mode. Welcoming this paradigm shift in higher education, Netaji Subhas Open University (NSOU) has resolved to adopt CBCS from the academic session 2021-22 at the Under Graduate Degree Programme level. The present syllabus, framed in the spirit of syllabi recommended by UGC, lays due stress on all aspects envisaged in the curricular framework of the apex body on higher education. It will be imparted to learners over the six semesters of the Programme. Self Learning Material (SLMs) are the mainstay of Student Support Services (SSS) of an Open University. From a logistic point of view, NSOU has embarked upon CBCS presently with SLMs in English / Bengali. Eventually, the English version SLMs will be translated into Bengali too, for the benefit of learners. As always, all of our teaching faculties contributed in this process. In addition to this we have also requisioned the services of best academics in each domain in preparation of the new SLMs. I am sure they will be of commendable academic support. We look forward to proactive feedback from all stakeholders who will participate in the teaching-learning based on these study materials. It has been a very challenging task well executed, and I congratulate all concerned in the preparation of these SLMs. I wish the venture a grand success. Professor (Dr.) Subha Sankar Sarkar Vice-Chancellor

Printed in accordance with the regulations of the Distance Education Bureau of the University Grants Commission. First Edition : November, 2021 Netaji Subhas Open University Under Graduate Degree Programme Choice Based Credit System (CBCS) Subject : Honours in Zoology (HZO) Course : Aquatic Biology (Theory) Course Code : GE-ZO-21

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7 Unit - 1 ❑ Aquatic Biomes Structure 1.0 Objectives 1.1 Introduction 1.2 Aquatic biome 1.3 Types of aquatic biome 1.4 Freshwater ecosystems 1.5 Lake ecosystem 1.5.1 Important abiotic factors in lake ecosystem 1.5.2 Primary producers in lake 1.5.3 Macroconsumer organisms in lake 1.5.4 Fish and other vertebrates 1.5.5 Decomposers 1.6 Wetland ecosystem 1.7 Stream ecosystem 1.8 River ecosystem 1.9 Estuary 1.9.1 Introduction 1.9.2 Definition 1.9.3 Important physico-chemical characteristics of estuary 1.9.4 Examples of estuaries 1.9.5 Classification of estuary 1.9.6 Estnarine organisms 1.9.7 Importance of estuarine ecosystem

8 1.10 Intertidal zone 1.10.1 Ecology 1.10.2 Zonation of intentidal zone 1.10.3 Adaptive features of intertidal zone animals 1.11 Marine benthic zone 1.11.1 Introduction 1.11.2 Benthic organisms 1.11.3 Classification of benthos 1.11.4 Benthos habitat 1.12 Marine pelagic zone 1.12.1 Introduction 1.12.2 Classification of pelagic zone 1.12.3 Pelagic zone animals 1.13 Summary 1.14 Questions 1.15 Suggested Readings 1.0 Objectives By studying this unit, students will be able to understand about the following— ● Aquatic biomes and its types. ● Different types of freshwater and wetland ecosystem. ● Intertidal zones and its zonation. ● General features of estuaries and its attributes. ● Marine benthic zone and marine pelagic zone.

9 1.1 Introduction In life sciences, plant and animal communities are studied separately, which obscures the concept of wholeness of the community that limits our understanding on ecosystem functions. In fact, plants and animals are closely associated with each other, and growth and distribution of animals are strongly dependent on plants and vegetation. This results in a more inclusive classification, which embraces several plant communities but includes all animal life associated with them; this classification is called a biome. The word biome is formed from two Greek words : bios = life and oma = group or mass. Therefore, it is as a biological unit which is a type of vegetation, climate, soil and altitude of that specific place. The term biome is a synonym for biotic community (Möbius, 1877) opined that A biome is, therefore, a collection of plants and animals that have common characteristics for the environment they exist in. Clements and Shelford (1939), the biome is the "biotic community of geographical extent characterized by distinctiveness in the life forms of the important climax species". In other words, biomes are broader term than habitat which has distinct biological communities formed in response to a shared physical climate. 1.2 Aquatic biome Aquatic biome refers to as a major biotic community characterized by the dominant forms of plant and the dominating aquatic environment. Aquatic biome is the largest biome in the world covering around 70% of the Earth. 1.3 Types of aquatic biome Aquatic biomes have been classified into five different types. These are as follows— 1. Freshwater biome : Freshwater biomes are communities of animals and plants found in regions with water characterized by less than 1% salt concentration. Types of freshwater biomes include lakes, rivers, ponds, streams and some wetlands. Freshwater regions can be found on every single continent that covers about 1 / 5 th area of the world. Freshwater biomes are the largest communities of freshwater microscopic bacteria, algae,

10 phytoplankton, zooplankton, invertebrates, vertebrates including fish. Freshwater biome is the resource of food and water to human. 2. Freshwater wetland biome : A wetland is a land area that is saturated with water, either permanently or seasonally, such that it takes on the characteristics of a distinct ecosystem. Freshwater wetlands are ecosystems that are affected by the permanent or temporary rising of a body of water and it's overflowing onto normally dry land. It plays an important role in the regulation of water flow, water quality to whole catchment areas. Wetland supports a great diversity of plants and animals especially the migratory birds, and provides refuge for fauna during droughts. Cattails and Sedges are common plants that grow up from the soil, through the water. All types of amphibians like frogs, toads, salamanders etc. are found in wetlands. The marsh, bog, fen, swamp, mire, slough, and prairie pothole are different types of freshwater wetlands. 3. Brackish water or estuarine biome : Estuary biomes are normally located along coasts, where freshwater rivers meet saltwater oceans. During high tides, salt water flows into the estuary. Likewise, freshwater flows down the rivers and creeks and mixes with the saltwater changed the physico- chemical characteristics of water. Estuary can be surrounded by swamps, coral reefs, and beaches. Estuary biome temperatures vary with seasons, which have also affects the health of the biome. Plants that grow in estuary biome must be adapted to tolerate (i) fluctuating salinity levels; (ii) varying exposure to wind and sunlight; (iii) strong currents and storm waves; (iv) low levels of oxygen in muddy soils. The plants that are found in estuary biomes include Eelgrass, Gumweed, Saltgrass, Red algae, Sea lettuce etc. 4. Marine biome : The marine biome is the region of the earth characterized by the presence of salt water. Although salinity of ocean varies largely from place to place, the average value may be around 35 ppt (parts per thousand). The marine biome is the largest biome of the Earth that includes all the oceans like, Pacific Ocean, Atlantic Ocean, Indian Ocean and Arctic Ocean. The water temperature of the marine biome may be warmer or colder depending on location. Oceans near the equator will have a higher temperature than those near the poles.

11 Marine biome is divided into the pelagic or photic zone and benthic or abyssal zone. Aquatic organisms are adapted to live in different vertical profiles of the ocean. The marine biome is the home to a vast array of living organisms ranging from microscopic algae and bacteria, and number of invertebrate animals, such as jelly fish, octopus, echinoderms, cray fish, etc. Marine biome animals include a vast array of fish species, including mackerel, butterfish, spiny dogfish, squid, monkfish and others. Many birds, such as shore birds, gulls, terns and wading birds, call the marine ecosystem their home. Coral reefs are home to some of the largest diversity of marine species anywhere on the planet. Most of the bottom dwelling marine animals are provided with bioluminescent organs that are used for vision in the darkness and helps to capture prey. Marine biome plays a crucial role in the global carbon cycle and hydrological cycle. The hydrologic cycle is largely influenced by the vast oceans via precipitation and evaporation. It influences the terrestrial climate, rainfall through circulation of air through waves and currents. Kelp forests are underwater ecosystems formed in shallow water by the dense growth of several different species known as kelps. Though they look like plants, kelp are large brown algae that live in cool, relatively shallow waters close to the shore. They grow in dense groupings much like a forest on land. Kelp forests can be seen along much of the west coast of North America. 5. Coral reef biome : Coral reef biome is another classic example of marine biome. Corals are marine colonial polyp characterized by a calcareous skeleton. Coral reefs are formed due to the accumulation and compaction of the skeletons of these lime secreting organisms. It is found in the clear tropical ocean entirely between latitudes 30°N and 25°S. It is the most diverse ecosystems on the planet and also considered the medicine cabinets of the 21 st century because several medicines are developed to treat cancer, arthritis, human bacterial infections, Alzheimer's disease, heart disease, viruses, and other diseases. Hence, it is very necessary to protect the coral bleaching which is happening due to environmental degradation.
12 1.4 Freshwater ecosystems

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Freshwater ecosystems are a subset of Earth's aquatic ecosystem that includes lakes, ponds, rivers, streams, springs, bogs and wetlands.

Different physico-chemical and biological factors such as, temperature, light, turbidity, salinity, nutrients, vegetation etc. influence the freshwater habitats. Freshwater ecosystems have undergone substantial transformations over time, which have had an impact over various characteristics of the ecosystems. All the freshwater ecosystems indeed exhibit self sufficient, self-regulating system. The components of freshwater ecosystem are as follows : 1. Abiotic components : The chief abiotic components are heat, light, pH value of water, and the basic inorganic and organic components, such as water itself, carbon dioxide gas, oxygen gas, calcium, nitrogen, phosphates, amino acids, humic acids etc. Some proportions of nutrients are in solution state but most of them are present as stored in particulate matter as well as in living organisms. 2. Biotic components : The various organisms that constitute the biotic components are as follows : (A) Producers : These are autotrophic, green plants and some photosynthetic bacteria. The producers fix radiant energy and with the help of minerals derived from the water and mud, they manufacture complex organic substances as carbohydrate, proteins, lipids etc. Producers are of two types- (i) Macrophytes : These are mainly rooted larger plants which include partly or completely submerged, floating and emergent hydrophytes. The common plants are the species of Trapa, Typha, Sagittaria, Nymphaea, Chara, Hydrilla, Vallisneria etc. (ii) Phytoplanktons : These are minute, floating or suspended lower plants. Majority of them are filamentous algae as Zygnema, Ulothrix, Spirogyra, Cladophora and Oedogonium. (B) Comsumers : They are the heterotrophs which depend for their nutrition on the organic food manufactured by producers, the green plants. Most of the consumers are herbivores, a few as insects and some

13 large fish are carnivores feeding on herbivores. The consumers have been divided into primary consumers, secondary consumers and tertiary consumers according to their feeding habit. (C) Decomposers : They are also known as microconsumers, since they absorb only a fraction of the decomposed organic matter. They bring about the decomposition of complex dead organic matter of both- producers (plants) as well as the macroconsumers (animals) to simple forms. Thus, they play an important role in the return of mineral elements again to the medium of freshwater ecosystem. These include a variety of heterotrophic microbes that are osmotrophs. Aspergillus, Cladosporium, Pythium, Rhizopus, Fusarium are most common decomposers. 1.5 Lake ecosystem Lakes are bodies of standing fresh water that may support emergent vegetation at their edges or over their entire area. Lakes may be shallow or deep, permanent or temporary. Lakes lack any direct exchange with an ocean. Lakes of all types share many ecological and biogeochemical processes and their study falls within the discipline of 'limnology'. Lake ecosystems provide a considerable quantity of 'goods and services' such as drinking water, waste removal, fisheries, agricultural irrigation, industrial activity, and recreation for the benefit of humans. Many organisms also depend on freshwater for survival. For these reasons lakes are important ecosystems. Lake ecosystem (Fig-1) are influenced by their watersheds, the geological, chemical and biological processes that occur on the land and uphill streams. A lake and its watershed are often considered to be a single ecosystem (Likens, 1985). Another factor that influences the composition of lake ecosystems is the degree to which light penetrates the water. The zone in which light penetrates sufficiently to support photosynthesis is known as the photic zone. The zone in which too little light penetrates to support photosynthesis is known as the aphotic (or profundal) zone.
14 Fig-1 : A representation of ideal lake ecosystem Lakes are divided into three different "zones" which are usually determined by depth and distance from the shoreline (Fig-2).

94%	MATCHING BLOCK 2/10	W

The topmost zone near the shore of a lake is the littoral zone. This zone is the warmest since it is shallow and can absorb more of the Sun's heat. It sustains a fairly diverse community, including several species of algae (like diatoms), rooted and floating aquatic plants, grazing snails, clams, insects, crustaceans, fishes and amphibians. In the case of the insects, such as dragonflies and midges, only the egg and larvae stages are found in this zone. The vegetation and animals living in the littoral zone are food for other creatures such as turtles, snakes, and ducks. The near-surface open water surrounded by the littoral zone is the limnetic zone. The limnetic zone is well-lighted and is dominated by phytoplankton and zooplankton which are small organisms that play a crucial role in the food chain.

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A variety of freshwater fish also occupy this zone. Plankton have short life spans-when they die, they fall into the deep-water part of the lake/pond, the profundal zone. This zone is much colder and denser than the other two. Little light penetrates all the way through limnetic zone into the profundal zone. Heterotrophic fauna that thrive on dead organisms and use oxygen for cellular respiration

are present in this zone. Mass input and output : water, organic matter, nutrients etc. Atmosphere : deposition, gas exchange Food web Processes (metebolism, nutrient cycling) Lake outflow Watershed Benthos Plankton inflow

15 Fig-2 : Three major zones of a freshwater lake 1.5.1 Important abiotic factors in lake ecosystem A lake ecosystem or lacustrain ecosystem includes biotic components (plants, animals and microorganisms) and non living abiotic components (physical and chemical factors) and their interactions. Lake ecosystems are diverse, ranging from a small, temporary rainwater pool a few inches deep to a larger one like Baikal lake, which has a maximum depth of 1642 m 2 (Hansson, 2005). The main difference between pools/ponds and lakes is that ponds and pools being shallow have their entire bottom surfaces exposed to light, while lakes are deep and do not. In addition, some deep lakes mostly in temperate countries become seasonally stratified. 1. Light : The main energy source of lentic (standing water) systems is light which drive the process of photosynthesis. Depending upon the light received, the entire lake can be divided into the surface photic zone and the bottom layer, the aphotic regions. 2. Temperature : Temperature is another important parameter to lake ecosystem. Water can be heated by direct radiation from the sun at the surface and conduction to or from the air and surrounding substrate. The special density distribution due to water temperature leads to thermal stratification in lakes, where a relatively stable, warm layer is found near the surface and colder layers in deep waters. In between there is a layer with a rapid water temperature decrease. It is called the metalimnion. Shallow ponds do not have thermal stratification, instead they show a continuous temperature Littoral zone Profuntal zone Limnetic zone Light compensation level SUN

16 gradient from warmer waters at the surface to cooler waters at the bottom. In addition, temperature fluctuations can vary greatly in these systems, both diurnally and seasonally. 3. Wind : In exposed systems, wind can create turbulent, spiral-formed surface currents called Langmuir circulations. It is the interaction between horizontal surface currents and surface gravity waves. The visible result of these rotations, can be seen in any lake, are the surface foam lines that run parallel to the wind direction. The degree of nutrient circulation is system specific, as it depends upon such factors as wind strength and duration, as well as lake or pool depth and productivity concern. 1.5.2 Primary producers in lake Different groups of algae, including phytoplankton, periphyton and nanoplankton, are the primary photosynthetic organisms in lakes. In addition, aquatic plants also contribute to primary production. Aquatic plants can be grouped according to their habitat distribution in lakes such as : (i) emergent : rooted in the substrate, but with leaves and flowers extending into the air. There are many species of emergent plants, among them, the reed (Phragmites), Cyperus papyrus, Typha sp. are important; (ii) floating-leaved : rooted in the substrate, but with floating leaves. Common- floating leaved macrophytes are water lilies (family-Nymphaeaceae), pondweeds (family-Potmogetonaceae); (iii) submerged : growing beneath the surface. Examples include stands of Equisetum fluviatile, Hippuris vulgaris, yellow flag (Iris pseudacorus), Typha etc. ; (iv) free-floating macrophytes : not rooted in the substrate, and floating on the surface. Free-floating macrophytes can occur anywhere on the system's surface. Examples include Pistia spp. commonly called water lettuce, water cabbage or Nile cabbage. 1.5.3 Macroconsumer organisms The macroconsumer organisms in lake ecosystem include zooplanktons, zoobenthos, insect larvae, crustaceans, fishes, etc. A large number of zooplankton and zoobenthos are found in the water column and surface sediment of the lake respectively. In addition, a variety of macroconsumers including insect larvae and fish are also found in lake. Like phytoplankton, these species have developed mechanisms that keep them from sinking to deeper waters, including drag-inducing

17 body forms, and the active flicking of appendages (such as, antennae or spines). As for example the zooplankton, Daphnia sp. make daily vertical migrations in the water column by passively sinking to the darker lower depths during the day, and actively moving towards the surface during the night. The invertebrates, like crustaceans (e.g., crabs, crayfish, shrimp), mollusks (e.g., clams and snails) and numerous types of insects that inhabit the benthic zone are numerically dominated by small species, and are species-rich compared to the zooplankton of the open water. 1.5.4 Fish and other vertebrates Fish is one of the important sentinel organisms inhabiting in the lake. Fish have a range of tolerance to physiological conditions and that can be used to quantify the tolerance level of a particular fish. Other vertebrate taxa like amphibians (e.g., salamanders and frogs), reptiles (e.g., snake, turtles and alligators) and a large number of waterfowl species inhabit lentic systems as well. Most of these vertebrates spend part of their time in terrestrial habitats, and thus, are not directly affected by abiotic factors in the lake or pond. Many fish species are important both as consumers and as prey species to the larger vertebrates. 1.5.5 Decomposers The major decomposers are bacteria and fungi. Decomposers may even become food themselves when they are attached to a piece of detritus that is eaten. Examples of decomposers include organisms like bacteria, mushrooms, mold, worms, springtails etc. Many decomposers need oxygen to survive and without it there is little or no decomposition. Oxygen is needed for decomposers to respire, to enable them to grow and multiply. Some decomposers can survive without oxygen, getting their energy by anaerobic respiration. 1.6 Wetland ecosystem A wetland is a distinct ecosystem that is flooded by water, either permanently or seasonally, where oxygen-free processes prevail. Wetlands are also considered the most biologically diverse of all ecosystems, serving as home to a wide range of plant and animal life. The primary factor that distinguishes wetlands from other land forms or water bodies is the characteristic vegetation and aquatic plants, adapted to the
18 unique hydric soil. Wetlands perform a number of functions, including water purification, water storage, processing of carbon and other nutrients, stabilization of shorelines, and support of plants and animals. For these reasons, they are often called as the kidney of the city. Despite the diversity of wetland types, all wetlands share some common features. To be considered a wetland, an area must have : ● hydrology that results in wet or flooded soils ; ● soils that are dominated by anaerobic process ; and ● biota, particularly rooted vascular plants, that are adopted to life in flooded, anaerobic environments. Wetlands are distributed worldwide. They may be with freshwater, brackish water or salt water. The main wetland types are swamp, marsh, bog and fen. There are different sub-types of wetlands which include mangrove forest, pocosin (a wetland bog with sandy peat soil) floodplains, vernal pool, sink and many others. Wetlands can be tidal (inundated by tides) or non-tidal. The largest wetlands include the Amazon river basin, the west Siberian plain, the Sundarbans in Ganges- Brahmaputra delta. Constructed wetlands are used to treat municipal and industrial wastewater as well as storm water runoff. They may also play a role in water sensitive urban design. To save the wetlands various discussions were made among the scientists throughout the Globe. In this context the Ramsar Convention on Wetlands was held as International importance especially as waterfowl habitat and sustainable use of wetlands. It is also known as the Convention on Wetlands. It is named after the city of Ramsar in Iran, where the convention was signed in 1971. 2 nd February is considered as World Wetlands Day, marking the convention's adoption on 2 February 1971. This convension defines wet lands as “areas

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of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of maine water the depth of which at low tides does not exceed six meters”.

There are 2414 Wetlands of International importance under Ramsar treaty spreading over 254,540,512 hactor of lands across the globe. The treaty came into force on February 01, 1982 in India. By 2019, India had 42 Ramsar sites. The following is the map of Ramsar sites in India (Fig-3).

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19 Fig-3 : Ramsar Wetland Sites of India (Source : http://www.wiienvis.nic.in/Database/ ramsar_wetland_sites_8224.aspx) In wetlands, high levels of nutrients and light support a large biomass of photosynthetic organisms. Most common plant life includes floating pond lilies, cypress, tamarack, blue spruce etc. Wetland supports diverse communities of invertebrate and vertebrate animals that burrow in the sediment, crawl or perch on plants, or swim or wade in standing water. Primary consumer from crustaceans, molluscs and aquatic insect larvae to muskrats, geese, and deer rely on abundance of algee, plants and detritus for food. Wetlands also support a variety of carnivores including dragon flies, otters, alligators and osprey. 1.7 Stream ecosystem A stream is a body of water with surface water flowing within the bed and banks of a channel. As such, river ecosystems are prime examples of lotic ecosystems. Lotic refers to flowing water, from the Latin lotus, meaning washed. Lotic waters
20 range from springs only a few centimeters wide to few kilometers in width particularly major rivers. Lotic ecosystems can be contrasted with lentic ecosystems, which are still water or standing water bodies such as lakes, ponds, and wetlands. The flow of a stream is controlled by three inputs, surface water, subsurface water and groundwater. The surface and subsurface water are highly variable between periods of rainfall. Groundwater, on the other hand, has a relatively constant input and is controlled more by long-term patterns of precipitation. Depending on its location or certain characteristics, a stream may be referred to by a variety of local or regional names. Long large streams are usually called rivers. Streams are important as conduits in the water cycle, instruments in groundwater recharge, and corridors for fish and wildlife migration. The biological habitat in the immediate vicinity of a stream is called a riparine zone. Streams play an important corridor role in connecting fragmented habitats and thus in conserving biodiversity. 1.8 River ecosystem In general, rivers are the largest types of stream, moving large amounts of water from higher to lower elevations. River ecosystems are flowing waters that drain the landscape, and include the biotic (living) interactions amongst plants, animals and micro-organisms, as well as abiotic (nonliving) physical and chemical interactions of its many parts. River ecosystems are part of larger watersheds networks or catchments, where smaller headwater streams drain into mid-size streams, which progressively drain into larger river networks. Some of the characteristic features that make rivers unique among aquatic habitats are as follows : (i) Flow of water is unidirectional; (ii) There is a state of continuous physical change; (iii) The level of oxygen is high and not liming unless it is heavily polluted. (iv) There is a high degree of spatial and temporal heterogeneity at all scales (microhabitats); (v) Variability of physico-chemical parameters across the river length is high forming a gradient; (vi) Primary productivity is low; (vii) Detritus feeding bottom animals are abundant; (viii) The biota is specialized to live with flow conditions.
21 The physico-chemical and biological

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characteristics of a river or stream change during the journey from the source to mouth. The source features cooler temperature that it is at the mouth. The water is also clear, has higher oxygen levels and freshwater fish such as trout and heterotrophs can be found there. Towards the middle part of stream/river, the wide increase, numerous aquatic green plants and algae can be found. Toward the mouth of the river/stream

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since there is less light, there is less diversity of flora, and because of lower oxygen levels, fish that require less oxygen (catfish) can be found. 1.9

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Estuary 1.9.1 Introduction The word "estuary" is derived from the Latin word aestuarium meaning tidal inlet of the sea, which in itself is derived from the term aestus, meaning tide. An estuary is a dynamic ecosystem having a connection to the open sea through which the sea water enters with the rhythm of the tides. The seawater entering the estuary is diluted by the fresh water flowing from rivers and streams. The pattern of dilution varies between different estuaries and depends on the volume of freshwater, the tidal range, and the extent of evaporation of the water in the estuary. 1.9.2 Definition There are many definitions proposed to describe an estuary. A more comprehensive definition of an estuary is "a semi-enclosed body of water connected to the sea as far as the tidal limit or the salt intrusion limit and receiving freshwater runoff; however the freshwater inflow may not be perennial, the connection to the sea may be closed for part of the year and tidal influence may be negligible" (Wolanski, 2007). 1.9.3 Important physico-chemical characteristics of estuary The most important variable characteristics of estuary water are the concentration of dissolved oxygen, salinity and sediment load. There is extreme spatial variability in salinity, with a range of near-zero at the tidal limit of tributary rivers to 3.4% at the estuary mouth. At any one point, the salinity will vary considerably over time and seasons, making it a harsh environment for organisms. Sediment often settles in intertidal mudflats which are extremely difficult to colonize, thus vegetation based habitat is not established. Sediment can also clog feeding and respiratory structures of species, and special adaptations exist within mudflat species to cope with this
22 problem. Dissolved oxygen variation can cause problems for life forms. Nutrient-rich sediment from man-made sources can promote primary production life cycles, perhaps leading to eventual decay removing the dissolved oxygen from the water; thus hypoxic and anoxic zones can develop (Kaiser et al, 2005). Phytoplanktons are key primary producers in estuaries. They move with the water bodies and can be flushed in and out with the tides. Their productivity is largely dependent upon the turbidity of the water. The main phytoplankton present is diatoms and dinoflagellates, which are abundant in the sediment. It is important to remember that a primary source of food for many organisms on estuaries, including bacteria, is detritus from the settlement of the sedimentation 1.9.4 Examples of estuaries The following are different estuaries lying in different continents of the world. Sl. No. Continents Estuaries 1. Africa ● Orange River Estuary ● Lake St Lucia Estuary 2. Asia ● Yenisei Gulf Estuary ● Han River Estuary ● Meghna River Estuary 3. Europe ● Golden Horn ● Severn Estuary ● Thames Estuary 4. North America ● East River ● Great Bay ● San Francisco Bay 5. Oceania ● Spencer Gulf ● Gippsland lakes ● Port Jackson (Sydney Harbour) 6. South America ● Rio de la Plata ● Amazon River
23 A few important estuaries in India are - (i) Thane Creek : Thane Creek is an estuary that separates the city of Mumbai from the Indian Mainland; (ii) Kayamkulam Estuary : The Kayamkulam estuary is the famous Kayamkulam Lake located between Panmana and Karthikapally in Kollam; (iii) Zuari River Estuary : The Zuari river is one of the prominent rivers in Goa. The Zuari river along with the Mandovi river joins the Arabian Sea near Marmugoa; (iv) Baga Creek : The Baga creek is a tidal inlet that joins the Arabian Sea at Baga (Goa). 1.9.5 Classification of estuary Estuary can be classified as following four types : 1. Drowned river valleys : Drowned river valleys are also known as coastal plain estuaries. In places where the sea level is rising relative to the land, sea water progressively penetrates into river valleys and the topography of the estuary remains similar to that of a river valley. This is the most common type of estuary in temperate climates. An example of drowned river valleys is Severn Estuary in UK. 2. Lagoon-type or bar-built : Bar-built estuaries are found in a place where the deposition of sediment has kept pace with rising sea levels so that the estuaries are shallow and separated from the sea by sand spits or barrier islands. They are relatively common in tropical and subtropical locations. Example : Galveston Bay, Albemarle – Pamlico sound. 3. Fjord-type : Fjords were formed where pleistocene glaciers deepened and widened existing river valleys, so that they become U-shaped in cross- sections. At their mouths there are typically rocks, bars or silts of glacial deposits, which have the effects of modifying the estuarine circulation. Fjord-type estuaries can be found along the coasts of Alaska, the Puget region of western Washington State, New Zealand, and Norway. 4. Tectonically produced : These estuaries are formed by subsidence or land cut off from the ocean by land movement associated with faulting, volcanoes, and landslides. Inundation from ecstatic sea-level rise during the Holocene Epoch has also contributed to the formation of these estuaries. There are only a small number of tectonically produced estuaries. Example : San Francisco Bay, which was formed by the crustal movements of the San Andreas fault system causing the inundation of the lower reaches of the Sacramento and San Joaquine rivers.

24 1.9.6 Estuarine organisms Estuaries are tough environments where organisms in estuaries are subject to tremendous osmotic stress. Organisms adapted to fresh water have relatively low salt concentrations in their body fluids. When immersed in salt water, the greater osmatic potential of sea water sucks water out of them until their tissues become saltier. Some organisms can regulate their osmotic state using powerful kidneys to excrete salt or water as needed to maintain osmotic homeostasis. The anadromous salmonid fishs are an example. 1.9.7 Importance of estuarine ecosystem The following are the importance of estuarine ecosystem. (i) Important in hydrological cycles. (ii) Sediments supplies to ocean. (iii) Habitat for a large variety of life. (iv) Highly productive among aquatic systems. (v) Food resources of socio-economic relevance. 1.10 Intertidal zone Intertidal zone are traditional coastal regions located between the high and low tide marks. The intertidal zone, also known as the foreshore or seashore, is the area that is above water level at low tide and underwater at high tide (in other words, the area within the tidal range). This area can include several types of habitats with various species of life, such as sea stars, sea urchins, and many species of coral. Sometimes it is referred to as the littoral zone, although that can be defined as a wider region. Organisms in the intertidal zone are adapted to an environment of harsh extremes. The intertidal zone is also home to several species from different phyla, such as, porifera, annelida, coelentareta, mollusca, arthropoda etc. Water is available regularly with the tides, but varies from fresh with rain to highly saline and dry salt, with drying between tidal inundations. With the intertidal zone's high exposure to sunlight, the temperature can range from very hot with full sunshine to near freezing in colder climates. Some microclimates in the littoral zone are moderated by local features and larger plants such as mangroves. Adaptation in the littoral zone allows the use of nutrients supplied in high volume on a regular basis from the sea, which is actively moved to the zone by tides. Edges of habitats, in this case land and sea, are themselves often significant ecologies, and the littoral zone is a prime example.

25 1.10.1 Ecology The intertidal region is an important model system for the study of ecology, especially on wave-swept rocky shores. The region contains a high diversity of species, and the zonation created by the tides causes species ranges to be compressed into very narrow bands. This makes it relatively simple to study species across their entire cross-shore range, something that can be extremely difficult in, for instance, terrestrial habitats that can stretch thousands of kilometres. The burrowing invertebrates, such as insects, spiders, sea urchins, crustaceans, clams and worms that make up large portions of sandy beach ecosystems are known to travel relatively great distances in cross-shore directions as beaches change on the order of days, semilunar cycles, seasons, or years. Since the intertidal zone is alternately covered by the sea and exposed to the air, organisms living in this environment must have adaptions for both wet and dry conditions. Hazards include being smashed or carried away by rough waves, exposure to dangerously high temperatures, and desiccation. Typical inhabitants of the intertidal rocky shore include urchins, sea anemones, barnacles, chitons, crabs, isopods, mussels, starfish, and many marine gastropod molluscs such as limpets and whelks. 1.10.2 Zonation of intertial zone The four zones in intertidal zone include from the highest to the lowest is splash zone, high zone, mid zone and low zone (Fig-4). Fig-4 : Zonation of intertidal zone Zone Characteristics Typical Organism Splash zone High Intertidal Mid-Intertidal Low-Intertidal ● This is the area located above the highest high tide mark. ● Highest zone ● Driest zone ● Sparsely populated ● This area is completely covered by water only during the highest high tide. ● Parts of this area are exposed to air for long periods of time. ● This area extends from the average high tide mark to the average low tide mark. ● This area is covered with water dur- ing most hist tides. ● This area is completely exposed of air during most low tides. ● This is the area extending form the reach of the average low tide to the reach of the lowest low tides. ● This area stays wet during most low tides. Periwinkle Snail Barnacles Mussel Sea Star

26 (i) The Splash Zone : The Splash zone is the area above the high tide water line and mainly depends on sea spray and mist from waves and freshwater runoff from rain and streams for water coverage. This relatively dry area is sparsely populated. Few organisms can withstand the extreme fluctuations in moisture, temperature and salinity found in this zone. The characteristics species of the splash zone are the Little Acorn Barnacles (Cthamalus dalli), Sea Lettuce (Ulva sp.) and the Periwinkle Snail (Littorina sp.). All species are adapted to withstand long periods of exposure. (ii) The High Zone : The High zone is the area of intertidal that is completely covered with water in high tides. Parts of this region are exposed to the air for long periods as the tides recede. The inhabitants of this area are study individuals and can remain wet even if they are exposed to the sun and wind. The organisms in this area have also developed attachment devices such as muscular feet, suction cups, byssal threads, or holdfasts to help them resist the force of the waves. The zone is characterized by the large Acorn Barnacle (Balanus glandula), Limpets, Chitons and two species or rockweed Selvetia compressa and Hesperophycus harveyanus. (iii) The Mid Zone : The mid-intertidal zone is the area between the average high tide and low tide mark. This region is covered by water during most high tides, but it is exposed to the air during most low tides. This environment supports a more highly populated and diverse group of organisms, than either the splash zone or high intertidal zone. In order to overcome space and competition problems, organisms that live here have developed specialized niches within the community. The highly recognizable intertidal species found here are the Seastar (Pisaster sp), the Mussel (Mytilus californianus) and the Gooseneck Barnacle (Pollicipes polymerus). The Mussel beds provide the characteristic band for this zone.
27 (iv) The Low Zone : The low intertidal zone is the area between the average low tide level and the lowest low tide level that can be found in both the intertidal and sub- tidal habitats. This area stays moist during most low tides making it an iedal home for many kinds of organisms. This zone also has lots of food as nutrients are circulated in near-shore waters. Many plankton are found within this habitat, and grazers enjoy the rich abundance of algae available. Large fleshy brown algae begin to appear in this zone. Other common algal species are the Feather Boa (Egregia menziesii) and the Sea Plam (Eisenia arborea). This zone acts as a better shelter and gives more portection from desiccation than the other intertidal zone. 1.10.3 Adaptive features of intertidal zone animals 1. Hardy organisms with the capacity to withstand the pounding waves and extremes in temperature, salinity and water availability are found in this zone. 2. Barnacles has a tough, protective covering made of chitin. During their juvenile, or larval stages, barnacles swim freely about in the water column searching for a place to live. Once they find a place to settle, they produce a glue from their head. They use this glue to attach themselves to the substrate which protects them from being tossed about by incoming waves. They use their feathery legs called cirri provided with sensory organs to locate plankton and filter food from the water. 3. Mussels live close together. Once settled, they secrete fibrous byssal threads from a gland in their foot which are used to help the mussel adhere to the rocks. They eat by filtering small particles of organic matter from the seawater. They close their shells tightly to keep in moisture while the tide is out or to protect themselves from predators such as the sea star. 4. Sea anemones have a cylindrical body and a central mouth surrounded by tentacles containing stinging cells called nematocysts that are used to stun prey such as small fish. In sexual reproduction, fertilized eggs are released in the water column and in asexual reproduction, anemones create clones
28 that can form large colonies where intruders are not welcome. To prevent drying out, anemones can turn their tentacles inward and shrink or move to a moist location using a special foot called a pedal. 5. The sea star (Pisaster ochraceus) is an echinoderm. They use their water vasular system to operate their tube feet. In this system, water enters and exists the sea star through an opening on its back. This opening is called the madreporite. Sea stars protect themselves with the help of a tough integument or outer covering that keeps them from drying out. They can also regenerate lost arms, so they can continue their predatory life stlye. 1.11 Marine benthic zone 1.11.1 Introduction The benthic zone

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is the ecological region at the lowest level of water body such as an ocean, lake or stream, including the sediment surface and some sub-surface layers. The benthic region of the ocean begins at the shore line (intertidal or littoral zone) and extends downward along the surface of the continental shelf out to sea. The continental shelf is a gently sloping benthic region that extends away from the land mass. At the continental shelf edge, usually about 200 metres (660 ft) deep, the gradient greatly increases and is known as the continental slope. The continental slope drops down to the deep sea floor. The deep-sea floor is called the abyssal plain and is usually about 4,000 metres (13,000 ft) deep. The ocean floor is not all flat but has submarine ridges and deep ocean trenches known as the hadal zone. Depending on the water-body, the benthic zone may include areas that are only a few inches below water, such as a stream or shallow pond; at the other end of the spectrum, benthos of the deep ocean includes the bottom levels of the oceanic abyssal zone. 1.11.2 Benthic organisms Organisms living in this zone are called benthos which include microorganisms (e.g., bacteria and fungi) as well as larger invertebrates, such as crustacean and polychetes. Organisms here generally live in close relationship with the substrate and many are permanently attached to the bottom. The benthic boundary layer, which includes the bottom layer of water and the uppermost layer of sediment directly 29 influenced by the overlying water, is an integral part of the benthic zone, as it greatly influences the biological activity that takes place there. Benthos are the organisms that live in the benthic zone, and are different from those elsewhere in the water column. Many have adapted to live on the substrate (bottom). In their habitats they can be considered as dominant creatures, but they are often a source of prey for Carcharhinidae such as the lemon shark (Dugan et al, 2013). Many organisms adapted to deep-water pressure cannot survive in the upper parts of the water column because the pressure difference can be very significant (approximately one atmosphere for each 10 meters of water depth). Because light does not penetrate very deep into ocean-water, the energy source for the benthic ecosystem is often organic matter from overlying water column that drifts down to the depths. This dead and decaying matter sustains the benthic food chain; most organisms in the benthic zone are scavengers or detritivores. Some microorganisms use chemosynthesis to produce biomass. Benthic organisms can be divided into two categories based on whether they make their home on the ocean floor or a few centimeters into the ocean floor. Those living on the surface of the ocean floor are known as epifauna (e.g. feather stars, sand dollars, sand crabs, mussels). Those who live burrowed into the ocean floor are known as infauna (e.g., Eastern oyster, European Green Crab, commpn cockle, Soft shell clam). Extremophiles, including piezophiles, which thrive in high pressures, may also live there. 1.11.3 Classification of benthos From the nutritional point of view, the benthos can be categorized into primary producers (algae, aquatic plants) living on the bottom as "phytobenthos" and "zoobenthos" that consume phytopenthos and protozoa. The term epibenthos is used for those organisms living on top of the sediment and hyperbenthos for those living just above the sediment. Benthos also can be categorized according to size : ● Macrobenthos, size greater than one mm. ● Meiobenthos, size less than one mm but greater than 32 μm (μm is a thousandth of a millimeter). ● Microbenthos, size less than 32 μm. 30 1.11.4 Benthos habitats The benthic zone is the lowest level of a marine or fresh water system and includes the sediment surface, the water just above it, a same sub-surface layers. The benthic zone starts at the shore and extends down along the bottom of the lake or ocean giving rise to following zone — (i) Littoral or intertidal zone : area betwen high and low tide. (ii) Sublittoral zone : from low tide to shelf break, i.e., continental shelf. (iii) Bathyal zone : Shelf break to 2000 m. (iv) Abyssal zone : from 2000 to 6000 m. (v) Hadal zone : Sea floor deeper than 6000 m. Because of the depths it can reach, the benthic zone is often characterised by low sunlight and low temperature, but may drop to 2 – 3° C at the most extreme depth of abyssal zone. The lower zones are in deep, pressurized areas of the ocean. Human impacts have occurred at all ocean depths, but are most significant on shallow continental shelf and slope habitats. Many benthic organisms have retained their historic evolutionary characteristics. Some organisms are significantly larger than their relatives living in shallower zones, largely because of higher oxygen concentration in deep water. 1.12 Marine pelagic zone 1.12.1 Introduction The pelagic zone is that region of lake, river or ocean that is not associated with the shore or the bottom. Pelagic zone is the ecological realm that includes the entire ocean water column. Of all the inhabited Earth environments, the pelagic zone has the largest volume, 1,370,000,000 cubic kilometres (330,000,000 cubic miles), and the greatest vertical range, 11,000 metres (36,000 feet). Although, the pelagic zone is nutrient poor, but pelagic life is found throughout the water column, although the numbers of individuals and species decrease with increasing depth. The regional and vertical distributions of pelagic life are governed by the abundance of nutrients and dissolved oxygen; the presence or absence of sunlight, water temperature, salinity, and pressure; and the presence of continental or submarine topographic barriers.

31 1.12.2 Classification of pelagic zone The pelagic zone is divided into the following sub-zones based on the penetration of light (Fig-5). 10,000 m 4,000 m 1,000 m 200 m photic mesopelagic neritic pelagic oceanic aphotic abyssalpelagic bathypelagic hadal abyssal bathyal benthic Sublittoral littoral 1. Epipelagic Zone : (i) This zone stretches from the surface to a depth of less than 200 metres. (ii) It is the surface zone where sufficient light penetrates for photosynthesis. (iii) This region is dominated by phytoplankton, diatoms, and dinoflagellates. (iv) Large fishes such as tunas and sharks are found in this zone. That is why the smaller animals come up to this zone only at night to stay away from the large predators around. Fig-5 : Zonation of the ocean

32 2. Mesopelagic Zone : (i) This zone extends from 200-1,000 metres below the epipelagic zone. (ii) This is known as the twilight zone. (iii) Although some light reaches the region, it is not sufficient for photosynthesis. (iv) Some animals found in this zone have large eyes to make the best use of limited light. (v) The oxygen concentration is also very low in this zone. (vi) The organisms such as squids, nautilus shells, swordfish, etc. have the capacity to survive in this zone. 3. Bathypelagic zone : (i) This is known as the dark zone where no light can reach. (ii) This zone extends from 1,000 to 4,000 metres below the continental slope. (iii) This is the zone of high pressure. The organisms with special features to withstand such high pressures can survive in this zone. For example, the fishes found here lack the swim bladder. (iv) The organisms stay here to conserve energy. (v) The fishes exhibiting bioluminescence are prominent in this zone. (vi) The temperature in this zone stays between 2 – 4° C. (vii) Giant squids and sperm whales are found in this zone. 4. Abyssopelagic zone : (i) This zone extends from 4,000- 6,000 metres and is the region where the continental slope levels off. (ii) It comprises of more than 30% of the bottom ocean. (iii) The organism remains here are colourless and blind. 5. Hadopelagic zone : (i) This zone extends from 6,000-11,000 metres. (ii) Very few species are observed in this zone, as this is the aphotic zone with no light penetration.

33 (iii) Food availability is very low here. (iv) Many organisms are found here to live in hydrothermal vents. 1.12.3 Pelagic zone animals The organisms in the pelagic zone range from the tiny planktons to large mammals like whales. The biotic components of pelagic zone consist of phytoplankton, zooplankton and macroconsumers and decompsers. Invertebrates like jellyfish, squids, octopus and krill are also found in the pelagic zone. Large ocean vertebrates such as crustaceans, sharks, bluefin tuna, and sea turtles live or migrate through the pelagic zone. Seabirds such as shearwaters, petrels and gannets can be found above the pelagic zone. Coral reefs are discussed in the Unit–3 part of the sutdy material 1.13 Summary ● Aquatic biomes refers to as a major biotic community characterized by the dominant forms of plants and the dominating aquatic environment. ● Freshwater ecosystems are of two main components—abiotic and biotic components. ● Lakes are bodies of standing freshwater that may support emergent vegetation at their edges or over their entire area. ● Wetland is a distinct ecosystem that is flooded by water, either permanently or seasonally, where oxygen-free processes prevail. ● A stream is a body of water with surface water flowing within the bed and banks of a channel. ● Estuary is a semi-enclosed body of water connected to the sea. ● Intertidal zone are traditional coastal regions located between the high and low tide marks. 1.14 Questions (i) What is aquatic biome?

34 (ii) Write a short note on marine biome. (iii) What are the primary producers in lake? (iv) Differentiate between stream and river ecosystem. (v) Classify pelagic zone with characteristics. (vi) Write a few examples of pelagic zone animals. (vii) What is kelp forest? (viii) Write a short note on Ramsar Convention. 1.15 Suggested Readings 1. Hansson, CLA (2005). The Biology of Lakes and Ponds. Oxford University Press, Oxford. p. 285. 2. Brown, AL (1987). Freshwater Ecology. Heinimann Educational Books, London. p. 163. . 3. McLusky, DS and Elliott, M (2004). The Estuarine Ecosystem : Ecology, Threats and Management. New York : Oxford University Press. ISBN : 978- 0-19-852508-0 4. Wolanski, E. (2007). Estuarine Ecohydrology. Amsterdam : Elsevier. ISBN : 978-0-444-53066-0 5. Kaiser et al. (2005). Marine Ecology. Processes, Systems and Impacts. New York : Oxford University Press. ISBN : 978-0199249756 6. What is the intertidal zone? World Atlas. Retrieved on 17. 09. 2019. 7. Dugan, JE, Hubbard, DM and Quigley, BJ (2013). "Beyond beach width : Steps toward identifying and integrating ecological envelopes with geomorphic features and datums for sandy beach ecosystems". Geomorphology. 199: 95–105. 8. Wetzel, RG (2001). Limnology : Lake and River Ecosystems, 3rd edn. Academic Press, San Diego. pp. 635–637. 9. Fenchel, T, King, G and Blackburn, TH (2012). Bacterial Biogeochemistry :

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37 Unit - 2 ❑ Freshwater biology of lakes Structure 2.0 Objectives 2.1 Introduction 2.2 Definition of lake 2.3 Origin of lakes 2.4 Classification of lake 2.5 Problems in lake 2.6 Lake ecosystem 2.6.1 Introduction 2.6.2 Ecology of lakes 2.6.3 Biotic communities in lake 2.6.4 Lake organisms 2.7 Lake morphometry 2.7.1 Introduction 2.7.2 Morphometry of lakes 2.8 Physico-chemical characteristics of lake 2.9 Nutrient cycle in lakes 2.9.1 Phosphorus cycle 2.9.2 Sulpher cycle 2.9.3 Nitrogen cycle 2.10 Streams : different stages of stream development 2.10.1 Introduction 2.10.2 Stages of stream development
38 2.11 Adaptation of hill stream fishes 2.11.1 Introduction 2.11.2 Example of few hill stream fishes 2.11.3 Environmental conditions of the hill stream 2.11.4 Adaptive modification in the hill stream fishes 2.12 Summary 2.13 Questions 2.14 Suggested Readings 2.0 Objectives By studying this unit, students will be able to understand about the following— ● Lake and its characteristics. ● To know about lake ecosystem. ● Nitrogen, phosphorus and sulpher cycle. ● Stream and adaptive modification of hill steam fishes. 2.1 Introduction Lake is a large body of natural water collected in a depression. On our Earth, a body of water is considered as lake when it is inland, not part of the ocean, is larger and deeper than a pond. It differs from a pond/ tank due to its larger size, depth and related ecological factors. The presence of a lake, in any region, greatly influences the life of the people living adjacent to it. Lakes are helpful in controlling weather and local climate. In some places, lakes are good sources for water supply for drinking. In terms of area, one-third of the world's standing water is represented by lakes. Streams of watershed are the feeding sources to lakes. India has a vast resource of lakes which are exploited for the development of fisheries and tourism. Fisheries of lakes are called lacustrine fisheries. Every lake is characterized by-
39 (a) Its basin, which is the depression holding the water; (b) Its maximum depth of water; (c) Its volume of water; (d) Its surface area; (e) Rate of inflow and outflow of water; (f) Quality of water; (g) Total dissolved load of nutrients and sediments; (h) Biotic species and their density. 2.2 Definition of lake Lakes are defined as naturally formed hollow depressions on the surface of the earth, which get filled with water. Ponds, in contrast are man made water bodies. According to Forel (1892), lakes are a body of standing water occupying a basin and lacking continuity with sea. Welch (1952) regards all large bodies of standing water as lakes, in contrast to ponds which are small shallow bodies of quite standing water. Lake Baikal is the world's largest freshwater lake in terms of volume, while the Caspian sea (salty water) is the world's largest lake say surface area. 2.3 Origin of lakes In geological terms lakes are ephemeral. They originate as a product of geological processes and terminate as a result of evaporation caused by changes in hydrological balance, or by in filling caused by sedmentation. There are various ways by which lake has been formed. 1. Tectonic basins : These are of two types A. New land lakes : This types of lakes are formed by uplifting of marine sediments. These lakes are often large and shallow. Ex- Lake Okeechobee, Florida.

40 B. Structural basins : Lake in a down faulted depression or uplifting forms of a dam or uplifting around entire basin or by local depression due to earthquakes. Ex- Baikal lake, Pyramid lake (Nevada), Lake Victoria, East Africa. 2. Lakes associated with volcanic activity : Lakes formed due to collapsed or exploded volcanoes and surrounded by rim of lava. Sometimes lava or ash dams form a stream or collapsed lava flow cavern. Ex- Tagus Lake (Galapagos), Lake Kivu (Central Africa). 3. Lakes formed by landslides : Landslides obstruct valleys forming natural dams and thereby formed lakes. Ex- Quake Lake, Yellowstone; most of the Kumaun lakes in Uttar Pradesh (India). 4. Lakes formed by wind : In arid regions, the movement of fine, loose materials such as, clay and sand particles may result in the formation of lake basins. The deposition of soil particles may happen to block an existing stream, thus giving rise to a dammed lake. Ex-Pan lake, Sambhar lake in Rajasthan (India). 5. Lakes formed by rivers : A. Plunge pools : This includes basins of old waterfalls in now dry river systems. Ex-Falls lake. B. Oxbow lakes : Bends in river that becomes isolated. These lakes are shallow and oddly shaped. Ex-Delta lake. C. Floodplain or varzea lakes : Formed due to depressions in the flood plain area. Some are due to sediments deposited across mouths of inflowing streams. 6. Lakes formed by glaciers and ice : A. Existing glaciers or ice : Pockets of meltwater on the surface or below glaciers. In this form, lakes are situated at the front of a receding glacier. Ex-Permafrost lakes (Cryogenic lakes). B. Past glaciers : Glacially deepened valley or fault adjoining the sea. They may be isolated from the sea or may be dammed. Ex- Finger lakes (Lake Mendota, WI).
41 7. Solution lakes : Formed by dissolution of soluble rock (often limestone) by percolating water. The formulae is : $CaCO_3 + CO_2 + H_2O = Ca^{2+} + 2HCO_3^-$. Areas with numerous solution lakes are known as "Karst topography". Ex- Lake Ohrid, Yugoslavia. 8. Lakes associated with shorelines : These lakes are formed at the shores of oceans and they are large lakes. A. deltaic lakes : Sedimentation as river currents slowed down when they enter a large lake or the ocean. They may isolate lakes on deltas. B. coastal lake : Movement of sand in spits and bars may enclose basins. 9. Biogenic lakes : These lakes are mainly human made lakes. They are mainly the reservoirs with dams over 15 m high, 0.1 km 3 surface area and 10% volume of natural lakes. 2.4 Classification of lake Classification helps us to understand and visualize the relationships and also helps us to communicate. The simplest classification is based on the dimension of a lake, whether a lake is small, big or very large. The following are the classification of lakes based on water quality and trophic level of water. (A) Classification based on water quality : Based on water quality lakes are broadly classified into three main categories : fresh water lake, salt water lake and brackish water lake. 1. Freshwater lake : Fresh water lakes are comprises of naturally occurring water with low amounts of dissolved salts. The following are the examples of fresh water lakes. (i) Kolleru lake : Located in Andhra Pradesh. Total area covered is 90000 hactor. The lake is faced with the problem of inflow of effluents, siltation and infestation of water hyacinth. (ii) The Hussain sagar lake : This is one of the largest man-made lake in Asia, located in the heart of Hyderabad, contributing to its immense
42 beauty. It is a sprawling artificial lake that holds water perennially. It was built during the region of Ibrahim Qutub Shah in 1562, on the tributary of the river Musi. 2. Brackishwater lake : Brackishwater lakes are comprises of water having salinity between freshwater and seawater. The following are the examples of brackishwater lakes. (i) Chilka lake : Chilka lake is situated in the Ganjam district of Orissa with a water spread area of 906 sq. km. The water area increases during monsoon to about 1165 sq. km. The lake is connected to the Bay of Bengal by a long outer channel through a single mouth while on the other side it receives several branches of Mahanadi river system. It is a shallow lake, the maximum depth being 3 meters in the south western region, 2.5 metre in the central region and 1.5 metre in the north west. (ii) Pulicat lake : This lake is distributed over two states. The major part is located in the Nellore district of Andhra Pradesh while the rest part is located in the Chingleput distrct of Tamilnadu, where it is connected to the Bay of Bengal to the Pulicat village. Two seasonal rivulets Rayrla Vagu and Kalangi drain in the Pulicat lake. The tidal influence from the Bay of Bengal is restricted upto 16 km from the mouth of the lake with the Bay of Bengal. 3. Saline water lake : A highly concentrated solution of salt in water is found in saline water lake. The following are the few examples of saline water lake. (i) Sambher lake : Located in the arid zone of Rajasthan, the sambhar lake is one of the largest inland saline lakes in India. Salt extraction is one of the major activities in the wetland. (ii) Pangon Tso : One of the most spectacular lakes in Ladakh is the Pangon Tso, which lies across the Changla Pass from Leh. At an altitude of almost 4,500 meters, the Pangon Tso is only 8 km wide at its broadest point, but is an amazing 134 km long. The Pangong is considered to be the longest lake in Ladakh. It is a saltwater lake formed in much the same way as the Tso Morari lake during Ice Age.

43 (B) Classification based trophic levels : Trophic level states a water body's ability to support plants, fish, and wildlife. The richness in nutrient level is called as productivity. It is the basis for the trophic concept of classification. Based on the productivity, this type of lakes are classified into following eight categories: (a) Oligotrophic lakes : Oligotrophic lakes are characterized by the following features : (i) Very low concentrations of nutrients required for plant growth. (ii) Low productivity. (iii) Small populations of phytoplankton, zooplankton, attached algae, macrophytes (aquatic weeds), bacteria, and fish. (iv) Very little consumption of oxygen. (v) Good water clarity (a deep Secchi disk reading, averaging about 10 meters or 33 feet). (vi) Low chlorophyll readings (average about 1.7 mg/m 3). (vii) Sandy or rocky bottom. (b) Mesotrophic lake : The mesotrophic lake is intermediate in most characteristics between the oligotrophic and eutrophic stages. Mesotrophic lakes are characterized by the following features- (i) Production of the plankton is intermediate, so some organic sediment accumulating and some loss of oxygen in the lower waters. (ii) The oxygen may not be entirely depleted except near the bottom (the relative depth of the lake has a bearing on this characteristics). (c) Eutrophic lake : These are in contrast to the oligotrophic lakes having the following characteristics. (i) Rich in plant nutrients. (ii) Productivity is high. (iii) Produce high numbers of phytoplankton (suspended algae). (iv) Poor Secchi disk readings (average about 2.5 meters or 8.0 feet).
44 (v) High numbers of zooplankton and minnows and other small fish that feed on the zooplankton. (vi) Contain considerable amount of organic sediments. (vii) Depletion of oxygen from the lower depths of these lakes. (viii) Chlorophyll concentrations averaging about 14 mg /m 3 or higher. (ix) Phosphorus concentration averages something over 80 mg /m 3 . (d) Dystrophic lakes : The dystrophic lakes are developed from the accumulation of organic matter derived from outside the lake. In this case, the watershed is often forested and there is an input of organic acids (e.g. humic acids) from the breakdown of leaves and evergreen needles. This is followed by a series of processes resulting in a lake having low in pH in water acidic and often has moderately colored (yellow/brown) water. These lakes are poor in plankton production and have sparse fish populations largely because of the acid conditions and have low nutrient concentrations. (e) Acidotrophic lakes : Acidotrophic lakes show low production with low phosphorus and nitrogen, but pH > 5.5. (f) Alkalitrophic lakes : Alkalitrophic lakes show high production with high calcium. (g) Argillotrophic lakes : Argillotrophic lakes show low production with high clay turbidity. (h) Siderotrophic lakes : Siderotrophic lakes show low production with high iron. 2.5 Problems in lake Most of the lakes in India are degraded, depleted and contaminated mainly by human activities : The main causes are : (i) Inflow of domestic sewage. (ii) Agricultural run-off. (iii) Discharge of industrial effluents.
45 (iv) Over fishing. (v) Introduction of exotic species and habitat degradation from population growth. (vi) Expansion of cities. As more water is withdrawn for human use and more of it is returned to lakes and rivers as badly polluted, there is less water available to maintain vital freshwater ecosystems. 2.6 Lake ecosystem 2.6.1 Introduction Pond and lake ecosystems are a prime example of lentic ecosystems. Lentic refers to stationary or relatively still water, from the Latin word lentus, which means sluggish. Like all other aquatic ecosystem, a lake ecosystem includes both the biotic and abiotic components. The biotic components include living plants, animals and micro-organisms. On the other hand the abiotic components include physical and chemical interactions of non-living components. 2.6.2 Ecology of lakes The freshwater lake habitats are vertically stratified into five distinct zones depending upon the intensity of light, temperature and absorption of light, which are as follows — 1. Littoral Zone : The shallow water zone with rooted vegetation near the shore that contains the oxygen riched circulating layer of warm water. In a deep water lake it is extended upto 10 mitre depth. 2. Sub littoral zone : It extends from the littoral zone to non circulating poor oxygenated cold water zone. It extends upto 10 mitre depth. 3. Limnetic zone : The open deep water zone upto the depth of 50 mitre. Light penetrates to entire depth and active photosynthesis occurs all along the depth. 4. Profundal zone : This zone situated beneath the limnetic zone with no penetration of light.

46 5. Abyssal zone : In very deep lake the sub-littoral zone is extended to dark bottom of the lake and is called as abyssal zone. 2.6.3 Biotic communities in lake Biotic communities in lakes determined the productivity of the water bodies. Biotic communities are constituted by : (i) Plankton : Small animals and plants that have limited power of locomotion and remain at the mercy of the waves and currents of water. Plankton of plant origins are called phytoplankton (Votox sp.) and those of animal origin are called zooplankton (Dhapnia sp.). (ii) Nekton : The swimming animals are called nekton and are represented mostly by the fish in ponds and lakes. (iii) Neuston : The animals clinging on the surface of water are called neuston. Some aquatic insects and protozoans constitute these groups of animals. (iv) Benthos : Organisms living at the bottom of the ponds and the lakes are called benthos. The worms, molluscs, nematods etc. from important benthic community in a pond or lake. 2.6.4 Lake organisms Animals : The animals mainly lives in the lakes are small and large fishes, amphibians, turtles, larger zooplankton and insects. The important characteristics of these animals and zooplanktons are that they may move where they chose. Floating animals and plants : These animals move where the water takes them. Some of them are living things (plankton) and some are dead staff (detritus). Among the living things, the important organisms are zooplankton, phytoplankton and bacterio-plankton. The detritus are internal (produced within lake) or external (washed in from watershed) in nature. Benthos : The organisms live on the lake bottom. They are mainly aquatic insects, molluscs (clams, snails and other invertebrates) worms, crayfish etc. There are also some higher plants (macrophytes), attached algae (periphyton), sewage sludge and aufwuchs (mixture of algae, fungi and bacteria). 47 2.7 Lake morphometry 2.7.1 Introduction Morphometrics (Greek morphe means "shape" and metria means "measurement") or morphometry refers to the quantitative analysis of form, a concept that encompasses size and shape. Morphometric analyses are commonly performed on organisms, and are useful in analyzing their fossil record. Morphometrics can be used to quantify a trait of evolutionary significance, and by detecting changes in the shape, deduce something of their ontogeny, function or evolutionary relationships. A major objective of morphometrics is to statistically test hypotheses about the factors that affect shape. 2.7.2 Morphometry of lakes Morphometry is the measurement of external form or shape of a selected water body. It is that branch of limnology which deals with the measurement of significant morphological features of any basin which included water mass is known as morphometry. Traditional methods for calculating lake morphometry metrics have relied upon the use of paper bathymetry maps, planimeters, or simple heuristics. In addition, detailed bathymetry is a requirement for the calculation of most lake morphometry metrics, but is generally only available for a relatively small number of lakes. Studying lake morphometry can also help us appreciate lakes for what they are and manage them with more realistic expectations. 2.8 Physico-chemical characteristics of lake The physico-chemical parameters of water play a significant role in lake ecosystem. The diversity of flora and fauna depend upon the optimum physical condition of water. The following is a brief discussion about the physico-chemical characteristics of lake. Depth : Depth of a lake has an important bearing on the physical and chemical qualities of water. In shallow lakes, sunlight penetrates upto the bottom, warms up the water and facilitates increase in productivity. While depth greater than 5 mitre it is considered congenial from the point of view of biological productivity of a lake.

48 Light : Sunlight determines the maximum depth of the littoral zone, the depth of the lake where enough light reaches to allow plants and algae to grow. That depth is called the compensation point, generally at about 1% of incident light. If nutrients are available, sunlight can support algae across the surface of a lake. Temperature : A temperature increase of only a few degrees does not only cause an increase in the temperature of large water masses such as oceans, seas, lakes and ponds but it also causes hydrological events that cause a change in the physical and chemical characteristics of water. Thermal stratification : Thermal saratification is influenced chiefly by seasonal variation. Strong thermal stratification is formed in the summer months which prevent or slow the exchange of water in the epilimnion. The upper stratum, which usually has the highest dissolved concentration and is characterised by a temperature gradient of less than 1°C per metre of depth is the epilimnion and hypolimnion. It induces water quality deterioration in the bottom because of anoxia in the hypolimnion. The lowest streatum of water characterised by a tempeature gradient of less than 1°C per metre of depth in the hypolimnion. Turbidity : In water bodies such as lakes, rivers and reservoirs, high turbidity levels can reduce the amount of light reaching lower depths, which can inhibit growth of submerged aquatic plants and consequently affect species which are dependent on them, such as fish and shellfish. Dissolved solids : In water bodies like lake or rivers, higher levels of total dissolved solids often harm aquatic species. The total dissolved solids changes the mineral content of the water, which is important to survival of many animals. Dissolved salt can dehydrate the skin of aquatic animals, which can be fatal. Carbonate and bicarbonate : Calcium carbonate is a dietary supplement used when the amount of calcium taken in the diet is not enough. Calcium is needed by the body for healthy bones, muscles, nervous system, and heart. Alkaline lake is, typically with a pH value between 9 and 12. They are characterized by high concentrations of carbonate salts (typically sodium carbonate and related salt complexes), giving rise to their alkalinity. In addition, many alkaline lakes also contain high concentrations of sodium chloride and other dissolved salts, making them saline or hypersaline lakes as well. The resulting hypersaline and highly
49 alkaline lakes are considered some of the most extreme aquatic environments on the lake. Phosphorus : Phosphorus is an essential element for plant life, but when there is too much of it in water, it can speed up eutrophication (a reduction in dissolved oxygen in water bodies caused by an increase of mineral and organic nutrients) of rivers and lakes. Nitrate : Basically, any excess nitrate in the water is a source of fertilizer for aquatic plants and algae. If there is an excess level of nitrates, plants and algae will grow excessively. Oxygen :

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Dissolved oxygen levels in water below 5.0 mg/l put aquatic life under stress. Thus lower the concentration, the greater the stress in faunal density. Oxygen levels that remain below 1-2 mg/l for a few hours can result in large fish kills. Thus optimum dissolved oxygen is

required in any lake to sustain good aquatic environment. Carbon dioxide : Carbon dioxide is found in water as a dissolved gas. It can dissolve in water 200 times more easily than oxygen. Aquatic plants depend on carbon dioxide for life and growth, just as fish depend on oxygen. Plants use carbon dioxide during the process of photosynthesis. 2.9 Nutrient cycle in lakes 2.9.1 Phosphorus cycle Phosphorus is an essential nutrient for plants and animals as well as it is considered as limiting nutrient for aquatic organisms. Phosphorus does enter the atmosphere in very small amounts when the dust is dissolved in rainwater and sea spray but remains mostly on land and in rock and soil minerals. Eighty percent of the mined phosphorus is used to make fertilizers. Phosphates from fertilizers, sewage and detergents can cause pollution in lakes and streams. Over-enrichment of phosphate in both fresh and inshore marine waters can lead to massive algal blooms. In fresh water, the death and decay of these blooms leads to eutrophication. The phosphorus cycle is the biogeochemical cycle that describes the movement of phosphorus through the lithosphere, hydrosphere and biosphere. As phosphorus and phosphorus-based compounds are usually solids at the typical ranges of

50 temperature and pressure found on Earth, thus unlike many other biogeochemical cycles, the atmosphere does not play a significant role in the movement of phosphorus. This is to mention that the phosphorus cycle should be viewed from whole Earth system and then specifically focused on the cycle in terrestrial and aquatic systems (Fig-1). Fig-1 : The aquatic phosphorus cycle Major pools of phosphorus in aquatic systems There are four major pools of phosphorus in freshwater ecosystems: dissolved inorganic phosphorus (DIP), dissolved organic phosphorus (DOP), particulate organic phosphorus (POP), and particulate inorganic phosphorus (PIP). Dissolved material is defined as substances that pass through a 0.45 µm filter. DIP consists mainly of orthophosphate (PO 4 3−) and polyphosphate, while DOP consists of DNA and phosphoproteins. Particulate matter are the substances that get caught on a 0.45 µm filter and do not pass through. POP consists of both living and dead organisms, while PIP mainly consists ofhydroxyapatite, Ca 5 (PO 4) 3 OH. Phosphorus cycling Phosphates move quickly through plants and animals; however, the processes that move them through the soil or ocean are very slow, making the phosphorus cycle overall one of the slowest biogeochemical cycles. The global phosphorus cycle includes four major processes : Death Excretion Decomposition (organic P converted to inorganic P by bacterial section) Inorganic P returned to water column Death Grazing and predation by animals (organic P) Intake by plants (connected to organic P) Inorganic phosphorus (from various natural and human sources) THE PHOSPHORUS CYCLE

51 (i) tectonic uplift and exposure of phosphorus-bearing rocks such as apatite to surface weathering; (ii) physical erosion, and chemical and biological weathering of phosphorus- bearing rocks to provide dissolved and particulate phosphorus to soils, lakes and rivers; (iii) riverine and subsurface transportation of phosphorus to various lakes and run-off to the ocean; (iv) sedimentation of particulate phosphorus (e.g., phosphorus associated with organic matter and oxide/carbonate minerals) and eventually burial in marine sediments (this process can also occur in lakes and rivers). Soil phosphorus is usually transported to rivers and lakes and can then either be buried in lake sediments or transported to the ocean via river runoff. Atmospheric phosphorus deposition is another important marine phosphorus source to the ocean. In surface seawater, dissolved inorganic phosphorus, mainly orthophosphate (PO 4 3−), is assimilated by phytoplankton and transformed into organic phosphorus compounds. Phytoplankton cell lysis releases cellular dissolved inorganic and organic phosphorus to the surrounding environment. Some of the organic phosphorus compounds can be hydrolyzed by enzymes synthesized by bacteria and phytoplankton and subsequently assimilated. The vast majority of phosphorus is remineralized within the water column, and approximately 1% of associated phosphorus carried to the deep sea by the falling particles is removed from the ocean reservoir by burial in sediments. A series of diagenetic processes act to enrich sediment pore water phosphorus concentrations, resulting in an appreciable benthic return flux of phosphorus to overlying bottom waters. These processes include- (i) microbial respiration of organic matter in sediments; (ii) microbial reduction and dissolution of iron and manganese (oxyhydro) oxides with subsequent release of associated phosphorus, which connects the phosphorus cycle to the iron cycle; (iii) abiotic reduction of iron (oxyhydro) oxides by hydrogen sulfide and liberation of iron-associated phosphorus. (iv) phosphate associated with calcium carbonate; and (v) transformation of iron oxide-bound phosphorus to vivianite play critical roles in phosphorus burial in marine sediments.

52 These processes are similar to phosphorus cycling in lakes and rivers (Fig-2). Although orthophosphate (PO 4 3−), the dominant inorganic P species in nature, is oxidation state (P 5+), certain microorganisms can use phosphonate and phosphite (P 3+ oxidation state) as a P source by oxidizing it to orthophosphate. Recently, rapid production and release of reduced phosphorus compounds has provided new clues about the role of reduced P as a missing link in oceanic phosphorus. Fig-2 : Phosphorus cycle in a lake 2.9.2 Sulpher cycle Sulpher is a versatile element, importantly linked to numerous fundamental biotic and abiotic geochemical reactions and cycling processes within the Earth's geosphere, biosphere, hydrosphere and atomosphere. The sulfur cycle is the collection of processes by which sulfer moves between rocks, waterways and living systems. Such biogeochemical cycles are important in geology because they affect many minerals. Biochemical cycles are also important for life because sulfur is an essential element, being a constituent of many proteins and cofactors, and sulfur compounds can be used as oxidants or reductants in microbial respiration. The global sulpher cycle involves the transformations of sulfur species through different oxidation states, which play an important role in both geological and biological processes. Steps of the sulfur cycle are : Iron - P Iron - P Iron - P Iron - P Iron - P Iron - P 4. Anoxia releases phosphorus 5. Phosphorus mixes upward in the fall Thermocline WARM Sunlight COLD ANOXIC 1. Phosphorus defines phytoplankton 2. Phytoplankton help define the thermocline 3. The thermocline and productivity defines the deep oxygen Great Pond Cartoon External loading Pexport streams Pexport sodiment

53 ● Mineralization of organic sulfer into inorganic forms, such as hydrogen sulfide (H_2S), elemental sulfur, as well as sulfide minerals. ● Oxidation of hydrogen sulfide, sulfide, and elemental sulfur (S) to sulfate (SO_4^{2-}). ● Reduction of sulfate to sulfide. ● Incorporation of sulfide into organic compounds (including metal-containing derivatives). The important factor controlling the rate of sulphate reduction in lakes is the concentration of sulphate and an enhanced input may stimulate reduction, substantially altering the cycling of elements such as carbon, nitrogen, phosphorus and iron in lakes. Information on the impact of enhanced sulphate concentration is, however, sparse and the modern phenomenon of a raised atmospheric concentration in acid rain and the discharge of wastewater with a high concentration underlines the importance of understanding sulphur cycling in lakes (Fig-3). Fig-3 : Schematic presentation of the sulphur cycle in freshwater sediments (modified from Jørgensen, 1988). Many lakes have changed from oligotrophy to meso- or eu-trophic conditions during the past decades because of nutrient loading from wastewater and fertilizers. The formation and precipitation of insoluble iron sulphide compounds reduces the binding of phosphate iron oxides and a release of phosphate from the sediments may enhance the eutrophic status of lakes. There is, however, a general lack of understanding of the interactions between sulphur cycling and eutrophication. Lake water Sediment Organic sulphur Sulphide oxidation Pyrite formation Sulphate reducation SO_4^{2-} H_2S FeS_2 Oxic Anoxic

54 2.9.3 Nitrogen cycle Introduction Nitrogen is one of the primary nutrients critical for the survival of all living organisms. It is a necessary component of many biomolecules, including proteins, DNA and chlorophyll. Nitrogen Cycle is a biogeochemical process which transforms the inert nitrogen present in the atmosphere to a more usable form for living organisms. The nitrogen gas exists in both organic and inorganic forms. Organic nitrogen exists in living organisms, and they get passed through the food chain by the consumption of other living organisms. Inorganic forms of nitrogen are found in abundance in the atmosphere. This nitrogen is made available to plants by symbiotic bacteria which can convert the inert nitrogen into a usable form – such as nitrites and nitrates. Nitrogen undergoes various types of transformation to maintain a balance in the ecosystem. Furthermore, this process extends to various biomes, with the marine nitrogen cycle being one of the most complicated biogeochemical cycles. Steps of nitrogen cycle Process of Nitrogen Cycle consists of the following steps : (i) Nitrogen fixation; (ii) Ammonification (iii) Nitrification; (iv) Denitrification (v) Assimilation; These processes take place in several stages and are explained below: (i)Nitrogen fixation It is the initial step of the nitrogen cycle. Here, Atmospheric nitrogen (N_2) which is primarily available in an inert form, is converted into the usable form ammonia (NH_3). The entire process of Nitrogen fixation is completed by symbiotic bacteria which is known as Diazotrophs. Azotobacter and Rhizobium also have a major role in this process. These bacteria consist of a nitrogenase enzyme which has the capability to combine gaseous nitrogen with hydrogen to form ammonia. Nitrogen fixation can occur either by the atmospheric fixation- which involves lightening or industrial fixation by manufacturing ammonia under high temperature and pressure condition. This can also be fixed through man-made processes, primarily industrial processes that create ammonia and nitrogen-rich fertilizers. The reaction involved in the process of nitrogen fixation is as follows : $N_2 + 8H^+ + 8e^- \rightarrow 2NH_3 + H_2$

55 (ii) Nitrification In this process, the ammonia is converted into nitrate by the presence of bacteria in the soil. Nitrites are formed by the oxidation of Ammonia with the help of Nitrosomonas bacterium species. Later, the produced nitrites are converted into nitrates by Nitrobacter. This conversion is very important as ammonia gas is toxic for plants. The reaction involved in the process of nitrification is as follows : $2NH_4^+ + 3O_2 \rightarrow 2NO_2^- + 4H^+ + 2H_2O$ $2NO_2^- + O_2 \rightarrow 2NO_3^-$ (iii) Assimilation Primary producers – plants take in the nitrogen compounds from the soil with the help of their roots, which are available in the form of ammonia, nitrite ions, nitrate ions or ammonium ions and are used in the formation of the plant and animal proteins. This way, it enters the food web when the primary consumers eat the plants. (iv) Ammonification When plants or animals die, the nitrogen present in the organic matter is released back into the soil. The decomposers, namely, bacteria or fungi present in the soil, convert the organic matter back into ammonium. This process of decomposition produces ammonia, which is further used for other biological processes. (v) Denitrification Denitrification is the process in which the nitrogen compounds makes its way back into the atmosphere by converting nitrate (NO_3^-) into gaseous nitrogen (N). This process of the nitrogen cycle is the final stage and occurs in the absence of oxygen. Denitrification is carried out by the denitrifying bacterial species- Clostridium and Pseudomonas, which will process nitrate to gain oxygen and gives out free nitrogen gas as a byproduct. The reaction involved in denitrification process is an follows : $NO_3^- \longrightarrow NO_2^- \longrightarrow NO + N_2O \longrightarrow N_2$ $2NO_3^- + 10e^- + 12H^+ \longrightarrow N_2 + 6H_2O$

56 Fig-4 : Marine nitrogen cycle under future ocean acidification Much of the nitrogen applied to agricultural and urban areas ultimately enters rivers and nearshore coastal system leading to anoxia (no oxygen) or hypoxia (low oxygen) altered biodiversity, changes in food web structure, and general habitat degradation. One common consequence of increased nitrogen is an increase in harmful algal blooms (Howalth, 2008). Additionally, increases in nitrogen in aquatic systems can lead to increased acidification in freshwater ecosystems. Importance of Nitrogen Cycle Importance of the nitrogen cycle is as follows : 1. Helps plants to synthesise chlorophyll from the nitrogen compounds. 2. Helps in converting inert nitrogen gas into a usable form for the plants through the biochemical process. 3. In the process of ammonification, the bacteria help in decomposing the animal and plant matter, which indirectly helps to clean up the environment. 4. Nitrates and nitrites are released into the soil, which helps in enriching the soil with necessary nutrients required for cultivation. Nitrification Nitrification Nitrogen fixation Atomsphere Ocean N 2 N 2 CO 2 N 2 pH NH 3 NO 2 – NO 3 – NH 4 + Denitrification

57 5. Nitrogen is an integral component of the cell and it forms many crucial compounds and important biomolecules. 2.10 Streams : Different stages of stream development 2.10.1 Introduction When excess water from rain, snowmelt, or near surface groundwater accumulates on the ground surface and begins to run downhill, streams are created. Moving waters differ in the three major aspects from lakes and ponds : (i) current is a controlling and limiting factor; (ii) land water interchange is great because of small size and depth of moving water systems as compared with lakes; (iii) oxygen is almost always in abundant supply except when there is pollution. Temperature extremes tend to be greater than in standing water. Besides these, the most distinctive features of moving water ecosystems are those related to their motion, i.e., the rate of flow and the stream velocity. 2.10.2 Stages of stream development There are three stages of stream development : (i) young streams, (ii) mature streams, and (iii) old streams. (i) Young stream : The characteristics of young stream are as follows- ● Flows very rapidly. ● Usually located on a steep valley that has steep sides. ● May have whitewater rapids and waterfalls. (ii) Mature stream : The characteristics of mature stream are as follows- ● Flow less swiftly than a young stream. ● Located in a valley. ● Water in it's shallow areas is slowed down by friction caused at the bottom of a river. ● Formation of meanders (due to increased in width, the stream begins to shift its course in a series of bends or turns called meanders).

58 (iii) Old stream : The characteristics of old stream are as follows- ● Flows slowly. ● Located on a broad flat floodplain that is carved. ● In can only carry smaller sized sediments like silt. ● Leads to a fan-shaped deposite extending out to sea called a delta. ● Dut to the larger size of meanders ox-bow lakes are often seen. Fig-5 : Stages of stream development 2.11 Adaptation of hill stream fishes 2.11.1 Introduction A number of fishes have migrated from sluggish waters of the lower streams to colonize in the torrential waters of the upper streams. These migrations were chiefly in search of food and the shelter from the predators. Hill stream fishes upon reaching the new habitat, adapted themselves through a number of structural modifications with the particular environment. Young Stage Mature Stage Old Age Stage

59 2.11.2 Example of few hill stream fishes The important fishes of the hill streams belong to several genera of three families of order cypriniformes as listed below : Sl. No. Family Scientific names of hill stream fishes 1. Cyprinidae Barelius, Barbus (Tor), Garra, Labeo 2. Siluri Erethistes, Glyptothorax, Laguvia 3. Cobitidae Botia, Nemacheilus 2.11.3 Environmental conditions of the hill stream The following environmental conditions persist in the hill streams that influence the fishes to thrive in the particular habitat. 1. Strength of water currents : It appears to be the primary factor in the evolution of hill stream fishes. The water moves predominantly in one direction on the hills, causing both, the lesser stability of bottom materials as well as the erosion. Fishes living in hill streams have, therefore, to develop adhesive organs to avoid being swept away with the water currents. 2. Light intensity : The sun rays in hill streams penetrate deep into the water because it is shallow and very clear owing to absence of suspended particles. Fishes, therefore, have to adopt either to withstand the intense light or to shelter themselves under the rocks or stones. The small sized fishes can hide themselves below rocks and stones. 3. Dissolved oxygen : The water is well aerated with plenty of oxygen due to rapid rate of flow of water. Abundance of O 2 is, therefore, a favourable condition to fishes inhabiting the torrential streams. 4. Temperature : The temperature of hill streams fluctuates rapidly but remains more or less constant from surface to the bottom. The water is generally cooler but get heated by sun. 5. Availability of food : Good amount of food is available in the hill streams but is in the form of algae covering stones and rocks, as any other type of vegetation cannot grow due to rapid flow of water. Fishes, therefore, have to largely depend upon the algal filaments. In certain regions the microbes and the insect larva may also become available to the fishes.

60 2.11.4 Adaptive modification in hill stream fishes 1. Shape : Hill stream fishes usually have greatly flattened head and body in contrast to cylindrical bodies of fishes found in tanks and lakes. In highly specialized species of Balitora, Glyptosternum, Glyptothorax and Pseudoechensis, the body becomes leaf like. The dorsal surface of hill stream fishes is mostly arched while the ventral surface flattened. Fishes living in the streams in which the water flow is not very fast have almost cylindrical bodies as Crossocheilus latia. The head of hill stream fishes is generally small and semi-circular. Fig-6 : Body shape of hill stream of (a) Glyptothorax ; (b) Erethistes 2. Size : Hill streams fishes are generally small in size, having short and thicker bodies and semicircular heads. Their small size permits them to hide under the rocks and stones during the intense sunlight and prevents them from being crushed between the rolling stones in flood. (a) (b)

61 3. Scales and bony armour : The scales and bony armour in hill stream fishes are poorly developed. It is because that they remain free from the danger of predators. Absence of scales from the ventral side also makes the ventral surface smooth for attachment on the rocky bottom. In some species the scales are present on the dorsal and lateral surfaces of body, but become greatly reduced or absent on the ventral surface. Scales are very minute and embedded in the skin in Schizothorax and Nemacheilus. 4. Mouth : The mouth of hill stream fishes is crescentic or semi-circular in shape. The jaws are strong. In some species like Schizothorax, the jaws are covered by a strong horny covering which helps the fish in scraping algal material from stones for feeding. 5. Lips : The lips in most of the hill stream fishes are modified to form suckers of diverse types. They are used for scooping mud as well as for clinging on stones. In Homaloptera, the lips are modified so as to form a sucker with the help of mouth. In Nemacheilus, the lips are divided in the middle and are swollen, so that they form a ring-like sucker when pulled outwards. In Glyptosternum and Glyptothorax, the lips are reflected and spread around the mouth so as to form a broad sucker for attachment. Fig-7 : Different types of lips, barbells and adhesive devices of hill stream fishes 6. Barbels : Barbels in the hill stream fishes are specialized, greatly reduced being short and stumpy as in Balitora. In Glyptothorax and Pseudoecheneis, the barbels are short, but thick and fleshy at the base.

62 7. Eyes : The eyes in the hill stream fishes are generally small in size and are pushed towards the upper surface of the head where they lie close to each other. The small size of eyes is regarded as a protective measure against the intense sunlight, while their dorsal shift is an obvious adaptation to let free the ventral surface for attachment. This is seen in most of the hill stream fishes like Balitora, Glyptothorax, Pseudoecheneis and Glyptosternum. 8. Fins : The fins in the hill stream fishes are used as organs of locomotion as well as for attachment. To perform dual function various modifications in the structure of fins persist, which are as follows : (a) Paired fins : In some hill stream fishes both the pectoral and pelvic fins are set low on the body to provide greater friction against the rocks and stones (viz.; Garra). In Astroblepus chotae, paired fin forms a sucker, which together with a suctorial mouth is used alternately to enable the fish to climb over the vertical rocks of water fall. In many hill stream fishes, the outer rays of the paired fins are modified for adhesion and the number of inner rays is, therefore, increased. The outer rays of the paired fins become thick and flat and serve for adhesion, while the inner rays are directed upwards against the sides of the body and are kept in motion. Thus, the inner rays may help in respiration also. Fig-8 : Fin-rays of (a) & (b) Glyptothorax ; (c) Oreoglanis. c

63 (b) Caudal fin and its peduncle : Hill stream fishes usually possess a long, narrow, muscular, band shaped caudal peduncle as in Glyptothorax striatus, Homaloptera and Balitora etc. A long and narrow caudal peduncle appears to be an adaptation for life at high altitudes and rapid flowing water. Fig-9 : Different shapes and sizes of caudal fin and caudal penduncle 9. Pectoral and pelvic girdles : The girdles are modified in some species of the hill stream fishes, particularly in those species which are used their fins as organs of adhesion. In Glyptothorax and Pseudoecheneis various bones of the pectoral girdle are fused to provide strength. Keel-like ridges are present on the ventral surface of the inter-clavicular bone, to provide surface for attachment to their muscles. The pelvic fins possess a special muscle besides the adductor and abductor muscles. This special muscle keeps the fin closely pressed against the rocks in resting position of the fish. 10. Breathing apparatus : The ventral surface of gill is used for adhesion to rocks and stones, the gill slits lie on the sides and the gill chamber specialized for retaining water for a longer time. In some species of Garra, the gill openings are little wider, but still separated from each other with a considerable distance. The restriction of the gill openings to the sides may effect respiration of fishes. When the fish is feeding algal slime, or is attached to rocks and stones, respiration may become difficult. However, the fishes may overcome these problems due to the following reasons- (a) Water in the hills is well oxygenated. (b) As the gill openings are small, the fish is able to retain water in the branchial chamber for a longer time.

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64 (c) The inner rays of the pectoral fins are kept in constant motion and help in respiration by forcing the water in and out of the gill openings. They themselves serve for oxygenation, being supplied by numerous capillaries. 11. Air bladder : The air bladder used chiefly as a hydrostatic organ in most fishes is much reduced or degenerate in hill stream fishes, because the buoyancy would be a disadvantage in swift currents. The bladder, if present is enclosed in a thin bony capsule. 12. Adhesive devices : One of the major problem of hill stream fishes is to avoid being swept away in the rapid currents of mountain streams. For this, the skin is variously modified to form organs of adhesion. The Asiatic silurids (cat fishes), Glyptosternum and Pseudoecheneis bear a series of ridges on the ventral surface of the body. These ridges act as a frictional device in preventing the fishes from slipping in rapid water current. Fig-10 : Adhesive devices of (a) Glyptothorax ; (b) Pseudecheneis ; (c) Pseudolaguvia

65 In Glyptothorax, a well-developed U-shaped or V-shaped adhesive apparatus formed of folds of the skin is present between the bases of the pectoral fins. In Garra, the adhesive organ is in the form of a disc behind the mouth. 2.12 Summary ● Lake originate as a product of geological processes and terminate as a result of evaporation. ● Lake organisms includes different animals, floating animals and plants, benthos etc. ● The phosphorus cycle is a biogeochemical cycle that describes the movement of phosphorus through the lithosphere. ● Sulpher cycle play an important role in both geological and biological processes. ● Nitrogen cycle starts with the fixation of environmental nitrogen and ends with denitrification processes via several consequitive steps. ● Hill stream fishes adapted by structural modifications of different organs. 2.13 Questions (i) Define lake. Give examples of freshwater, brackishwater and saline water lake. (ii) Write in your own words about the origin of lake. (iii) Write few examples of lake organisms. (iv) State the major problems of lake. (v) What is ox-bow lake? (vi) Write brief note on nitrogen cycle of lake. (vii) What do you mean by meanders? (viii) Write the adaptive modifications of hill stream fishes. (ix) What are different stages of stream development? (x) What are the major pool of phosphorus in aquatic system?

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68 Unit - 3 ❑ Marine biology Structure 3.0 Objectives 3.1 Introduction 3.2 Salinity 3.3 Density 3.4 Continental Self 3.4.1 Introduction 3.4.2 Definition 3.4.3 Topography of continental shelf 3.4.4 Continental shelf areas 3.4.5 Biota of continental shelf 3.5 Adaptation of deep sea organisms 3.5.1 Introduction 3.5.2 Physical environment of deep sea 3.5.3 Adaptive changes of deep sea animals 3.5.4 Structural modifications in deep sea animals 3.6 Coral reef 3.6.1 Introduction 3.6.2 Defination of coral reef 3.6.3 Types of coral reef 3.6.4 Importance of coral reef ecosystem 3.7 Seaweed

69 3.7.1 Introduction 3.7.2 Ecology 3.7.3 Examples of sea weeds 3.7.4 Uses of sea weeds 3.8 Summary 3.9 Questions 3.10 Suggested Readings 3.0 Objectives By studying this unit, students will be able to understand about the following— • Salinity and density of marine environment. • Continental shelf and its characteristic. • Adaptation of dee sea organisms. • Coral reefs, its types and importance. • Sea weeds and its uses. 3.1 Introduction The marine environment of seas and oceans is vast, occupying 70 percent of the earth's surface. In comparison to the total water bodies in the Earth, the volume of surface area of marine environment lighted by the sun is small. All the seas are interconnected by currents, dominated by waves, influenced by tides and characterized by saline water. Not only the seashore and banks which are the homes of many organisms but the open ocean, many hundreds of kilometers away from land, supports plant and animal communities of great diversity and complexity. In the marine environment, the most important physical factors which influence marine life are light, temperature, pressure, density, salinity, tides and currents. In this section the discussion will be emphasized on salinity and density of sea water.

70 3.2 Salinity The marine animal life has specific osmoregulatory adaptation for high saline sea waters. The absence of many animal species in marine environment has been related to their inability to tolerate the high salt contents of sea water. Salinity is the saltiness or amount of salt dissolved in a body of water, called saline water. This is an important factor in determining many aspects of the chemistry of natural waters and of biological processes within it. Salinity along with temperature and pressure governs different physical characteristics like density and heat capacity of the water. Salinity can be used as a conservative (up changing) tracer for determining the origin and mixing of water types. Zones where salinity decreases with depth are typically found occur at low latitudes and mid latitudes, between the mixed surface layer and the deep ocean are known as thermoclines. On average, seawater in the world's oceans has a salinity of about 3.5% (35 g/l, 599 mM). This means that every kilogram (roughly one litre by volume) of seawater has approximately 35 grams of dissolved salts (predominantly sodium (Na^+) and chloride (Cl^-) ions). Seawater is denser than both fresh water and pure water (density 1.0 kg/l at 4 °C (39 °F)), because the dissolved salts increase the mass by a larger proportion than the volume. The freezing point of seawater decreases as salt concentration increases. Seawater pH is typically limited to a range between 7.5 and 8.4. 3.3 Density The density of a material is given in units of mass per unit volume and expressed in kilograms per cubic metre in the SI system of units. In oceanography, the density of seawater has been expressed in grams per cubic centimetre. The density of seawater is a function of temperature, salinity, and pressure. Except at high altitudes, the ocean is divided into three horizontal zones based on density : 1. Mixed layer : Stirring of surface water by wind produces a well mixed layer of uniforn or nearly uniform density. Thus, the ocean surface is called the mixed layer. 2. Polycline : Pycnocline is situated between the mixed layer and the deep

71 layer. Here water density increases rapidly with depth because of changes in temperature and/or salinity. 3. Deep layer : Below the pycnocline, there is a dark, cold layer called as deep layer which accounts for most of the oceans mass. With the deep layer, density increases gradually with depth and water moves slowly. The density of surface seawater ranges from about 1020 to 1029 kg/m^3, depending on the temperature and salinity. At a temperature of 25 °C, salinity of 35 g/kg and 1 atm pressure, the density of seawater is 1023.6 kg/m^3. Deep in the ocean, under high pressure, seawater can reach a density of 1050 kg/m^3 or higher. There is a relationship between the density and the depth of the water. Values associated with the change in seawater density with depth are listed in the table. Table : Density changes with depth (seawater 35 ppt and 0° C) Depth (m) Pressure (decibars) Density (g/cm^3) 0 0 1.02813 1,000 1,000 1.03285 2,000 2,000 1.03747 4,000 4,000 1.04640 6,000 6,000 1.05495 8,000 8,000 1.06315 10,000 10,000 1.07104 3.4 Continental Self 3.4.1 Introduction A continental shelf is a portion of a continent that is submerged under an area of relatively shallow water known as a shelf sea. Under the United Nations Convention on the law of the sea, the name continental shelf was given a legal definition as the stretch of the seabed adjacent to the shores of a particular country to which it belongs. Though the continental shelf is treated as a physiographic province of the ocean, it is not part of the deep ocean basin proper, but the flooded margins of the continent.

72 3.4.2 Definition In 1958 continental shelf convention used the term “continental shelf” as referring “to the seabed and subsoil of the submarine areas adjacent to the coast but outside the area of the territorial sea, to a depth of 200 meters or beyond that limit, to where the depth of the superjacent waters admits of the exploitation of the natural resources of the said areas” (Young, 1958). The legal definition of a continental shelf differs significantly from the geological definition. UNCLOS states that the shelf extends to the limit of the continental margin, but no less than 200 nmi (370 km; 230 mi) and no more than 350 nmi (650 km; 400 mi) from the baseline of the sea. 3.4.3 Topography of continental shelf The continental shelf usually ends at a point of increasing slope called the shelf break. The sea floor below the break is the continental slope. Below the slope is the continental rise, which finally merges into the deep ocean floor, the abyssal plain. The continental shelf and the slope are part of the continental margin. The shelf area is commonly subdivided into the inner continental shelf, mid continental shelf, and outer continental shelf, each with their specific geomorphology and marine biology. The following figure will give the idea about continental shelf of ocean (Fig-1). The continental shelves are covered by terrigenous sediments; that is, those derived from erosion of the continents. However, little of the sediment is from current rivers. Coast Continental Shelf Continental Slope Ocean Continental Rise Fig-1 : Continental shelf of ocean 3.4.4 Continental shelf areas Shelf seas refer to the ocean waters on the continental shelf. Their motion is controlled by the combined influences of the tides, wind-forcing and brackish water
73 formed from river inflows (regions of freshwater influence). These regions can often be biologically highly productive due to mixing caused by the shallower waters and the enhanced current speeds. Despite covering only about 8% of the Earth's ocean surface area, shelf seas support 15-20% of global primary productivity. The following table will give us the idea about Continental shelf widths of different oceans. Active Active Passive Passive Total Total Ocean Margin Margin Margin Margin Margin Margin Mean Maximum Mean Maximum Mean Maximum (km) (km) (km) m (km) (km) m (km) Arctic Ocean 0 0 104.1 ± 1.7 389 104.1 ± 1.7 389 Indian Ocean 19 ± 0.61 175 47.6 ± 0.8 238 37 ± 0.58 238 Mediterr- anean and 11 ± 0.29 79 38.7 ± 1.5 166 17 ± 0.44 166 Black Seas North Atlantic 28 ± 1.08 259 115.7 ± 1.6 434 85 ± 1.14 434 Ocean North Pacific 39 ± 0.71 412 34.9 ± 1.2 114 39 ± 0.68 412 Ocean South Atlantic 24 ± 2.6 55 123.0 ± 2.5 453 104 ± 2.4 453 Ocean South Pacific 214 ± 2.86 357 96.1 ± 2.0 778 110 ± 1.92 778 Ocean All Oceans 31 ± 0.4 412 88.2 ± 0.7 778 57 ± 0.41 778 3.4.5 Biota of continental shelf Continental shelves teem with life because of the sunlight available in shallow waters, in contrast to the biotic desert of the oceans’ abyssal plain. The pelagic (water column) environment of the continental shelf constitutes the neritic, and the benthic (sea floor) province of the shelf is the sublittoral zone. The shelves makes up less
74 than ten percent of the ocean, and a rough estimate suggest that only about 30% of the continental shelf sea floor receives enough sunlight to allow benthic photosynthesis. Though the shelves are usually fertile, if anoxic conditions prevail during sedimentation, the deposits may over geologic time become sources for fossil fuels. Lobster, Dungeness, Tuna, cod, Halibut, Sole and Mackerel are found in the continental shelf. Permanent rock fixtuers are home to anemones, sponges, clams, oysters, scallops, mussels and coral. Larger animals such as whales and sea turfles can be seen in continental shelf areas as they follow migration routes. 3.5 Adaptation of deep sea organisms 3.5.1 Introduction Adaptation is a physiological process by which an animal adjust himself to exist in a particular environment. Structural and functional modification of living organisms occur as the environment undergoes changes. Temporary changes occur to counteract the environmental changes and it reverts back to the previous form when the environmental changes are over. This type of change is called acclimatization. 3.5.2 Physical environment of deep sea The physical environment of deep sea has special characteristics. To cope with this environment, the animals living there undergo suitable adaptation. Five remarkable characteristics prevail in deep sea, which are- (i) Absence of sunlight : Beyond 200 fathoms there is no sunlight. (ii) Quiescence : Because of depth the movement of water is almost absent. (iii) Cold temperature : In the deep sea the temperature is nearing the freezing point and the temperature remains constant. (iv) Pressure : The pressure is high as it increases with depth. (v) Lack of green vegetation : Total absence of light is the reason for total absence of green vegetation in the deep sea environment. 3.5.3 Adaptive changes of deep sea animals For survival in the deep sea environment, the animals have to develop adaptive changes to cope with adverse physical condition present there. The general characteristics of deep sea animals are as follows-

75 (i) The deep sea organisms are weak and delicate. (ii) The body is generally simplified. (iii) They are either totally blind or they process powerful telescopic eyes to catch maximum amount of light. (iv) They develop long feelers to act as tactile organs. (v) Almost all the deep sea animals are luminescent. (vi) Most of the deep sea fishes live on the exudes of decaying matters and so animals lose the masticatory power. There are other animals which possess powerful jaws. (vii) Most of the animals develop wonderful devices for carrying the youngs. Other produces large number of youngs to overcome the hostile environment. (viii) Small size is an important characteristics of deep sea living. 3.5.4 Structural modifications in deep sea animals Almost all the phyla have representatives who lead deep sea life. The modification of the invertebrates is diverse as compare to the vertebrates. The structural modification in deep sea forms are due to peculiar physical condition of deep sea environment. Many of the crustaceans in the deep sea have the reddish colouration. They have olfactory hairs and extremely long antennae, which are used for touch. Squids have virtually no olfactory organs and therefore need well-developed eyes at all depths. Modification of the vertebrates of the deep sea have been discussed as follows- Amongst the elasmobranch fishes, the true sharks do not exhibit deep sea characteristics excepting the luminous sharks. The silver shark, however, possess deep sea characteristics in having huge eyes, long alternated body and tail. Amongst the teleosts, the typical deep sea form is Cetomimus. It has a long mouth, small teeth, very small eyes and scaleless body. However, in Ipnops, there are no eyes and only too large luminous organ are found on the head. Scaleless body and well developed luminescent organs are the characteristics features in Stomiatidae. In Gastrostomus, the body is long, slender with rows of luminous organs on the lateral side of the body and the mouth is bounded by very large jaws. The Gadiforms (cod like forms) have reduced mouth and dentition; the eyes are extremely large, the trunk is reduced and has a filamentous tapering tail.
76 The Anglers show typical deep sea characteristics. The paired fins are adapted for crawling on the bottom of the sea and the anterior fin rays of the dorsal fin function as a lure. In Linophryne, the fin rays are provided with luminous organs to compensate for the loss of eyes. In another deep sea fish, Protostomias, specialized light producing organs are present in roes on the lateral side of the body. Another important feature of deep sea fishes is flatness of the body to adjust with high pressure. The body in these fishes becomes flattened and the mouth is shifted to the lateral side of the body. 3.6 Coral reef 3.6.1 Introduction The phylum cnidaria is definitely advanced in having tissue grade of structural organization. The variety of forms which are included under this phylum are distributed throughout the world. The coral islands and the coral reefs are the secretary products of some skeleton forming cnidarians, especially the stony corals belonging to the order Madreporadia. They are composed of hard skeleton of calcium carbonate. Starting with a very simple pattern, cnadirians built up huge coral reefs or islands of various shapes and sizes. 3.6.2 Defination of coral reef Hubbard (1997) described coral reefs as wave-resistant piles of limestone and calcarious sediments built by a thin veneer of living organisms. A coral reef is an underwater ecosystem characterized by

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reef-building corals. Reefs are formed of colonies of coral polyps held together by calcium carbonate.

Most coral reefs are built from stony corals, whose polyps cluster in groups. Corals in course of time form coral reefs and coral islands. Formation of coral reefs needs particular environmental conditions. In general coral reefs cannot stand the temprerature below 18° C and they show flourishing growth above 22° C. Usually the coral reefs are restricted in their vertical distribution and they donot form reef below 50 meters from the sea level. 3.6.3 Types of coral reefs Coral reefs are usually divided into three primary types : (i) Fringing reefs; (ii) Barrier reefs; (iii) Platform reef; (iv) Atolls (Fig-2).

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77 (i) Fringing reefs : A fringing reef, also called a shore reef, is directly attached to a shore, or borders with an intervening narrow, shallow channel or lagoon. Fringing reefs are initially formed on the shore at the low water level and expand seawards as they grow in size. The fringing reef is extended from the shore up to 400 metres and takes the contour of the shore. It has a reef edge, called the front where the most active coral growth occurs. Between the front and the shore there lies a more or less flat surface which is known as the reef flat. The fringing reef is largely composed of coral, sand, mud, dead coral and other debris. It is partly composed of coral colonies and other animals. Fringing reef is cut by a narrow water channel (lagoon) and the depth of the water channel is 97 to 55 metres. The fringing reefs of the Red Sea are "some of the best developed in the world" and occur along all its shores except off sandy bays (ii) Barrier reefs : Barrier reefs are separated from a mainland or island shore by a deep channel or lagoon. Their lagoons can be several kilometres wide and 30 to 70 metres deep. Above all, the offshore outer reef edge formed in open water rather than next to a shoreline. It resembles the fringing coral reefs, but it follows the contour of the shore less regularly. The reef flat is separated from the shore by a lagoon of 90 to 110 metres deep. Ex- the Great Barrier Reef of the northern coast of Australia. (iii) Platform reef : Platform reefs, variously called bank or table reefs, can form on the continental shelf, as well as in the open ocean. Platform reefs are found in the southern Great Barrier Reef, the Swain and Capricorn Group on the continental shelf, about 100–200 km from the coast. Some platform reefs of the northern Mascarenes are several thousand kilometres from the mainland. Unlike fringing and barrier reefs which extend only seaward, platform reefs grow in all directions. They are variable in size, ranging from a few hundred metres to many kilometres across. Their usual shape is oval to elongated. Parts of these reefs can reach the surface and form sandbanks and small islands around which may form fringing reefs. A lagoon may form in the middle of a platform reef. (iv) Atoll : The atoll is more or less circular or horse shoe shaped reef and encloses a few kilometers to 64-80 kilometres across. The depth of the lagoon is 37-55 meters. The lagoon usually contains inner islands and reef.
78 Atolls or atoll reefs are a more or less circular or continuous barrier reef that extends all the way around a lagoon without a central island. Atolls are found in the Indian Ocean, for example, in the Maldives, the Chagos Islands, the Seychelles and around Cocos Island. The entire Maldives are reported consists of 26 atolls. Fig-2 : Different type of coral reefs 3.6.4 Importance of coral reef ecosystem (i) Economic : Millions of people around the globe rely on coral reefs for part of their livilihood or for part of their protein intake (Salvat, 1992). Coral reefs provide approximately $30 billion dollar's worth of goods and serivces to human being each year (Kittinger et. al, 2012).Coral reefs also provide other employment opportuities for people working in hotels, recreational fishing operations and other sector of tourism industry (Spalding et al., 2017). (ii) Ecology : Coral reefs serve as important spawning and nursery sites and create habitats for a variety of different coral reef organisms. In addition, coral reefs serve as corridors through which organisms can migrate between different ecosystems such as mangrove logoons and sea grass beds. Coral reefs protect coastlines from the energy produced by currents, wave action and strom events. 3.7 Seaweed 3.7.1 Introduction Seaweed, or macroalgae, refers to several species of macroscopic, multicellular, marine algae. The term includes some types of Rhodophyta (red), Phaeophyta FRINGING BARRIER ATOLL sea level lagoon reef
79 (brown) and Chlorophyta (green) macroalgae. Seaweed species such as kelps provide essential nursery habitat for fisheries and other marine species and thus protect food sources; other species, such as planktonic algae, play a vital role in capturing carbon, producing up to 90% of Earth's oxygen. Understanding these roles offers principles for conservation and sustainable use. 3.7.2 Ecology Two environmental requirements dominate seaweed ecology. These are seawater (or at least brackish water) and light sufficient to support photosynthesis. Another common requirement is an attachment point, although genera such as Sargassum and Gracilaria have species that float freely. Seaweed most commonly inhabits the littoral zone (nearshore waters) and, within that zone, on rocky shores more than on sand or shingle. Seaweed occupies various ecological niches. At the surface, they are only wetted by the tops of sea spray, while some species may attach to a substrate several meters deep. In some areas, littoral seaweed colonies can extend miles out to sea. The deepest living seaweed are some species of red algae. Others have adapted to live in tidal rock pools. In this habitat, seaweed must withstand rapidly changing temperature and salinity and occasional drying. 3.7.3 Examples of sea weeds The following table lists a very few example genera of seaweed. Genus Photographs Colour Remarks of sea weeds Caulerpa Green Submerged Fucus Brown In intertidal zones on rocky shores

80 Genus Photographs Colour Remarks of sea weeds Gracilaria Red Cultivated for food Laminaria Brown Also known as kelp, 8–30 m under water, cultivated for food Macrocystis Brown Giant kelp, forming floating canopies Porphyra Red Intertidal zones in temperate climate. Cultivated for food 3.7.4 Uses of sea weeds Food : Seaweed is consumed across the world, particularly in East Asia (e.g., Japan, China, Korea, Taiwan) and south east Asia. Seaweed is mixed with milk, nutmeg, cinnamon and vanilla to make “dulce” (“sweet”). Alginate, agar and carrageenan are gelatinous seaweed products collectively known as hydrocolloids or phycocolloids. Hydrocolloids are food additives. The food industry exploits their gelling, water- Fig-3

81 retention, emulsifying and other physical properties. Agar is used in foods such as confectionery, meat and poultry products, desserts and beverages and moulded foods. Carrageenan is used in salad dressings and sauces, dietetic foods, and as a preservative in meat and fish, dairy items and baked goods. Medicine and herbs : Alginates are used in wound dressings, and dental moulds. In microbiology, agar is used as a culture medium. Carrageenans, alginates and agaroses, with other macroalgal polysaccharides, have biomedicine applications. Delisea pulchra may interfere with bacterial colonization. Sulfated saccharides from red and green algae inhibit some DNA and RNA-enveloped viruses. Seaweed extract is used in some diet pills. Other seaweed pills exploit the same effect as gastric banding, expanding in the stomach to make the stomach feel more full. Bioremediation : Seaweed (macroalgae), as opposed to phytoplankton (microalgae), is used almost universally for filtration purposes because of the need to be able to easily remove (harvest) the algae from the water, which then removes the nutrients. Marine species of Cladophora, Ulva (sea lettuce) and Chaetomorpha are preferred for filtration. Freshwater filtration applications commonly involve species such as Spirogyra. Climate change : “Ocean afforestation” is a proposal for farming seaweed for carbon removal. After harvesting the seaweed decomposes into biogas, (60% methane and 40% carbon dioxide) in an anaerobic digester. The methane can be used as a biofuel, while the carbon dioxide can be stored to keep it from the atmosphere. Seaweed grows quickly and takes no space on land. Afforesting (9%) of the ocean could sequester 53 billion tons of carbon dioxide annually (annual emissions are about 40 billion tons). Other uses : (i) Other seaweed may be used as fertilizer, compost for landscaping, or to combat beach erosion through burial in beach dunes. (ii) Seaweed is under consideration as a potential source of bioethanol.

82 (iii) Seaweed is an ingredient in toothpaste, cosmetics and paints. Seaweed is used for the production of bio yarn (a textile). (iv) Seaweeds are used as animal feeds. They have long been grazed by sheep, horses and cattle in Northern Europe. They are valued for fish production. Adding seaweed to livestock feed can substantially reduce methane emissions from cattle. 3.8 Summary ● The continental shelf is a portion of a continent that is submarged under an area of relatively shallow water known as shelf sea. ● To cope with the physical environment of deep sea the deep sea animals undergoes adabtire modification. ● Coral reefs are wave resistant piles of limestone and calcarious sediments built by a thin veneer of living organisms. ● Sea weeds refers to several species of microscopic, multicellular marine algae. 3.9 Questions (i) What is the role of salinity and density in marine ecosystem? (ii) What is meant by marine ecosystem ? (iii) What is continental shelf ? (iv) Write short note on different biota in continental shelf. (v) What are the adaptive changes found in deep sea animals ? (vi) Write a short note on structural modifications in deep sea animals. (vi) What is Coral reef ? (vii) Write different uses in sea weeds. (viii) Write few examples of sea weeds.

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85 Unit - 4 ❑ Management of aquatic resources, causes of pollution Structure 4.0 Objectives 4.1 Introduction 4.2 Definition and types of pollution 4.2.1 Definition 4.2.2 Types of pollution 4.2.2.1 Agricultural pollution 4.2.2.2 Industrial pollution 4.2.2.3 Sewage pollution 4.2.2.4 Thermal pollution 4.2.2.5 Oil spill pollution 4.3 Eutrophication 4.4 Water (prevention and control of pollution) Act, 1974 4.4.1 Objectives 4.4.2 Merits 4.4.3 Demerits 4.5 Biological oxygen demand (BOD) 4.6 Chemical oxygen demand (COD) 4.7 Essential differences between BOD and COD 4.8 Summary 4.9 Questions 4.10 Suggested Readings
86 4.0 Objectives By studying this unit, students will be able to understand about the following— ● Different type pollution. ● Eutrophication and its attributes. ● Water (prevention and control of pollution) Act, 1974. ● General features of estuaries. ● BOD, COD and their essential differences. 4.1 Introduction Every human society, be it rural, urban, industrial and most technologically advanced society, dispose of certain kinds of by-products and waste products, which when are injected into the biosphere in quantities so great that they affect the normal functioning of ecosystems and have an adverse effect on plant, animals, and human beings are collectively called as pollutants (Smith, 1977). Sometimes the pollutants are in anthropogenic in nature. All these pollutants individually and/or collectively are responsible for pollution mainly in the air, water and sound. Based on this there are different types of pollution, such as, agricultural, industrial, sewage, thermal, nuclear, oil spills of varied nature. In a broader sense, pollution is classified into two broad categories : (i) natural pollution, which originates from natural process; and (ii) artificial pollution, which originates due to the activities of man. In this section we will discuss about the major cause of agricultural, industrial, sewage, thermal and oil spills pollution. 4.2 Definition and types of pollution 4.2.1 Definition Pollution is an undesirable change in the physical, chemical or biological characteristics of our air, land, water that may or will harmful effect on human life or that of desirable species, our industrial processes, living conditions, and cultural assets (Odum, 1971). According to Southwick (1976) "pollution is the unfavourable alteration of our environment, largely as a result of human activities".
87 4.2.2 Types of pollution 4.2.2.1 Agricultural pollution : India is an agriculture based country. Around 67% of Indian people are dependent on agriculture and agriculture base products. Now-a-days, due to urbanization, industrialization and other agriculture based practices agricultural fields become prone to pollution in varied nature. The agricultural pollutants are mainly the chemicals used as fertilizers (both organic and inorganic) and the pesticides (biocides) used in disease control. India uses about 16 kg/ha of fertilizers (chemicals) on an average, whereas the world average is 54 kg/ha. The following is a discussion about different types of agricultural pollutants. 1. Artificial fertilizers : Modern agricultural practices rely heavily on a wide range of synthetic chemicals which include different types of fertilizers and biocides (pesticides, herbicides or weedicides etc.). These chemicals along with wastes are wasted off lands through irrigation, rainfall, drainage etc. reaching into the water bodies particularly rivers, lakes, streams etc. where they alter the physicochemical characteristics of the water and thus disturb the natural ecosystem. 2. Pesticides and biocides : Pesticides are the chemicals used for killing the plant and animal pests. It includes bactericides, fungicides, nematicides, insecticides and also the herbicides or weedicides. Since weeds (herbs) are not pests like bacteria, fungi, nematodes, insects, the spectrum of activity of these chemicals is extended beyond the pests; and thus a broader term biocide is used to include herbicide etc. There is a wide range of chemicals used as biocides. But the most harmful are those which either do not degrade or degrade very slowly in nature. We prefer to distinguish such chemical substances as hazardous substances or toxicants. These are highly potent chemicals but enter our food chain and then begin to increase in their concentrations at successive trophic levels in the food chain. Some of the pesticides are—DDT, Aldrin, Dieldrin, Malathion, Hexachlora Benzena etc. 4.2.2.2 Industrial pollution : Industrial pollution is a big issue because most pollution is caused by some industry, making it the most significant form of pollution on the planet. Most of the Indian rivers and fresh water streams are seriously polluted by industrial wastes or

88 effluents (see table-1), which come along waste waters of different industries like petro-chemical complexes, fertilizer factories, oil refineries, pulp, paper, textiles, sugar and steel plants, tanneries, distilleries, coal washeries, synthetic material plants for drugs, fibres, rubber, plastics etc. The industrial wastes of these industries and mills include metals (copper, zinc, lead, mercury etc.), detergents, petroleum, acids, alkalies, phenols, carbamates, alcohols, cyanide, arsenic, chlorine and many other inorganic and organic toxicants. All these chemicals of industrial wastes are toxic in nature to animals and may cause death or sublethal pathology of the liver, kidneys, reproductive systems, respiratory systems, or nervous systems in both vertebrate and invertebrate aquatic animals (Wilbur, 1969). Chlorine which is added to water to control growth of algae and bacteria in the cooling system of power station may persist in streams to cause mortality of plankton and fish. Heavy metals like mercury, lead and cadmium has cropped up as a toxic agent of serious nature. Mercury poisoning produced a crippling and often fatal disease called Minamata disease. The toxic and pathological effects of some heavy metal industrial pollutants have been tabulated in table-2. Table-1: Some Indian rivers and their major sources of pollution Sl. No River Sources of pollution 1. Jamuna near Delhi DDT factory, sewage, power station 2. Ganga at Kanpur Jute, chemical, metal and surgical industries; tanneries, textile mills and bulk of domestic sewage of highly organic nature 3. Gomti near Lucknow Paper and pulp mills, sewage 4. Damodar between Fertilizers, fly ash from still plants, suspended Bokaro and Panchet coal particles from washeries and thermal power station 5. Hooghly near Calcutta Power stations, paper pulp, jute, textiles, chemical mills, paint, vernishes, metal, steel, hydrocarbonated vegetable oils, rayon, shop and polythene industries and sewage
89 Sl. No River Sources of pollution 6. Cauvery (Tamilnadu) Sewage, tanneries, distilleries, paper and rayon mills 7. Godavari Paper mills 8. Siwan (Bihar) Paper, sulpher, cement, suger mills 9. Bhadra (Karnataka) Pulp, paper and steel industries 10. Kulu (near Mumbai) Chemical factories, rayon mills and tanneries Table-2 : Pathological effects of heavy metal industrial pollutants Sl. No Metal Pathological effects 1. Mercury Abdominal pain, headache, diarrhea, hemolysis, chest pain 2. Lead Anemia, vomiting, loss of appetite, convulsions, damage of brain, liver and kidney 3. Arsenic Disturbed peripheral circulation, liver cirrhosis, hyperkeratosis, lung cancer, ulcers in gastrointestinal tract, kidney damage 4. Cadmium Diarrhoea, bone deformation, kidney damage, testicular atrophy, anaemia, injury of central nervous system and liver, hypertension 5. Copper Hypertension, uremia, sporadic fever 6. Barium Excessive salivation, vomiting, diarrhoea, paralysis, colic pain 7. Zinc Vomiting, renal damage, cramps 8. Selenium Damage of liver, kidney and spleen, fever, nervousness, vomiting, low blood pressure, blindness 9. Chromium Gastro-intestinal ulceration, disease in central nervous system, cancer 10. Cobalt Diarrhoea, low blood pressure, lung irritation, bone deformities, paralysis
90 The causes of industrial pollution are extensive but the following is a discussion about the major causes of industrial pollution. 1. Unplanned industrial growth : One of the important causes of industrial pollution is unplanned industrial growth because a lot of air and water pollution has occurred from companies who ignored rules or standard practices to facilitate rapid growth. Different companies are known to release significant amounts of toxic gas, making pollution an even more substantial issue from those smaller industries. 2. Lack of effective policies : Many industries have been able to ignore or entirely bypass pollution laws because the policies are either not valid, or not adequately enforced by pollution control boards. 3. Using old and outdated technology : Uses of older technologies in many industries tend to produce large amounts of waste. 4. Use of natural resources : Raw material is necessary for a lot of industries, which requires them to pull underground elements. One of the most common forms of leaching from natural resources is fracking for oil. When industries pull minerals, the process causes pollution in the soil and also causes oil leaks and spills that are harmful and deadly to people and animals. 5. Improper disposal of waste : One of the most common forms of soil and water pollution is improper disposal of wastes from the industries. This is one of the most significant causes of pollution because the effects include severe and chronic health issues and lower air quality. 4.2.2.3 Sewage pollution : Sewage includes mostly biodegradable pollutants such as human faecal matter, animal wastes, and certain dissolved organic compounds (eg., carbohydrates, urea etc.) and inorganic salts such as nitrates and phosphates of detergents and sodium, potassium, calcium and chloride ions. Contamination of fresh waters and shallow offshore seas by sewage is a common occurrence in recent times. Domestic sewage and waste water is about 99.9 percent water and 0.02-0.04 percent solids of which proteins and carbohydrates each comprise 40-50 percent and fats 5-10 percent (Simmons, 1974). Under natural process most of the biodegradable pollutants of sewage are rapidly decomposed, but, when they accumulate in large quantities, they

91 create problem, i.e., when their input into environment exceeds the decomposition or dispersal capacity of the latter. Now-a-days, most cities in well developed countries and some cities of developing countries like India have evolved certain engineering systems, such as, septic tanks, oxidation ponds, filter beds, waste water treatment plants and municipal sewage treatment plants for the removal of many harmful bacteria and other microbes, organic wastes and other pollutants from the sewage, before it is tipped in to rivers or sea. 4.2.2.4 Thermal pollution : Various industrial processes may utilize water for cooling, and resultant warmed water has often been discharged into streams or lakes. Coal-oil-fired generators and atomic energy plants cause into large amount of waste heat which is carried away as hot water and cause thermal pollution or calefaction (warming). Thermal pollution produces distinct changes in aquatic biota mainly by depleting the dissolved oxygen of the water bodies and exerts a disruptive effect on aquatic ecosystem. The following are the major causes of thermal pollution. 1. Production and manufacturing plants : Production and manufacturing plants draw water from a nearby source to keep machines cool and then release back to the source with higher temperatures. When heated water returns to the river or ocean, the water temperature rises sharply and altered the oxygen level, which can also degrade the quality and longevity of life that lives underwater. 2. Soil erosion : Consistent soil erosion causes water bodies to rise, making them more exposed to sunlight and thus increased the temperature of the water bodies. The high temperature could prove fetal for aquatic biomes as it may give rise to anaerobic condition. 3. Deforestation : Tress and plant prevent sunlight from falling directly on lakes, ponds or rivers. When deforestation takes place, these water bodies are directly exposed to sunlight, thus absorbing more heat and raising its temperature. 4. Runoff from paved surfaces : Urban runoff discharged to surface waters from paved surfaces like roads and parking lots can make the water warmer. During summer, the pavement gets quite hot, which makes warm runoffs that makes the water bodies hot.

92 5. Natural causes : Natural causes like volcanoes, geothermal vents and hot springs under the oceans and seas can trigger warm lava to raise the temperature of water bodies. Lightening can also introduce a massive amount of heat into the oceans. This means that the overall temperature of water source will rise, having significant impacts on the environment. 6. Domestic sewage : Domestic sewage is often discharged into rivers, lakes, canals or streams without treating the waste. The temperature of municipal water sewage is normally high than receiving water. With the increase in temperature of the receiving water, the dissolved oxygen decreases, and the demand for oxygen increases, causing anaerobic conditions. 4.2.2.5 Oil spill pollution : An oil spill is the release of a liquid petroleum hydrocarbon into the environment, especially the marine ecosystem, due to human activity, and is a form of pollution. The term oil spill is usually given to marine oil spills, where oil is released into the ocean or coastal waters, but spills may also occur on land. Oil spills may be due to releases of crude oil from tankers, offshore platforms, drilling rigs and wells, as well as spills of refined petroleum (such as gasoline, diesel) and their by-products, heavier fuels used by large ships such as bunker fuel, or the spill of any oily refuse or waste oil. Oil spill is responsible for endangering water birds and coastal plants due to coating of oils and adversely affecting the normal activites. Oil spills penetrate into the structure of the plumage of birds and the fur of mammals, reducing its insulating ability, and making them more vulnerable to temperature fluctuations and much less buoyant in the water. Cleanup and recovery from an oil spill is difficult and depends upon many factors, including the type of oil spilled, the temperature of the water (affecting evaporation and biodegradation), and the types of shorelines and beaches involved. Spills may take weeks, months or even years to clean up. Oil spills at sea are generally much more damaging than those on land, since they can spread for hundreds of nautical miles in a thin oil slick which can cover beaches with a thin coating of oil. These can kill seabirds, mammals, shellfish and other organisms they coat. Oil spills on land are more readily containable if a makeshift earth dam can be rapidly bulldozed around the spill site before most of the oil escapes, and land animals can avoid the oil more easily. The following table will give a general idea about oil spill pollution in different times.

93 Spill / Location Date Tonnes of Barrels US Gallons Tanker crude oil (thousands) (thousands) (thousands) Kuwaiti Kuwait January 1991 – 3,409–6,818 25,000– 1,050,000– Oil Lakes November 1991 50,000 2,100,000 Lakeview Kern country, March 14, 1,200 9,000 378,000 Gusher California, 1910 – USA September 1911 Gulf war Kuwait, Iraq, January 19, 1991 818–1,091 6,000–8,000 252,000– oil spill and the Persian – January 28, 336,000 Gulf off the 1991 coast of Odyssey Nove, Scotia, November 132 968 40,704 Canada 10, 1988 4.3 Eutrophication According to Hutchinson (1969), the eutrophication is a natural process which literally means "well nourished or enriched". Due to addition of domestic waste (sewage), phosphates, nitrates etc. from wastes or their decomposition products in water bodies, they become rich in nutrients, specially phosphates and nitrate ions. Thus with the passage of these nutrients through such organic wastes, the water bodies become highly productive or eutrophic and the phenomenon is called as eutrophication. It is a natural state in many lakes and ponds which have a rich supply of nutrients, and it also occurs as part of aging process in lakes, as nutrients accumulate through natural succession. Eutrophication becomes excessive, however, when abnormally high amounts of nutrients from sewage, fertilizer, animal wastes and detergents, enter streams and lakes, causing excessive growth of "bloom" of micro-organisms and aquatic vegetation. It must be remembered that with the addition of nutrients, there is stimulated luxuriant growth of algae in water. There is also generally a shift in algal flora, blue-green algae begin to predominate which starts forming algal blooms, floating scums or blankets of algae. Blooms of algae are generally not utilized by zooplanktons. The algal blooms compete with other aquatic plants for light for photosynthesis. Thus oxygen level is depleted within the waterbodies. Moreover, these blooms also release some toxic chemicals which kill fish, birds and other animals, thus water begins to stink. Decomposition of blooms
94 also leads to oxygen depletion in water. Thus in a poorly oxygenated water with higher CO 2 levels, fish and other animals begin to die and clean water body turned into a stinking drain. Although eutrophication is commonly cause by human activities, it can also be a natural process, particularly in lakes. Eutrophy occurs in many lakes in temperate grassland, for instance. Paleolimnologists now recognize that climate change, geology, and other external influences are critical in regulating the natural productivity of lakes. Some lakes also demonstrate the reverse process (meiotrophication), becoming less nutrient rich with time. The main difference between natural and anthropogenic eutrophication is that the natural process is very slow, occurring on geological time scales. The main effects caused by eutrophication can be summarized as follows— (i) Species diversity decreases and the dominant biota changes. (ii) Plant and animal biomass increases. (iii) Turbidity increases. (iv) Rate of sedimentation increases, shortening the life span of lake. (v) Anoxic conditions may develop. 4.4 Water (prevention and control of pollution) Act, 1974 The water (prevention and control of pollution) Act, 1974, deals with the problem of water pollution comprehensively at National level. The act was enacted under article 252(1) of the constitution, which provides power to the Union Government to legislate on matters of state list, where two or more state legislatures consent to a central law. 4.4.1 Objectives The objectives of the act are to "prevent and control" water pollution and also maintain and restore the wholesomeness of water. It defines the term "pollution" as any contamination of water or alteration of properties of water, discharge of sewage or trade effluents or any other substances (liquid, solid or gaseous) into water (directly or indirectly) to create nuisance or injurious to life or human health, plants, animals, aquatic organisms etc. The act provides for establishing a central or state boards and joint boards for the accomplishment of the objectives of legislation.

95 4.4.2 Merits 1. The act provides a comprehensive scheme for the prevention and control of pollution except for the standards of the regulation of pollution but the central and state boards are given wide powers to decide their own standards and regulations for the local needs. 2. The act prohibits disposal of noxious, poisonous and polluting matter into streams or wells or onto the lands in excess of standard established by state board. 3. A person must obtain consent from the boards through an application before the establishment of any industry, operation or process which may result in disposal of sewage trade effluent into a stream. The consent by the boards will be given only after a thorough enquiry in the prescribed manner. 4. Persons who have been releasing water pollutant, without meting the consent requirements of section-25, penalties are imposed for contravention of the provisions of section 24, 25 and 26. Persons will be punished for the violation of the provisions of section 24 with imprisonment of one year and six months or which may extend. 5. The boards will take emergency measures, if the cause of pollution of well or stream is an accident or unforeseen act or event. 6. One significant and remarkable achievement of the 1988 amendment of water act is the incorporation of a provision for citizen's suit in section 49 of the act; citizens may file criminal complaints against offenders after 60 days, notice to the board. 4.4.3 Demerits 1. Definitions of some important terms like "pollutant", "discharge of pollutant", "toxic pollutant" etc. are not provided in the act. 2. This act includes a definition of stream but not an "estuary" as stream may be covered under the "river" or "sea" or "tidal waters". So, it is needed to add estuary in a suitable place. 3. The act has the provision for the establishment of central, state and joint boards but there is no adequate representation of the members of social groups and lawyers.

96 4. In making consent orders by state boards, there is no public participation in decision making process under the act. 5. Provisions for fixing up standards of quality and targets for eradication of pollution are absent from the act; just like public participation in fixing up these. 4.5 Biological oxygen demand (BOD)

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Biochemical oxygen demand (BOD) is the amount of dissolved oxygen needed (i.e., demanded) by aerobic biological organisms to break down organic material present in a given water sample at certain temperature over a specific

time period. The BOD value is most commonly expressed in milligrams of oxygen consumed per litre of sample during 5 days of incubation at 20° C and is often used as a surrogate of the degree of organic pollution of water. BOD values are generally used as a measure of degree of water pollution and waste level. Thus, mostly BOD value is proportional to the amount of organic waste present in water. In aquatic environment, aquatic pollutants come from various sources. Excessive nutrients, such as nitrates and phosphates, commonly originate in domestic sewage, run-off from agricultural fertilizer, waste materials from animal feed lots, packing plants etc. These nutrients cause pollution primarily because they stimulate the growth of micro-organisms which often increase the BOD of the water and reduce the amount of dissolved oxygen available for fish, higher animals and other aquatic animals. BOD analysis is similar in function to Chemical oxygen demand (COD) analysis, in that both measure the amount of organic compounds in water. However, COD analysis is less specific, since it measures everything that can be chemically oxidized, rather than just levels of biologically oxidized organic matter. 4.6 Chemical oxygen demand (COD) Chemical oxygen demand (COD) is an indicative measure of the amount of oxygen that can be consumed by reactions in a measured solution. It is commonly expressed in mass of oxygen consumed over volume of solution which in SI units is milligrams per litre (mg/L). A COD test can be used to easily quantify the amount of organics in water. The most common application of COD is in quantifying the amount of oxidizable pollutants found in surface water (e.g. lakes and rivers) or

97 waste water. COD is useful in terms of water quality by providing a metric to determine the effect an effluent will have on the receiving body, much like BOD. 4.7 Essential differences between BOD and COD ❑ COD always oxidize things that the BOD cannot or will not measure; therefore, COD is always higher than the BOD. The common compounds which cause COD to be hither than BOD inculde sulfides, sulfites, thiosulfates and chlorides. ❑ The general relationship betwen BOD and COD for sewage and most human wastes is about 1 unit of BOD ≈ 0.64 – 0.68 units of COD. The relationship is not consistent and it may vary considerably for industrial waste waters. 4.8 Summary ● Pollution is an undersirable change in the physical, chemical and biological characteristics of the environment. ● Different types of pollution are found in the environment, i.e., agricultural, air, sound, thermal, sewage, oil spill etc. ● in the water occurs due to the enrichment of nutrients in the water bodies. ● COD is an indicative measure of the amount of oxygen that can be consumed by reactions in a measured soultion. ● BOD is the amount of dissvoled oxygen needed by aerobic biological organisms to break down organic meterial present in the water bodies. 4.9 Questions (i) Define pollution. (ii) Write a brief note on industrial pollution. (iii) What is sewage pollution? (iv) What are the causes of thermal pollution? (v) What is oil spill pollution? water, Eutrophication

98 (vi) What is eutrophication? State example of eutrophication. (vii) Write the merits and demerits of water (prevention and control of pollution) Act, 1974. (viii) Define BOD and COD. 4.10 Suggested Readings 1. “Lingering lessons of the Exxon Valdez Oil Spill”. Commondreams. Org. 2004-03-22. Archived from the original on June 13, 2010. 2. NOAA Ocean Median Centre (2010-03-16). “Hindsight and Foresight, 20 years after the Exxon Valdez spill”. NOAA 3. Wout, B (2015). “Crisis-induced learning and issue politicization in the EU. Public Administration. 94 (2). 381-398. doi. 10.1111/padm.12170. 4. United States Geological Survey, Campbell, Robert Wellman, ed. 1999. Iraq and Kuwait : 1972, 1990, 1991, 1997. Earthshots : Satellite images of environmental change. U.S. Geological Survey. Archived February 19, 2013, at the Wayback Machine. 5. United Nations, Updated Scientific Report on the Environmental Effects of the Conflict between Iraq and Kuwait, 8 Mar, 1993. 6. National Aeronautics and space administration, Goddard Space Flight Centre News, 1991 Kuwait Oil Fires, 21 Mar, 2003. 7. Harvey, S (2010). “California’s legendary oil spill”. Los Angeles Times. 8. United States Environmental Protection Agency, Report to Congress United States Gulf Environmental Technical Assistance from January 27- July 31, 1991. 9. Information Services (2010). “Data & Statistics : Academic Marine oil spillages since 1970”. International Tanker owners Pollution Federation (ITOPF). 10. Walker, IR (2006). “Chironomid overview”, pp. 360-366 in S. A Elias (ed). Encyclopedia of Quatemary Science, Vol.1, Elsevier.
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Freshwater ecosystems are a subset of Earth's aquatic ecosystem that includes lakes, ponds, rivers, streams, springs, bogs and wetlands.

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2/10	SUBMITTED TEXT	128 WORDS	94% MATCHING TEXT	128 WORDS
The topmost zone near the shore of a lake is the littoral zone. This zone is the warmest since it is shallow and can absorb more of the Sun's heat. It sustains a fairly diverse community, including several species of algae (like diatoms), rooted and floating aquatic plants, grazing snails, clams, insects, crustaceans, fishes and amphibians. In the case of the insects, such as dragonflies and midges, only the egg and larvae stages are found in this zone. The vegetation and animals living in the littoral zone are food for other creatures such as turtles, snakes, and ducks. The near-surface open water surrounded by the littoral zone is the limnetic zone. The limnetic zone is well-lighted and is dominated by phytoplankton and zooplankton which are small organisms that play a crucial role in the food chain.			The topmost zone near the shore of a lake or pond is the littoral zone. This zone is the warmest since it is shallow and can absorb more of the Sun's heat. It sustains a fairly diverse community, which can include several species of algae (like diatoms), rooted and floating aquatic plants, grazing snails, clams, insects, crustaceans, fishes, and amphibians. In the case of the insects, such as dragonflies and midges, only the egg and larvae stages are found in this zone. The vegetation and animals living in the littoral zone are food for other creatures such as turtles, snakes, and ducks. The near-surface open water surrounded by the littoral zone is the limnetic zone. The limnetic zone is well-lighted (like the littoral zone) and is dominated by plankton, both phytoplankton and zooplankton. Plankton are small organisms that play a crucial role in the food chain.	

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3/10	SUBMITTED TEXT	67 WORDS	80% MATCHING TEXT	67 WORDS
characteristics of a river or stream change during the journey from the source to mouth. The source features cooler temperature that it is at the mouth. The water is also clear, has higher oxygen levels and freshwater fish such as trout and heterotrophs can be found there. Towards the middle part of stream/river, the wide increase, numerous aquatic green plants and algae can be found. Toward the mouth of the river/stream			characteristics of a river or stream change during the journey from the source to the mouth. The temperature is cooler at the source than it is at the mouth. The water is also clearer, has higher oxygen levels, and freshwater fish such as trout and heterotrophs can be found there. Towards the middle part of the stream/river, the width increases, as does species diversity—numerous aquatic green plants and algae can be found. Toward the mouth of the river/stream,	

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4/10	SUBMITTED TEXT	25 WORDS	90% MATCHING TEXT	25 WORDS
since there is less light, there is less diversity of flora, and because of lower oxygen levels, fish that require less oxygen (catfish) can be found. 1.9			Since there is less light, there is less diversity of flora, and because of the lower oxygen levels, fish that require less oxygen, such as catfish and carp, can be found.	

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5/10	SUBMITTED TEXT	60 WORDS	90%	MATCHING TEXT	60 WORDS

A variety of freshwater fish also occupy this zone. Plankton have short life spans-when they die, they fall into the deep-water part of the lake/pond, the profundal zone. This zone is much colder and denser than the other two. Little light penetrates all the way through limnetic zone into the profundal zone. Heterotrophic fauna that thrive on dead organisms and use oxygen for cellular respiration

A variety of freshwater fish also occupy this zone. Plankton have short life spans—when they die, they fall into the deep-water part of the lake/pond, the profundal zone. This zone is much colder and denser than the other two. Little light penetrates all the way through the limnetic zone into the profundal zone. The fauna are heterotrophs, meaning that they eat dead organisms and use oxygen for cellular respiration.

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6/10	SUBMITTED TEXT	39 WORDS	78%	MATCHING TEXT	39 WORDS

of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of maine water the depth of which at low tides does not exceed six meters".

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7/10	SUBMITTED TEXT	20 WORDS	72%	MATCHING TEXT	20 WORDS

is the ecological region at the lowest level of water body such as an ocean, lake or stream, including the

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8/10	SUBMITTED TEXT	44 WORDS	73%	MATCHING TEXT	44 WORDS

Dissolved oxygen levels in water below 5.0 mg/l put aquatic life under stress. Thus lower the concentration, the greater the stress in faunal density. Oxygen levels that remain below 1-2 mg/l for a few hours can result in large fish kills. Thus optimum dissolved oxygen is

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9/10	SUBMITTED TEXT	15 WORDS	71%	MATCHING TEXT	15 WORDS

reef-building corals. Reefs are formed of colonies of coral polyps held together by calcium carbonate.

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10/10	SUBMITTED TEXT	33 WORDS	57%	MATCHING TEXT	33 WORDS
Biochemical oxygen demand (BOD) is the amount of dissolved oxygen needed (i.e., demanded) by aerobic biological organisms to break down organic material present in a given water sample at certain temperature over a specific					

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PREFACE In a bid to standardize higher education in the country, the University Grants Commission (UGC) has introduced Choice Based Credit System (CBCS) based on five types of courses viz. core, generic, discipline specific elective, ability and skill enhancement for graduate students of all programmes at Honours level. This brings in the semester pattern which finds efficacy in sync with credit system, credit transfer, comprehensive continuous assessments and a graded pattern of evaluation. The objective is to offer learners ample flexibility to choose from a wide gamut of courses, as also to provide them lateral mobility between various educational institutions in the country where they can carry their acquired credits. I am happy to note that the university has been recently accredited by National Assessment and Accreditation Council of India (NAAC) with grade "A". UGC (Open and Distance Learning Programmes and Online Programmes) Regulations, 2020 have mandated compliance with CBCS for U.G. programmes for all the HEIs in this mode. Welcoming this paradigm shift in higher education, Netaji Subhas Open University (NSOU) has resolved to adopt CBCS from the academic session 2021-22 at the Under Graduate Degree Programme level. The present syllabus, framed in the spirit of syllabi recommended by UGC, lays due stress on all aspects envisaged in the curricular framework of the apex body on higher education. It will be imparted to learners over the six semesters of the Programme. Self Learning Material (SLMs) are the mainstay of Student Support Services (SSS) of an Open University. From a logistic point of view, NSOU has embarked upon CBCS presently with SLMs in English / Bengali. Eventually, the English version SLMs will be translated into Bengali too, for the benefit of learners. As always, all of our teaching faculties contributed in this process. In addition to this we have also requisioned the services of best academics in each domain in preparation of the new SLMs. I am sure they will be of commendable academic support. We look forward to proactive feedback from all stakeholders who will participate in the teaching-learning based on these study materials. It has been a very challenging task well executed, and I congratulate all concerned in the preparation of these SLMs. I wish the venture a grand success. Professor (Dr.) Subha Sankar Sarkar Vice-Chancellor

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Unit 1 Study of Polytene Chromosome from Chironomid Larvae 7-15 Unit 2 Cell Division 16-45 Unit 3 Study of Life stages of some Human Parasites 46-69 Unit 4 Study of Pediculus humanus, Ctenocephalides spp. and Cimex lectularis 70-81 Unit 5 Study of Nematode/Cestode Parasites from the intestine of Poultry Bird 82-89 Unit 6 Histological study of Spleen, Thymus and Lymph node 90-97 Unit 7
Preparation of Stained Blood Film to study Various types of White
Blood Cells 98-103 Unit 8 Demonstration of ELISA 104-112 Netaji Subhas Open University Course Code : CC-ZO-06 Course : Cell Biology, Immunology & Parasitology (Practical) UG Zoology (HZO)
NSOU ? CC-ZO-06 7 Unit 1 Study of Polytene Chromosome from Chironomid Larvae Structure 1.0 Objective 1.1 Introduction 1.2 Structure of Chromosome 1.3 Materials and Methods 1.3.1 Materials 1.3.2 Reagent Preparation 1.3.3 Protocols 1.4 Characters of Polytene chromosomes 1.5 Questions 1.0 Objective 1. To visualize the chromosome under light microscope. 2. To study the physical structure of a chromosome within a nucleus at polytene phase. 1.1 Introduction Chromosomes are thread-like structures located inside the nucleus of animal and plant cells. Each chromosome is made of protein and a single molecule of deoxyribonucleic acid (DNA). Passed from parents to offspring, DNA contains the specific instructions that make each type of living creature unique. The term chromosome comes from the Greek words for color (chroma) and body (soma). Scientists gave this name to chromosomes because they are cell structures, or bodies, that are strongly stained by some colorful dyes used in research.
NSOU ? CC-ZO-06 8 1.2 Structure of Chromosome 1. In eukarytoic cells, chromosomes are composed of single molecule of DNA with many copies of five types of histones. 2. Histones are protein molecules and are rich in lysine and arginine residues, they are positively charged. Hence they bind tightly to the negatively-charged phosphates in the DNA sequence. 3. A small number of non-histone proteins are also present, these are mostly transcription factors. Transcription factors regulate which parts of DNA to be transcribed into RNA. 4. During most of the cell's life cycle, chromosomes are elongated and cannot be observed under the microscope. Fig. 1.1 : Chironomid Lifecycle (Source : intechopen.com) Adult Egg Mass Pupa 1st Instar 2nd Instar 3rd Instar 4th Instar

NSOU ? CC-ZO-06 9 5. During the S phase of the mitotic cell cycle the chromosomes are duplicated. 6. At the beginning of mitosis the chromosomes are duplicated and they begin to condense into short structures which can be stained and observed easily under the light microscope. 7. These duplicated condensed chromosomes are known as dyads. 8. The duplicated chromosomes are held together at the region of centromeres. 9. The centromeres in humans are made of about 1-10 million base pairs of DNA. 10. The DNA of the centromere are mostly repetitive short sequences of DNA, the sequences are repeated over and over in tandem arrays. 11. The attached, duplicated chromosomes are commonly called sister chromatids. 12. Kinetochores are the attachment point for spindle fibers which helps to pull apart the sister chromatids as the mitosis process proceeds to anaphase stage. The kinetochores are a complex of about 80 different proteins. 13. The shorter arm of the two arms of the chromosome extending from the centromere is called the p arm and the longer arm is known the q arm. These chromosomes are primarily found in the nucleus of eukaryotic cells. But in certain animals like the Dipteran Insects during their developmental stages certain cells Fig. 1.2 : Chironomid Larvae Salivary gland and polytene chromosome (Source : cit.vfu.cz) Polytene Chromosome Chromosome Salivary gland Larva of Chironomid head tail

NSOU ? CC-ZO-06 10 contain a large chromosome and these chromosomes are commonly known as giant chromosome. Giant chromosomes were first time observed by E.G. Balbiani in the year 1881 in nuclei of certain secretory cells (salivary glands) of Chironomas larvae (Diptera). However he could not conclude them to be chromosomes. They were conclusively reported for the first time in insect cells (Drosophila) by Theophilus Painter of the University of Texas in the year 1933. Since they were discovered in the salivary glands of insects they were termed as salivary gland chromosomes. The name polytene chromosome was proposed by Kollar due to the occurrence of many chromonemata (DNA) in them. Cells in the larval salivary gland of Drosophila, mosquito and Chironema contain chromosomes with high DNA content. However they may also occur in malphigian tubules, rectum, gut, foot pads, fat bodies, ovarian nurse cells etc. Polyteney of giant chromosomes happens by replication of the chromosomal DNA several times without nuclear division (endomitosis) and the resulting daughter chromatids do not separate but remain aligned side by side. During endomitosis the nuclear envelope does not rupture and no spindle formation takes place. The polytene chromosomes are visible during interphase and prophase of mitosis. They are about 100 times thicker contain 1000 to 2000 chromosomes, than the chromosomes found in most other cells of the organism. When stained and viewed under compound microscope at 40X magnification they display about 5000 bands. Polytene chromosomes are giant chromosomes common to many dipteran (two- winged) flies. They begin as normal chromosomes, but through repeated rounds of DNA replication without any cell division (called endomitosis), they become large, banded chromosomes. Polytene chromosomes are usually found in the larval stages, where it is believed these many- replicated chromosomes allow for much faster larval growth than if the cells remained diploid and contain normal chromosome. Simply because each cell now has many copies of each gene, it can transcribe at a much higher rate than with only two copies in diploid cells. In polytene chromosomes, condensed (bands), decondensed (interbands), genetically active (puffs), and silent (pericentric and intercalary heterochromatin as well as regions subject to position effect variegation) regions were found and their features were described in detail. Analysis of the general organization of replication and transcription at the cytological level has become possible using polytene chromosomes.

NSOU ? CC-ZO-06 11 1.3 Materials and Methods 1.3.1 Materials Following chemicals and glass goods are essential to prepare and study the polytene chromosomes : l. Glacial Acetic Acid 2. Ethyl alcohol (Absolute) 3. Orcein stain 4. Glass slides 5. Cover glasses 6. Fine forceps 7. Fine needle 8. Watch glass 9. Sealing material (Nail polish or paraffin) 10. Dissecting binocular 11. Chironomus larvae or Drosophila larvae 1.3.2 Reagent Preparation Fixative preparation : Fixative is kind of chemicals which fixes and preserves the cells or animals itself against decomposition and autolysis. In this experiment Aceto- alcohol will act as a fixative. It is prepared by mixing equal volume of glacial acetic acid and absolute ethyl alcohol at the ratio 1:3. Stain preparation : 02 grams of Orcein powder is dissolved in 100 ml of glacial acetic acid (Remember the orcein powder is a very costly item and do not waste it.) 1.3.3 Protocols 1. The small head is brownish in colour with simple eyes and movable mouthparts. The tail region is characterized by the presence of tufty gills. 2. Hold the bloodworm firmly at a short distance behind the head with a pair of extra fine forceps under a dissecting binocular.

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NSOU ? CC-ZO-06 12 3. Then, with a downward and forward movement of another pair of forceps, pull the head end and separate it from the rest of the body. The salivary gland will generally drawn out completely with the head and can easily be recognized as two flat and whitish structures, attached to the anterior of the gut, with large cells and prominent nuclei. 4. After isolation of salivary glands add few drops aceto-alcohol(fixative) for 15-20 minutes. 5. Add a drop of aceto-orcein stain on the slide. Leave the gland in the aceto- orcein stain for about 30 minutes. If the gland begins to dry up, add another drop of stain. 6. Place a cover slip over the gland in the drop of stain. Lay a paper towel on the desk, turn the slide over, and lay it face down on the towel. Press firmly on the back of the slide with the tip of the finger, so as to blot thoroughly. 7. Place the slide on the desk with cover slip on top, hold the edge of the slide steadily with one hand, and press on the cover slip intermittently with the wooden handle of a dissecting needle. 8. Seal with proper sealing material(Nail-polish). 9. Observation of the giant chromosomes under the microscope. 1.4 Characters of Polytene chromosomes 1. The large size of the chromosome is due to the presence of many longitudinal strands called chromonemata; hence the name polytene (many stranded). 2. They are about 0.5 mm in length and 20 ?m in diameter. 3. The chromosomal strands are formed after repeated division of the chromosome in the absence of cytoplasmic division. This type of division is called endo mitosis. 4. The polytene chromosome contains two types of bands, dark bands and inter bands.

NSOU ? CC-ZO-06 13 Fig. 1.3A : Polytene Chromosomes of Chironomous Larvae (from Salivary gland) (Source : mun.cal)

NSOU ? CC-ZO-06 14 Fig. 1.4 : A. Chironomid (adult). B. Larvae C. Polytene chromosome, arrow indicates the centromere Fig. 1.3B : Polytene Chromosome under microscope (new.bhu.ac.in) 5. The bands of polytene chromosomes become enlarge at certain times to form swellings called puffs. 6. The puffs indicate the site of active genes where mRNA synthesis takes place.

NSOU ? CC-ZO-06 15 1.5 Questions 1. How the Chironomus Larvae Salivary glands have been extracted and prepared for observing polytene chromosome? 2. Describe the process of preparing and staining of polytene chromosome from Chironomus Larvae Salivary gland to observe under light microscope. 3. State the characteristics of the polytene chromose isolated from Chironomus Larvae observed under microscope? 4. Mention the reagents used to observe polytene chromosome from Chironomus Larvae.

NSOU ? CC-ZO-06 16 Unit 2 Cell Division Structure 2.0 Objectives 2.1 Introduction 2.2 Study of Mitosis from Bone Marrow of Goat (Capra hircus) 2.2.0 Objectives 2.2.1 Introduction 2.2.2 Materials and Methods 2.2.3 Observations 2.2.4 Comments 2.2.5 Questions 2.3 Study of Mitosis from Onion (Allium cepa) Root Tip 2.3.0 Objectives 2.3.1 Introduction 2.3.2 Materials and Methods 2.3.3 Observations 2.3.4 Comments 2.3.5 Questions 2.4 Study of Various Stages of Meiosis from Grasshopper Testis 2.4.0 Objectives 2.4.1 Introduction 2.4.2 Materials and Methods 2.4.3 Observations 2.4.4 Comments 2.4.5 Questions 2.5 Study of Various Stages of Meiosis from Mouse 2.5.0 Objectives 2.5.1 Introduction 2.5.2 Materials and Methods 2.5.3 Observations 2.5.4 Comments 2.5.5 Questions

NSOU ? CC-ZO-06 17 2.0 Objectives Cell division is one of the basic biological phenomene of living organism through which the life forms maintain their self-propagation and growth. In this unit learners are introduced with the following ideas. 1. Evidences of cell divisions among different organisms under light microscope. 2. Studying structural changes of a cell, its nucleus and chromosomes during the process of cell division. 3. Observing and studying different types and stages of the cell division processes. 4. Understanding the significances of different types and stages of cell divisions with their biological significances. 5. To provide practical knowledge and expertize to observe cell divisions. 6. Overall, this unit will provide a clear concept and understanding on cell division in enkaryotes and practical methodology to visualize and analyse them at the primary level. 2.1 Introduction All cells of the living body follows the rules of the cell cycle and will divide either to increase of cell numbers for growth and development purposes or for the production of specialized reproductive cells. Some cells will never divide and they are known as super specialised cells like nerve cells. In the cell cycle there are four phases which are S phase, M phase, G 1 phase and G 2 phase. The divisional phase is M phase where the cell will divide either through mitosis or through meiosis. Mitosis is also known as equational division that means the daughter cells produced are quite alike with that of the mother cells particularly in respect to the chromosomal number. All the somatic cells will divide through mitosis. Meiosis cell division will occur only in the germ line cells for the production male and female gamete. This cell division is also known as reduction division that means the daughter cells produced are containing the half of the chromosome number in comparison to the mother cells and these daughter cells are also known as haploid cells. Although there

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NSOU ? CC-ZO-06 18 are two kinds of cell divisions but the mechanism of division is more or less same in both the cases. The only difference is that mitosis cell division consists of only one phase of cell division and after division there are only two daughter cells produced while in case meiosis it consists of two phases of cell divisions, meiosis-I and meiosis-II, and produced four number of daughter cells from one mother cell. The mitosis cell division will require less time than meiosis cell division to complete the division. Both the cell division will occur in two major phases which are karyokinesis and cytokinesis. Karyokinesis means the division of nucleus while cytokinesis means the division of cytoplasm. Karyokinesis can again be divided into four sub phases which are prophase, metaphase, anaphase and telophase. These divisions of karyokinesis phase is done by the morphological changes of the cell during the time of cell division. In true sense there is no compartmentalisation during the time of cell division. 2.2 Study of Mitosis from Bone Marrow of Goat (Capra hircus) 2.2.0 Objective To study the stages of somatic cell division in mammalian specimen. 2.2.1 Introduction Before going into the detailed experimental procedure first we have to understand why the bone marrow? The bone marrow is the only tissue where all the cells are dividing through mitosis in all the time. Now the question Why? You must remember that bone marrow is actually a hematopoietic tissue that means here all the blood cells are formed and that's why this tissue requires mitosis cell division all the times. This is the only cause why we will take the bone marrow for the study of mitosis. Similarly in case of plant the root and shoot tips can be taken for the study of mitosis. Not only that the cells from the epithelium of fish gills and also from tail of the growing tadpole larvae of frog are also good sources for the study of mitosis.

NSOU ? CC-ZO-06 19 2.2.2 Materials and Methods The common Bengal variety goat, Capra hircus (Class: Mammalia; Order: Artiodactyla; Family: Bovidae; Subfamily: Caprinae; Genus: Capra; Species: Capra hircus) constituted the material for the present study. 1. Small 4 inch pieces of rib bones were collected from just slaughtered healthy goat as material and kept in cold (8°C) HBSS in an ice box and transported to the laboratory as quickly as possible. 2. The marrow was extracted by pressing the tips of the rib bones with the help of a bone cutter. 3. The bone marrow was flushed gently in HBSS along with 0.04% colchicines (0.5m g/l0 ml HBSS) as metaphase arrester and incubated for an hour in an incubator at 38°C. 4. The suspension

was then centrifuged at 1000 rpm. for 10 min. The supematant was discarded and the palette was

re-suspended in 75 mM potassium chloride (Analar) solution for hypotonic exposure and kept in an incubator at 37°C for 20 min. 5. The material was then centrifuged, supernatant was discarded and the palette was fixed slowly in chilled methanol-acetic acid (3:1 v/v) fixative and kept in refrigerator for 20 min. The process was repeated for 5 rounds. 6. The properly fixed cells were spread on clean grease-free slides by conventional air dry technique. 7. The cells spread on the slide were stained in Giemsa stain, diluted in phosphate buffer at pH 6.8. The entire process has been depicted in the form of flow chart. 8. Properly stained cells were then observed under microscope. 9. A careful observation of diploid cells revealed that all the chromosomes were of identical shape with a near terminal centromere. 10. Male animals with 58 autosomes and a single X chromosome and only one Y chromosome while female with the similar number of autosomes but there were 2X chromosomes.

NSOU ? CC-ZO-06 20 Fig. 2.2.1 : Flow chart for chromosome study of goat

NSOU ? CC-ZO-06 21 Fig. 2.2.2 : Metaphase spread from male goat bone marros cells showing 2n=60 acrocentric chromosomes. The arrow indicates the position of sex chromosomes.

NSOU ? CC-ZO-06 22 2.2.3 Observations The stages of mitosis can be broadly put into two events: karyokinesis (division of nucleus) followed by cytokinesis (division of cytoplasm, and ultimately of the cell). Those cells, which are not in the phases of cell division are considered to be in interphase. You will observe that most of the cells in a particular microscopic field are in interphase. Interphase The cells are mostly rectangular, oval or even circular in shape, with almost centrally situated densely stained nucleus. The chromatic (colored) material of the nucleus is homogeneous and looks granular. The boundary of the nucleus is distinct. One or few nucleoli (Sing: nucleolus) can also be observed inside the nucleus. Prophase Intact nuclear outline is seen. The chromatin (seen as a homogeneous material in the nucleus at interphase) appears as a network of fine threads(chromosomes). Nucleoli may- or may not be visible. If the cell under observation is in the early stage of prophase then the chromatin fibres (chromosomes) are very thin. However, in the cells at late prophase, comparatively thicker chromatin fibres would be visible. Besides this, in the late prophase the nuclear membrane may not be noticed. Metaphase The nuclear membrane disappears. Chromosomes are thick and are seen arranged at the equatorial plane of the cell. Each chromosome at this stage has two chromatids joined together at the centromere, which can be seen by changing the resolution of the microscope. Nucleolus is not observed during metaphase. Anaphase This stage shows the separation of the chromatids of each chromosome. The chromatids separate due to the splitting of the centromere. Each chromatid now represents a separate chromosome as it has its own centromere. The chromosomes are found as if they have moved towards the two poles of the cell. The chromosomes at this stage may look like the shape of alphabets 'V','J' or 'I' depending upon the position of centromere in them. Different anaphase cells show different stages of movement of chromosomes to opposite poles, and they are designated to represent early, mid and late anaphase.

NSOU ? CC-ZO-06 23 Telophase Chromosomes reach the opposite poles, lose their individuality, and look like a mass of chromatin. Nuclear membrane appears to form the nuclei of the two future daughter cells. 2.2.4 Comments Present method is a cheaper and easier method for observing somatic cell division stages. This method can be used as prognostic and diagnostic measures of farm animals and human diseases which are related to somatic cell division and chromosomal abnormalities. 2.2.5 Questions 1. State the materials used to prepare the bone marrow of goat for observing mitosis. 2. Describe the methodology to observe mitosis from goat bone marrow. Use a schematic diagram or flowchart to state the protocal. 3. What is the appearance of interphase of mitotic cells from goat bone marrow? 4. Who the metaphase stage can be differentiated from anaphase stage in mitotic cells of goat bone marrow? 5. Mention the probable applications of this practical knowledge. 2.3 Study of Mitosis from Onion (Allium cepa) Root Tip 2.3.0 Objective This study is performed to observe the mitosis cell division stages in the plant cells. ? Onion is a monocoty ledonous plant which possesses large chromosomes in the meristematic cells of root tip. Hence, the cell division stages with chromosomal structure is clearly visible. 2.3.1 Introduction Cell division in flowering plants takes place in particular regions of the plant called meristems. Cells in meristems are not specialized for any particular function and divide repeatedly by mitosis. Some of the daughter cells remain meristematic others cease dividing and become differentiated into appropriate cell types depending on their position. The root tip meristem is usually a denser white and more rounded than the cut end.

NSOU ? CC-ZO-06 24 Chromosomes in root tip tissue are made visible with the stain. Dividing cells (if present) will show up clearly with chromosomes in different forms according to the stage of mitosis. Individual chromosomes (as tightly-coiled threads) are visible during anaphase. The links between the cellulose walls of plant cells are broken down by the treatment with hydrochloric acid. This ensures that the stain can penetrate the cells and allows the tissue to be squashed out one cell thick. An onion root tip is a rapidly growing part of the onion and thus many cells will be in different stages of mitosis. The onion root tips can be prepared and squashed in a way that allows them to be flattened on a microscopic slide, so that the chromosomes of individual cells can be observed easily. A process by which a parent cell divides into two or more daughter cells is called cell division. Cell division is a small part of the cell cycle. In normal eukaryotic cells, the type of cell division is known as mitosis. Another type of cell division is present in reproductive cells of eukaryotes and is known as meiosis. Cell cycle is mainly classified into two segments: M-phase and Interphase. Interphase is the longer period of cell division. During this phase the cell prepares for its next stage. This Fig. 2.3.1A : Cell division stages of onion root tip tissue (alamy.com)

NSOU ? CC-ZO-06 25 Fig. 2.3.1B : Cell division stages of onion root tip tissue (quora.com) is a period of diverse activities and these activities are a prerequisite for the next mitotic phase. Interphase is mainly divided into three phases: G1 phase, S phase and G2 phase. S phase is the period of replication. G1 and G2 are the two gap phases during which the cell grows, producing proteins and preparing the cells. These phases also have certain check points and the whole cell cycle is strictly regulated. M phase of the cell cycle stands for Mitosis or nuclear division. In eukaryotes, DNA replication is followed by a process called mitosis which separates the chromosomes in its cell nucleus into

NSOU ? CC-ZO-06 26 two identical sets, in two individual nuclei. Mitosis is followed by cytokinesis. The process of Mitosis is divided into four phases: Prophase, Metaphase, Anaphase and Telophase. 2.3.2 Materials and Method 1. Cut off the last 6 mm (1/4 inch) of root tip from sprouting onions. Place 5 of them in the labeled Eppendorf-tube. 2. Add 01 ml Carnoy's fixative and make sure that all tips are immersed. 3. Close tube and incubate for 24 hours. 4. Remove your root tips from the Carnoy's fixative and immerse in a new tube filled with 1 ml 1N HCl. Incubate for 12 minutes at 60°C. 5. Remove the HCI with a Pasteur pipette and discard in the drain with running cold tap water. 6. Add 0.5 ml Feulgen stain. (Watch out: this stain does not look brightly colored, but stains strongly - keep it away from your clothes, books, etc) 7. Let the root tip stain in Feulgen for about 10 minutes, or until the very tip of the root shows distinct dark coloring. 8. Put one drop of 45% Glacial Acetic Acid on the slide. 9. Place the root tip in the Glacial Acetic Acid on the slide. With a scalpel or razor blade, remove all but the red-stained very tip of the root. 10. Add the cover slip on top of the root tip. 11. Place the slide on a white piece of paper on your bench. Tap gently and straight down with the eraser of a pencil until the stained tip is spread out to a faint purple monolayer. Do not smear the cover slip sideways - this will shear the chromo- somes. 12. Examine your spread under the microscope at low power to ensure that the cells are spread to a monolayer. If not, squish the cover slip some more. 13. Once you have spread your cells into a nice monolayer, switch to oil immersion. 14. Spend some time identifying the different stages of the cell cycle visible in your root section squashes. Illustrate examples of each mitotic stage (prophase, metaphase, anaphase, and telophase).

NSOU ? CC-ZO-06 27 The stages of mitosis can be broadly categorised into two parts: karyokinesis(division of nucleus) followed by cytokinesis (division of cytoplasm, and ultimately of the cell). Those cells, which are not in the phases of cell division are considered to be in interphase. 2.3.3 Observations The following stages can be observed with following characters under the microscope. Interphase 1. The cells are mostly rectangular, oval or even circular in shape, with almost centrally situated densely stained nucleus. 2. The chromatic (coloured) material of the nucleus is homogeneous and looks granular. The boundary of the nucleus is distinct. One or few nucleoli (sing: nucleolus) can also be observed inside the nucleus Prophase 1. Intact nuclear outline is seen. 2. The chromatin (seen as a homogeneous material in the nucleus at interphase) appears as a network of fine threads (chromosomes). 3. Nucleoli may-or may not be visible Metaphase 1. The nuclear membrane disappears. 2. Chromosomes are thick and are seen arranged at the equatorial plane of the cell. 3. Each chromosome at this stage has two chromatids joined together at the centromere. 4. Nucleolus is not observed during metaphase. Anaphase 1. Separation of the chromatids of each chromosome occurs. The chromatids separate due to the splitting of the centromere. 2. Each chromatid now represents a separate chromosome as it has its own centromere. The chromosomes are found as if they have moved towards the two poles of the cell.

NSOU ? CC-ZO-06 28 Fig. 2.3.2 : From top left Inetrphase, Prophase, Metaphase From bottom left Anaphase, Telophase and Late telophase 3. The chromosomes at this stage may look like the shape of alphabets 'V','J' or 'I' depending upon the position of centromere in them. 4. Different anaphase cells show different stages of movement of chromosomes to opposite poles, and they are designated to represent early, mid and late anaphase. Telophase l. Chromosomes reach the opposite poles, lose their individuality, and look like a mass of chromatin. 2. Nuclear membrane appears to form the nuclei of the two future daughter cells.

NSOU ? CC-ZO-06 29 Cytokinesis 1. In plants, a cell plate is formed in the middle after telophase. The plate can be seen to extend outwards to ultimately reach the margin of the cell and divide the cell into two. 2.3.4 Comments 1. Onion root-tip cells have a cell cycle of approximately 24-hour duration, i.e., they divide once in 24 hours, and this division usually takes place about two hours after sunrise. Therefore, roots grown on water should be cut only at that time to score maximum number of dividing cells. 2. Cell plates are characteristic of plant cells. However, in an animal cell, the two sides of the cell show in pushings or constrictions formed from the peripheral region in the middle of the cell, which grow inward and meet to divide the cell into two daughter cells. 2.3.5 Questions 1. State the method of preparing onion root tip to observe the cell division stages. 2. What are the observable features at different stages of onion root tip division— state with diagramatic representations. 3. Why onion root tip and goat bone marrow are prepared for observing mitotic cell division—justify with reasons. 4. Suggest names of a few tissues, which are suitable for the study of mitosis. 5. Why is mitosis also known as equational division? 6. What shape would a metacentric and a sub-metacentric chromosome exhibit during the anaphase stage? 7. How does cytokynesis differ in plant and animal cells.
NSOU ? CC-ZO-06 30 2.4 Study of Various Stages of Meiosis from Grasshopper Testis 2.4.0 Objectives ? Meiosis cell division is a reduction division where two of the division stages, i.e., Meiosis I and Meiosis II is observed. Such division stages with chromosomal positions and morphology are clearly visible in the grasshopper testis preparation. Therefore, this practical is done— ? to visualize the process of meiosis ? to make the squash preparation of sample tissue, and ? to observe different stages of Meiosis I and Meiosis II. 2.4.1 Introduction Meiosis cell division occurs only in germ line cells i.e. within testis and ovary in animals. In plants it occurs in stigma of androlcium and gynoecium of flower in phanerogamic plants. Now the question why we used the grasshopper testis for the study of meiosis. Since the beginning of this century the chromosomes of the short horned grasshoppers (Family Acrididae) have been used for a vast number of cytological studies. These chromosomes present a number of advantages to the cytologist which are : ? They are large and relatively few in number. ? The range of chromosome lengths in the complement is such that each bivalent formed at meiosis can usually be individually identified according to its length. ? Chiasmata are very clear during diplotene and diakinesis thus allowing analyses of their structure, frequency, distribution and movement. ? Often the position of the centromere is marked by relatively denser staining (precocious condensation) at early diplotene. ? Besides these cytological advantages, the techniques involved in the preparation of slides of this material are quick and simple and therefore it is ideal for demonstrating the stages of meiosis to students.
NSOU ? CC-ZO-06 31 2.4.1.1 Systematic position of Grasshopper Phylum: Arthropoda Subphylum: Mandibulata Class: Insecta Subclass: Pterygota Order: Orthoptera Family: Acrididae Genus: Gesonula Species: punctifrons 2.4.2 Materials and Methods 2.4.2.1 Materials Aceto-carmine or acetoorcein stain, Glass slide Cover slip Lab needle Sample (Grasshopper testis follicles) Antopipette Pasteur pipettes Watch glass Razor blades Dissection box 2.4.2.2 Methods/Protocols 1. The insects are chloroformed or etherised and then dissected in insect saline. The testes lie in a dorsal position in the anterior half of the abdomen and can be easily located by making a dorsal, longitudinal, abdominal cut. They can be identified by the orange-yellow fatty tissue that cover them. Once this is removed with dissecting needles (while still in the insect saline) each testis can be seen to consist of many follicles.

NSOU ? CC-ZO-06 32 2. The best fixative for these preparations is 1:3 aceto-alcohol. The testis material is left in the fixative for at 15 minutes. 3. The material can also be stored before being stained either in the fixative or by transferring it to 70 per cent ethyl alcohol after fixation. It will keep satisfactorily for at least a year either at room temperature or, preferably, in a refrigerator. 4. Place a small drop (about 5 mm. in diameter) of the stain in the middle of a clean slide. 5. Take three or four testis follicles from the fixative (or alcohol), drain off excess moisture on a piece of blotting paper, and leave in the stain for 35minutes. 6. After this time the follicles are broken up by firmly tapping them with a metal or glass rod until there is only a suspension of small particles in the stain. 7. After any remaining large pieces of material have been removed, a clean cover- slip can be applied. 8. Heating the slide gently over the flame of a spirit lamp at this stage will flatten and spread the chromosomes. The stain must not boil. 9. The slide should then be placed between two pieces of blotting paper which is firstly pressed down lightly so that excess stain around the edges of the cover- slip is absorbed, and then the preparation is squashed by firm, vertical, thumb pressure. 10. Seal with proper sealing material (molten wax, nail polish) 2.4.3 Observations The cells of testes are undergoing spermatogenesis which involves the process of meiosis. Meiosis-I and meiosis-II are continuous processes and have sub-stages. Hence, all the different meiotic divisions are observed such as Prophase-I which includes leptotene, zygotene, pachytene, diplotene, and diakinesis. Other stages of meiosis are Metaphase-I, Anaphase-I, Telophase-I, followed by second meiotic division i.e. Prophase-II, Metaphase- Il, Anaphase-H and Telophase-H. 2.4.3.1 Characteristic feature of Prophase-I sub phases Leptotene a. The chromosomes become distinct and appear as long and thin thread in the nucleus. b. The condensation and thickening of chromosomes is marked by coiling of the thin thread.

NSOU ? CC-ZO-06 33 c. Each chromosome consists of two chromatids held together by centromere but these are not easily visible. Zygotene a. Homologous chromosomes start pairing from one end. This pairing is known as synapsis. b. Each pair of homologous chromosomes is called bivalent. c. The chromosomes appear as loosely coiled threads. d. Nuclear membrane and nucleolus both visible. Pachytene a. The chromosomes become shorter and thicker due to contraction. b. Each paired unit the bivalent consists of four chromatids (hence known as tetrads). c. Crossing-over occurs by the end of this stages i.e. break and exchange of partners occurs between non-sister chromatids. d. The point of interchange and rejoining appears as (X-shaped) and is known as chiasma. Diplotene a. The homologous chromosomes begin to separate. b. The two non sister chromatids of a homologous pair remain attached at one or two points (the chiasmata). c. It is at the chiasmata that exchange of segment of chromatids (genes) between homologous chromosomes takes place. The process is known as genetic recom- bination. Diakinesis a. The homologous chromosomes of a bivalent move apart from each other and become more compact. b. Nuclear membrane and nucleolus disappears. c. Spindle formation is completed. Metaphase-I a. The Nuclear membrane and nucleolus have disappeared. b. The bivalents arrange themselves at the equator. c. The spindle fibres are attached at the centromere of the chromosomes.

NSOU ? CC-ZO-06 34 Anaphase-I a. The spindle fibres shorten. b. The centromeres of homologous chromosomes are pulled along by the spindle fibres towards the opposite pole. c. There is no division of centromere. Thus, half of the chromosomes of the parent nucleus go to one pole and the remaining half in the opposite pole. d. Each set of chromosomes that moves to one pole consists of a mixture of parental and maternal chromosome parts. Telophase-I a. The separated chromosomes form the nuclei. b. The daughter nuclei have half the number of chromosomes of the parent nucleus which had one pair of each chromosome (i.e diploid 2n). c. The daughter nuclei are now called haploid (i.e having n no. of chromosome). d. The nucleolus reappears and nuclear membrane is formed around each group of chromosomes. Fig. 2.4.1 : Different stages of Meiosis under microscope— a) Zygotene, b) Pachytene, c) Diplotene, d) Diakinesis, e) Metaphase I

NSOU ? CC-ZO-06 35 Fig. 2.4.2 : Different meiotic stages from Grasshopper testis

NSOU ? CC-ZO-06 36 2.4.3.2 Characteristics feature of Meiosis-II cell divisions Prophase II a. The chromosomes shorten and reappear. b. Formation of spindle starts. c. The two chromatids are attached to the single centromere. d. Nucleolus and nuclear membrane begin to disappear. Metaphase II a. The chromosomes arrange themselves along the equator. b. Formation of spindle apparatus is completed. c. The centromere of each chromosome is attached to the spindle fibre. d. The centromere in each chromosome divides. Anaphase II a. The centromere splits and the sister chromatids move towards the poles along the spindle fibres (due to the shortening of fibres). Telophase-II a. On reaching the poles, the chromosomes organize themselves into haploid daughter nuclei. b. The nucleolus and the nuclear membrane reappear. Cytokinesis May occur in two successive stages, once after meiosis-I and then after meiosis-II, or in some instances it occurs only after meiosis-II. This results in four haploid cells. 2.4.4 Comments In this practical grasshopper has been selected for several reasons. Firstly, grasshopper is easily available in nature and can be captured and handled easily. Secondly and more importantly, it possesses few number of diploid chromosomes which are large and metacentric. Also with proper squash preparation the chromosomes are very clearly seen with clear view of chiasmata in diplotene and diakinesis.

NSOU ? CC-ZO-06 37 2.4.5 Questions 1. What are the fixative and preservative reagents used to prepar the grasshopper testis? Specify their activity. 2. State the procedure of grasshopper testis preparation to observe meiosis stages. 3. Mention the differences observed between different stages of 1st and 2nd meiotic divisions. 4. What are the observable differences between diplotene and pachytene? 5. Show with diagram that how metaphase I and II look different in polar and equatorial views? Fig. 2.4.3 : Different stages of Meiosis under microscope— a) Zygotene, b) Pachytene, c) Diplotene, d) Diakinesis, e) Metaphase I

NSOU ? CC-ZO-06 38 6. What are the stages of Meiotic cell division. 7. What is Chiasmata? Where and when it is found? 8. Name the fixativs and stains used to visualize meiotic cell division stages from grasshopper testis. 9. Differentiate between : a) Metaphase I and II, b) Anaphase I and II. 10. How can you distinguish between diplotene and diakinesis. 11. Why grasshopper is a suitable model to study the meiotic cell division stages? 12. How the grasshopper testis is prepared to observe the meiotic stages?

NSOU ? CC-ZO-06 39 2.5 Study of Various Stages of Meiosis from Mouse 2.5.0 Objective ? Present protocal is to study mammalian meosis that occure in the germ cells. ? This will help to leran the process of isolating and spreading spermatocytes onto the slides to prepare and observe meosis cell division stages. ? Preparation and staining chromosomal with Gimsa stain will be learnt. ? Cellular and chromosomal morphology of germ cells during meosis will be observed. 2.5.1 Introduction Cell division is the basis for reproduction in all organisms. Cell divisions are of two types' mitosis and meiosis. Mitosis is the process of cell reproduction which involves the division of the nucleus to form two identical nuclei, followed by a division of the cytoplasm (i.e cytokinesis), which results in the two nuclei being separated into different cells. Meiosis occurs in sexually reproducing organism; a special division process called meiosis takes place. Unlike mitosis, meiosis results in the reduction of chromosome number; so that each daughter nucleus has half the number of chromosomes found in the somatic cells. Each haploid (n) nucleus produced through meiosis contains one chromosome of each pair found in diploid (2n) cells of the same organism. In Meiosis, which is also known as 'reduction division' from the mice testis the normal chromosome number (2n) of parent cell is reduced to half (i.e n no. of chromosomes) in the daughter cells. It occurs in reproductive cells, e.g in the testis of male organism and in the ovaries of females to produce gamates. In meiosis the chromosome number is reduced to half in gamates so that when doubled at fertilization it once again becomes 2n or normal. If these gametes were produced by mitosis, the offspring developing from zygote would then have double the number of chromosome in the next generation. Every living organism has a definite number of chromosomes in its body cells (e.g. Onion cell-16, potato-48, grasshopper-24, horse-64, man-46, mice-40, rat-42). Therefore, to keep the chromosome number constant the reproductive cells of the parents divide by this reduction division called Meiosis. Table showing different meiotic stages.

NSOU ? CC-ZO-06 40 2.5.2 Materials and Methods 2.5.2.1 Materials 1. Mice 2. 1.1% Sodium citrate (Hypotonic solution). l.lgms sodium citrate powder is dissolved in 100ml distilled water. 3. 2.2 % Sodium citrate (Isotonic solution). 2.2gms sodium citrate powder is dissolved in 100ml distilled water. 4. Fixative (l:3 Aceto-rnethanol) 5. 2% Giemsa stain. Take 19 mg Giemsa powder in 54ml glycerol. Stir and heat at 60°C for 1 hour. Cool and add 86ml Methanol to it and put the solution for Fig. 2.5.1 : Different meiotic stages

NSOU ? CC-ZO-06 41 overnight in dark. Next day pour the solution in amber colour bottle. 1 ml of this Stock solution is taken in 50ml-distilled water to get 2% giemsa stain 6. Pasteur pipettes slides etc. 2.5.2.2 Methods 1. Dissect out the testis from rat or mice. Place the testis into cuvette containing isotonic solution i.e. 2.2% sodium citrate. 2. Clear out fat bodies and connective tissue layer i.e. tunica albuginea. With the help of scissors separate and tease out semineferous tubules. 3. After the separation step, allow the larger tissue pieces to settle. 4. Transfer the supernatant from cuvette to the centrifuge tube and avoid taking larger particles. 5. Add a little amount of isotonic solution and are centrifuged at 2000rpm for 15 minutes at room temperature. 6. Remove the supernatant is carefully using a Pasteur pipette without disturbing the pellet. 7. Add 5ml of hypotonic solution to the pellet with the Pasteur pipette. 8. Incubate the tube in water-bath for 20 minutes at 37°C. After that add 5ml of the fixative l:3 aceto-methanol to the tube and agitate thoroughly with the help of the pipette, so that bubbles appear. 9. Centrifuge at 2000 rpm for 15 minutes. Remove the supernatant carefully and discard it. 10. Again add fresh chilled fixative. Agitate the contents properly and centrifuge at 2000 rpm for 15 minutes. 11. Repeat for 2-3 washes of fixative with thorough mixing till the pellet is clear. 12. Add some more fixative to the pellet to prepare a proper cell suspension and agitate thoroughly with the help of the pipette, so that bubbles appear. Slide preparation 1. Take 3-4 drops of cell suspension on a wet, clean, chilled slide the slide and flame dry it. Drain the extra solution on the slide and label it appropriately. 2. Let the slides cool at room temperature. 3. Now keep them in 2% giemsa for 3-5 minutes. Rinse in distilled water and observe under the microscope with oil immersion lens.

NSOU ? CC-ZO-06 42 2.5.3 Observations The cells of testes are undergoing spermatogenesis which involves the process of meiosis. Meiosis-I and meiosis-II are continuous processes and have sub-stages. Hence, all the different meiotic divisions are observed such as Prophase-I which includes leptotene, zygotene, pachytene, diplotene, and diakinesis. Other stages of meiosis are Metaphase-I, Anaphase-I, Telophase-I, followed by second meiotic division i.e. Prophase-II, Metaphase- II, Anaphase-II and Telophase-II. Prophase-I Leptotene or Leptonema a. The chromosomes become distinct and appear as long and thin thread in the nucleus. b. The condensation and thickening of chromosomes is marked by coiling of the thin thread. c. Each chromosome consists of two chromatids held together by centromere but these are not easily visible. Zygotene or Zygonema a. Homologous chromosomes start pairing from one end. This pairing is known as synapsis. b. Each pair of homologous chromosomes is called bivalent. c. The chromosomes appear as loosely coiled threads. d. Nuclear membrane and nucleolus both visible. Pachytene or Pachynema a. The chromosomes become shorter and thicker due to contraction. b. Each paired unit the bivalent consists of-four chromatids (hence known as tetrads). c. Crossing-over occurs by the end of this stages i.e. break and exchange of partners occurs between non-sister chromatids. d. The point of interchange and rejoining appears as (X-shaped) and is known as chiasma. Diplotene or Diplonema a. The homologous chromosomes begin to separate.

NSOU ? CC-ZO-06 43 b. The two non sister chromatids of a homologous pair remain attached at one or two points (the chiasmata). c. It is at the chiasmata that exchange of segment of chromatids (genes) between homologous chromosomes takes place. The process is known as genetic recom- bination. Diakinesis a. The homologous chromosomes of a bivalent move apart from each other and become more compact. b. Nuclear membrane and nucleolus disappears. c. Spindle formation is completed. Metaphase-I a. The Nuclear membrane and nucleolus have disappeared. b. The bivalents arrange themselves at the equator. c. The spindle fibres are attached at the centromere of the chromosomes. Anaphase-I a. The spindle fibres shorten. b. The centromeres of homologous chromosomes are pulled along by the spindle fibres towards the opposite pole. c. There is no division of centromere. Thus, half of the chromosomes of the parent nucleus go to one pole and the remaining half in the opposite pole. d. Each set of chromosomes that moves to one pole consists of a mixture of parental and maternal chromosome parts. Telophase-I a. The separated chromosomes form the nuclei. b. The daughter nuclei have half the number of chromosomes of the parent nucleus which had one pair of each chromosome (i.e diploid 2n). c. The daughter nuclei are now called haploid (i.e having n no. of chromosome). d. The nucleolus reappears and nuclear membrane is formed around each group of chromosomes.

NSOU ? CC-ZO-06 44 Meiosis-II Prophase II a. The chromosomes shorten and reappear. b. Formation of spindle starts. c. The two chromatids are attached to the single centromere. d. Nucleolus and nuclear membrane begin to disappear. Metaphase 11 a. The chromosomes arrange themselves along the equator. b. Formation of spindle apparatus is completed. c. The centromere of each chromosome is attached to the spindle fibre. d. The centromere in each chromosome divides. Anaphase 11 a. The centromere splits and the sister chromatids move towards the poles along the spindle fibres (due to the shortening of fibres). Telophase-II a. On reaching the poles, the chromosomes organize themselves into haploid daughter nuclei. b. The nucleolus and the nuclear membrane reappear. Cytokinesis May occur in two successive stages, once after meiosis-I and then after meiosis-II, or in some instances it occurs only after meiosis-II. This results in four haploid cells. 2.5.4 Comments 2.5.4.1 Significance It helps to maintain constant number of chromosomes in a species in sexual reproduction. Meiosis occurs during gamete formation (gametogenesis) and reduces the number of chromosomes from diploid (2n) to haploid (n) in the gametes. These haploid gametes fuse to form diploid zygote during fertilization. The diploid zygote develops into a normal diploid individual. Meiosis establishes new combination of characters due to: 1. Mixing of paternal and maternal chromosomes.

NSOU ? CC-ZO-06 45 2. Crossing over during prophase 1. As a result, the progeny inherits traits of both mother and the father in a new combination. 2.5.4.2 Precautionary measure 1. The temperature of water-bath should be maintained at 37°C and hence should be checked periodically. 2. The fixative used here is, which should always be freshly prepared and chilled. 2.5.5 Questions 1. What are the reagents and stains used for observing meosis stages from grasshopper testis? 2. Mention the methodology of slide preparation through a flow-chart for observing meosis stages from grasshopper testis. 3. What is the cell type to observe meiosis stages from grass hopper testis tissue? 4. How can you distinguish between pachytene and diakinesis? 5. State the differences between telophase I and II. 6. What is the significance of prophase I in meiosis? —Explain in the light of your observation in the mouse testis preparation.

NSOU ? CC-ZO-06 46 Unit 3 Study of Life stages of some Human Parasites 3.2 Objectives 3.1 Introduction 3.2 Entamoeba histolytica 3.3 Leishmania donovani 3.4 Plasmodium vivax 3.5 Taenia solium 3.6 Ascaris lumbricoides 3.7 Ancylostoma duodenale 3.8 Wuchereria bancrofti 3.9 Questions 3.0 Objectives The objectives of this unit are as follows— ? To develop ideas about the parasitic association of some organisms with the human body. ? To identify the parasites and their injective stages. ? To learn about parasitic behaviour and consequences of the organisms with proper identification. 3.1 Introduction Parasitology is an important part of biology where the association between two organisms, that is, host and parasite, are being discussed. Parasitism is a form of ecological interaction, in which a member, the parasite, benifits from the use of resources gathered by another member, the host. Parasites have significant influences on host which affect its state of health, reproductive capacity and ability to obtain resources and survival quality. In contrary, host is like the habitat of a parasite, sustainability of which is dependent on the utilization or exploitation of parasite. Such animal association is dynamic and evolving.

NSOU ? CC-ZO-06 47 Parasitic diseases are long been considered as serious public health problem around the world. They are particularly very relevant in the tropical countries like us. For this reason, etiological agents, biological life cycles, processes of infection and propagation as well as pathological manifestation are to be studied. Medical parasitology traditionally has included the study of three major groups of animals : parasitic protozoa, parasitic helminths (worms), and those arthropodes that directly cause disease or act as vactors of various pathogens. Many of the parasitic diseases may cause epidemic problems locally regionally or globally. Therefore, sufficient ideas an these parasitic diseases may also help to develop knowledge to create social awareness to improve human health. In Unit 3 different protozoan and helminth parasites has been discussed which are endoparasitic in nature. In the next unit, i.e. Unit 4 some arthropode parasites, which are ectoparasitic in nature, has been presented to study. 3.2 Entamoeba histolytica Entamoeba histolytica is an invasive, pathogenic protozoan, causing amoebiasis, and an important cause of diarrhoea in developing countries. Our understanding of its epidemiology has dramatically changed since this amoeba was distinguished from another morphologically similar one, Entamoeba dispar, a non-pathogenic and commensal para- site. These two species can now be distinguished mainly through molecular and immuno- logical procedures. The life cycle of the parasite is represented by two forms: the cyst and the trophozoite. The cyst is the infective and non-motile form of the parasite. It is excreted in the faces and can survive for weeks in the environment. Mature cysts possess 4 nuclei and average 20 ?m in diameter. The trophozoite is the motile form, with a size ranging from 10 to 60 ?m. It colonizes the intestinal tract leading mainly to tissue destruction and secretory bloody diarrhoea. Amoebiasis is basically an acute disease acquired by: (i) ingestion of cysts present in contaminated food, water, or plants, (ii) through person to person contact, (iii) exposure in endemic areas, and (iv) swimming in contaminated water. Clinical manifestations range from the asymp- tomatic carrier state to dysenteric symptoms represented by abdominal pain and bloody diarrhoea

NSOU ? CC-ZO-06 48 The organism can be prevalent in cold regions as well as tropical and subtropical regions that have contaminated water. In fact, E. histolytica is an important cause of morbidity and/or mortality wherever sewage facilities are inadequate. As is the case for other intestinal protozoan pathogens, wastewater treatment techniques are reported not to be very efficient for E. histolytica elimination possibly because of their resistance to disinfectants and the small size of the cysts. Stabilization ponds have been reported to be more effective than activated sludge for their abatement. Sedimentation and filtration can enhance the removal of cysts from wastewater. Entamoeba species are single cell organisms with two life cycle stages. Cysts are directly excreted in the stool and spread through the environment via contaminated water, soil, and fresh vegetables as well as unsanitary household conditions. Species cannot be differentiated based on cyst or trophozoite morphology. Following ingestion, cysts transform into vegetative forms or Fig. 3.1 : Entamoeba histolytica life stages (bramkart.com) Pseudopodium Ingested food Nucleus Nucleus Pro- cystic stage Chromatid bar Uninucieate cyst Binucleate cyst Quadrantid cyst Trophozoite

NSOU ? CC-ZO-06 49 trophozoites, the motile stage that moves with the aid of pseudopodia and colonize the intestinal mucosa of the large bowel. Damage to the colon is caused by neutrophils that respond to infection from E. histolytica. Trophozoites can also invade the intestinal mucosal barrier and, via the bloodstream, disseminate to the liver, lung, and other sites with resultant pathologic manifestations. Drug treatments are available. Lagoons and constructed wetlands, sedimentation, filtration, flocculation, chemical and ultraviolet disinfection have all been employed for removal of cysts from water with varying degrees of success. E. histolytica presence and the kind of amebiasis manifestations are cosmopolitan in their distribution: amoebic liver abscess is the major form of amebiasis in South Africa, while, Fig. 3.2 : E. histolytica life cycle (wikipedia.com)

NSOU ? CC-ZO-06 50 in Egypt, in central and South America, Africa and Asia, intestinal invasive manifestation is the predominant form. Systematic position Subkingdom: Protozoa

Phylum: Sarcomastigophora Subphylum: Sarcodina Superclass: Rhizhopoda Class: Lobosea Order: Amoebida Genus: Entamoeba Species: histolytica

Trophozoites Identifying Characters 1. Trophozoites vary remarkably in size-from 10 to 60 ?m or more in diameter, actively motile by pseudopodia. 2. Amebas are anaerobic organisms and do not have mitochondria. 3. Shape changes constantly due to pseudopodial movement. 4. Cytoplasm is divided into clear outer ectoplasm and inner granular endoplasm. 5. Endoplasm contains the nucleus and food vacuoles. 6. The nucleus has a distinctive central karyosome and a rim of finely beaded chromatin lining the nuclear membrane. The food vacuoles contain may contain bacteria or red blood cells. Cyst Identifying Characters 1. The cyst is spherical, 10-20 ?m in diameter, with a thin transparent wall. 2. Fully mature cysts contain four nuclei. The nuclei have fine evenly distributed uniform granular peripheral chromatin, with small discrete central karyosome. 3. Chromatoidal bars, crystallized ribonucleo-proteins, are present variably, and are more common in immature cysts. They are elongated bars with bluntly rounded ends.

NSOU ? CC-ZO-06 51 4. Inclusions in the form of glycogen masses also may be present. Usually diffuse concentrated masses often present young cysts. They stain reddish brown with iodine. 3.3 Leishmania donovani Leishmaniasis is a vectorborne disease that is transmitted by sand flies and caused by obligate intracellular protozoa of the genus Leishmania.Leishmania species are intracellular parasites in the white blood cells, liver cells and spleen cells Human infection is caused by more than 20 species. These include the L. donovani complex with 2 species (L. donovani, L. infantum [also known as L. chagasi in the New World]); the L. mexicana complex with 3 main species (L. mexicana, L. amazonensis, and L. venezuelensis); L. tropica; L. major; L. aethiopica; and the sub genus Viannia with 4 main species (L. [V.] braziliensis, L. [V] guyanensis, L. [V] panamensis, and L. [V] peruviana). The different species are morphologically indistinguishable, but they can be differentiated by isozyme analysis, molecular methods, or mono clonal antibodies. Leishmania donovani is known to infect man in India, China, South America, parts of Africa and Mediterranean countries. This genus was created by Ronald Ross in 1903. The species was simultaneously reported by Leishman in London and Donovan from Madras (India), hence the name given as Leishmania donovani. Systematic position Subkingdom: Protozoa Phylum: Sarcomastigophora Subphylum: Mastogophora Class: Zoomastigophora Order: Kinetoplastida Genus: Leishmania Species: donovani Amastigote stage (leishmanial form): Identifying Characters 1. Amastigote forms are intracellular, non-flagellate, oval 2 to 5 ?m in length and 1 to 2.5 ?m in breadth. They contain a central nucleus measuring less than urn in

NSOU ? CC-ZO-06 52 Fig. 3.4 : L. donovani under microscope (sciencephoto.com) Fig. 3.3 : L. donovani life cycle stages (microbenotes.com)

NSOU ? CC-ZO-06 53 diameter. During this stage, the parasite resides inside the cells of the reticulo- endothelml system of man. 2. A minute structure, called kinetoplast lies at right angle to the nucleus. Kinetoplast contains a DNA containing body and a mitochondrial structure. 3. A delicate filament extending from kinetoplast to the margin of the body is axoneme (rhizoplast). Axonemes represent the root of the flagellum. A clear vacuole surrounds the axoneme. Promastigote stage (Leptomonad form): Identifying Characters 1. It is also known as the flagellar form. In the gut of the sand-fly, the mastigote form transforms into the pro mastigote form. 2. A fully developed promastigote is long, slender; spindle shaped measuring 15 to 20 ?m in length and I to 2 ?m in breadth. 3. A single nucleus lies in the centre while kinetoplast (Basal body) near the anterior end. In front of the kinetoplast is found an eosinophilic vacuole, over which the root of flagellum runs. 4. A single long flagellum orginates from the basal body which protrudes outside the body. Flagellum is almost of the same length of the body or is even longer. 3.4 Plasmodium vivax Life cycle of Plasmodium vivax is digenetic and the malarial parasite has a complex, multi stage life cycle occurring within two living beings, the vector mosquitoes and the vertebrate hosts. 1. Primary host or definitive host: Female Anopheles mosquito is the primary host. The organism which contains sexual phase of the parasite and is regarded as definitive host. 2. Secondary host or intermediate host: human is the secondary host. Human contains asexual phase of the parasite and develops symptoms of disease due to the presence of parasite and is termed as secondary host. The survival and development of the parasite within the invertebrate and vertebrate hosts, in intracellular and extracellular environments, is made possible by a toolkit of more

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NSOU ? CC-ZO-06 54 than 5,000 genes and their specialized proteins that help the parasite to invade and grow within multiple cell types and to evade host immune responses. The parasite passes through several stages of development such as the sporozoites (Gr. Sporos = seeds; the infectious form injected by the mosquito), merozoites (Gr. Meros = piece; the stage invading the erythrocytes), trophozoites (Gr. Trophes = nourishment; the form multiplying in erythro- cytes), and gametocytes (sexual stages) and all these stages have their own unique shapes and structures and protein complements. The sexual phase of malarial parasite is called sporogony and results in the development of innumerable infecting forms of the parasite within the mosquito that induce disease in the human host following their injection with the mosquito bite. After the sporogonic phase of 8-15 days, the oocyst bursts and releases Fig. 3.5 : Different life stages of P. vivax (microbewiki.kenyon.edu) ring form mature ring form trophozoite mature schizont schizont early schizont trophozoite developing gametocyte female gametocyte male gametocyte

NSOU ? CC-ZO-06 55 Fig. 3.6 : P. vivax infected RBC. Trophozoites visible in enlarged RBC (wilcimedia commons) Fig. 3.7 : Peripheral smear showing schizont stage of P. vivax (wilcimedia commons)

NSOU ? CC-ZO-06 56 sporozoites into the body cavity of the mosquito, from where they travel to and invade the mosquito salivary glands. When the mosquito thus loaded with sporozoites takes another blood meal, the sporozoites get injected from its salivary glands into the human blood- stream, causing malaria infection in the human host. The sporozoites inoculated by the infested mosquito initiate this phase of the cycle from the liver, and the latter part continues within the red blood cells, which results in the various clinical manifestations of the disease. Each sporozoite develop into a schizont containing 10,000-30,000 merozoites. The merozoites that develop within the hepatocyte are contained inside host cell-derived vesicles called merosomes that exit the liver intact, thereby protecting the merozoites from phagocytosis by Kupffer cells. In P. vivax malaria, some of the sporozoites may remain dormant for months within the liver. Termed as hypnozoites, these forms develop into schizonts after some latent period, usually of a few weeks to months. Each merozoite grows and divides within the vacuole into 8-32 (average 10) fresh merozoites, through the stages of ring, trophozoite, and schizont. Systematic position Subkingdom: Protozoa Phylum: Apicomplexa Class: Sporozoa Subclass: Coccidia Genus: Plasmodium Species: vivax Trophozoite Stage:- Adult stage or feeding stage of parasitic protozoa is known as trophozoite stage. Human blood film containing trophozoites of P. vivax stained with Leishman stain show the following characters. Identifying Characters 1. Within RBC the parasite appears as a half ring form, known as signet ring. Diameter varies from 2.5 ?m to 3 ?m. 2. Cytoplasm of the trophozoite stains blue surrounding a vacuole. 3. The cytoplasm on the one side of the vacuole is thick and broad while on the other side is narrow and thin.

NSOU ? CC-ZO-06 57 4. The redish chromatin granules, the nucleus lies on this thin side. 5. The haemozoin granules, the undigested waste haematin materials, are deposited in the broader part of the cytoplasm. 6. Cytoplasm contains characteristic Schuffner's dot. 7. Matured trophozoite is irregular shaped with pseupodia like projections. 3.5 Taenia solium Life cycle of Taenia solium or cysticercosis. Cysticercosis is an infection of both humans and pigs with the larval stages of the parasitic cestode, Taenia solium. This infection is caused by ingestion of eggs shed in the feces of a human tapeworm carner. Pigs and humans become infected by ingesting eggs or gravid proglottids. Humans are infected either by ingestion of food contaminated with feces, or by auto infection. Human infected with adult T solium can ingest eggs produced by that tapeworm, either through fecal contamination or, possibly, from proglottids carried into the stomach by reverse peristalsis. Once eggs are ingested, oncospheres hatch in the intestine invade the intestinal wall, and migrate to striated muscles, as well as the brain, liver, and other tissues, where they develop into cysticerci. In humans, cysts can cause serious sequellae if they localize in the brain, resulting in neuro cysticercosis. The parasite life cycle is completed, resulting in human tapeworm infection, when humans ingest under-cooked pork containing cysticerci. Cysts evaginate and attach to the small intestine by their scolex. Adult tapeworms develop, (up to 2 to 7 m in length and produce less than 1000 proglottids, each with approximately 50,000 eggs) and reside in the small intestine for years. Humans infected with adult T. solium worms are asymptomatic or have mild Gastro Intestinal complaints. Cysticerci may also infect the spinal cord, muscles, subcutaneous tissues, and eyes.

NSOU ? CC-ZO-06 58 Systematic position Phylum: Platyhelminthes Class: Cestoda Subclass: Eucestoda Order: Cyclophyllida Genus: Taenia Species: solium Identifying Characters 1. Body divisible into scolex, neck and strobila. 2. Scolex bears four cup-shaped suckers and a terminal rostellum crowned with double rows of hooks. 3. Hermaphroditic, sex organs are fully developed in posterior segments 4. Mature uterus with a central stem and lateral branches 5. Yellowis white in colour 6. Scolex with 4 suckers and rostellum with 25-30 hooks. 7. Uterus bears 7-12 lateral branches on each side. Fig. 3.8 : Taenia solium

NSOU ? CC-ZO-06 59 3.6 Ascaris lumbricoides Ascaris lumbricoides is the largest nematode (roundworm) parasitizing the human intestine. (Adult females: 20 to 35 cm; adult male: 15 to 30 cm.) Human is the definitive host. There is no intermediate host. Tramission is human—feces—human. Adult ascarids live in the small intestines. Females produce 200 000 eggs per day. Eggs are deposited in the lumen, passed in faces, and must embryonate for 3 weeks in the soil before becoming infectious. Ingestion of infective eggs by another human from contaminated soil results in infection. After ingestion, the hatched larvae penetrate intestinal mucosa and invade portal venules. They are carried to the liver, and travel via the hepatic vein to the right heart and into the lungs. Larvage enlarge and rupture into alveoli, are coughed up and subsequently swallowed. Upon reaching the small bowel, they mature, mate and deposit eggs. The incubation period is prolonged. The interval between ingestion of the egg and the evelopment of egg-laying adults is approximately 8 weeks. Systematic position Phylum: Aschelminthes Class: Nematoda Order: Ascaroidea Genus: Ascaris Species: lumbricoides Identifying Characters 1. The body of the roundworms is elongated and cylindrical. It gradually tapers at both ends. The anterior end is more slender than that of the posterior end.

NSOU ? CC-ZO-06 60 2. The body of these worms is covered by cuticle, which has minute striations which imparts a pseudo segmented appearance to the worms. 3. The fresh specimens are light yellow to light pink in color. 4. The sex of the roundworms is separate with sexual dimorphism. 5. Female roundworm measures about 20-40 cm in length and 4-6 mm in diameter, the posterior end of the female round worm is straight compared to that of the male. 6. Male roundworms measure upto 20 cm in length and 2-4 mm in diameter. The males are smaller compared to the females. The posterior end of the male roundworms is curved with a pair of equal pineal setae. 7. Body cavity pseudocoel. 8. Alimentary canal straight with mouth and anus at opposite end. 9. Excretory pore is at the anterior end. Fig. 3.9 : Ascaris lumbricoides—male & female (biologyeducare.com)

NSOU ? CC-ZO-06 61 3.7 Ancylostoma duodenale Ancylostoma duodenale is a nematode endoparasite, inhabiting the small intestine of man particularly in the jejunum, causing a disease called ancylostomiasis. A. duodena le is commonly known as “hook worm”. They are especially prevalent in the areas where the humidity and temperature of the soil is favourable for the growth and Fig. 3.10 : Ascaris lumbricoides—male & female (vedantu.com)

NSOU ? CC-ZO-06 62 development their larvae. Regions of the world like Europe, North Africa, Egypt, Sri Lanka Central and Northern China, South America, Pacific islands and India are the endemic areas. In India Punjab and Uttar Pradesh are favourable belts for this parasite. A. duodenale is a monogenetic parasite. Man is the only host. Adult worms live inside the jejunum part of the small intestine of man. The worms are small, cylindrical, greyish- white nematode. Female laid eggs in the lumen of the gut of the infected person from where they pass out the body of the host along with the faeces. The eggs are colourless, oval in shape, measuring 65 ?m in length and 40 ?m in breadth. At the time of lying, the eggs are unsegmented and remain surrounded by a hyaline shell membrane. During their passage to outside, the zygote inside the egg divides twice to reach 4-celled stage. A female lay about 25,000 eggs each day. The eggs arrive in the soil along with faeces. At this time it is non-infective. Within 48 hours a “rhabditiform larva” emerges out from each egg. Each larva measures about 250 ?m in length. Inside soil, the rhabdatiform larva moults twice, once on the 3rd day and then on the 5th day to develop into a “filariform larva”, measuring 500 to 600 ?m in length. The filariform is the infective stage larva. Eight to ten days are required to develop the egg into the infective stage larva. When a bare footed man moves on the soil containing the Fig. 3.11A : Ancylostoma sp. under microscope (cdc.gov)

NSOU ? CC-ZO-06 63 infective larvae, the larvae casts off their outer covering sheath and penetrate the skin of the host to enter into its body. After entering into the body of the host, the larvae migrates through the different organs and parts of body. A filariform larva after penetrating through the skin reaches the sub-cutaneous tissues, from where it enters into the lymphatic vessels and through venous circulation reaches the right heart. From heart, through pulmonary artery the larvae reach into lungs where, after breaking the capillary wall they get freed into the alveolar spaces. Through, bronchi, trachea the larva enters into the pharynx and ultimately is swallowed to reach the small intestine. Fig. 3.11B : Ancylostoma duodenale A. Adult O , B. Adult O, C. Anterior end D. Posterior end of O (biologydiscussion.com) + ? ?

NSOU ? CC-ZO-06 64 Systematic position Phylum: Nematoda Class: Secernentia Subclass: Rhabditia Order: Strongylida Genus: Ancylostoma Species: duodenale Identifying Characters 1. The worm is pinkish-white, cylindrical, dimorphic. 2. S-shaped worm because of its flexure at the frontal end. 3. Adult male hookworms range in size from 8-11 mm long, whereas adult females range in size from 10-l3 mm long. 4. The males having copulatory bursa made up of three lobes, of which one is dorsal and two are lateral, l3 chitinous rays support it. 5. Females have a vulva located approximately one-third of the body length from the posterior end. 6. Both male and female hookworms have two powerful ventral teeth in the adult forms of the parasite, one along each side of the buccal capsule; smaller pairs of teeth are located deeper in the capsule. 3.8 Wuchereria bancrofti Wuchereria bancrofti is a nematode causing lymphatic filariasis throughout the tropics and subtropics. There are two strains of W bancrofti; the nocturnal periodic strain which is widely distributed in endemic regions, the microfilariae being in their highest concentra- tions between the hours of 10pm and 2am, and the sub-periodic strain which is found in the Pacific region, and has a microfilaraemia all the time with the highest numbers being detected between noon and 8pm. Humans are the only known reservoir host of W bancrofti. NSOU ? CC-ZO-06 65 Lymphatic filariasis is caused by three species of parasitic worm, Wuchereria bancrofti. Brugia malayi and B. timori, which have generally similar life cycle. In the human body, adult worms (male and female) live in nodules in the lymphatic system and, after mating, produce numerous microfilariae, which circulate in the bloodstream. The lifespan of adult worms is 4-6 years. Microfilariae migrate between the lymph system and blood channels to reach the peripheral blood vessels, often at times of the day that coincide with the peak biting activity of local vectors. When female mosquitoes ingest a blood meal, they consume microfilariae with the blood. In the mosquitoes' stomachs, they lose their sheath, and some of the parasites migrate through the stomach wall to reach the thoracic flight muscles, where they develop into first-stage larvae (L1). The larvae grow and moult into second-stage larvae (L2) and moult again to produce highly active infective third-stage larvae (L3), a process that takes 10-12 days from the LI stage to the L3 Fig. 3.12A : Wuchereria bancrofti microfileria is blood smear (veterinaryparasitology.com)
NSOU ? CC-ZO-06 66 Fig. 3.12B : Adult female and male (studyandscore.com) stage. The
infective larvae migrate to the mosquito's proboscis, where they can infect another human host when the mosquito takes a blood meal.
The L3 are deposited on the skin and find their way through a bite wound. The L3 develop to fourth-stage larvae (L4) as they migrate through the human body to the lymphatic vessels and lymph nodes, where they develop into adult worms. NSOU ? CC-ZO-06 67 The rate of uptake of microfilariae by a mosquito vector from a human host depends on the prevalence and intensity of infection in the community and the biting rate of the mosquito. In general, the greater the number of infectious hosts available in a community with a moderate-to-high density of circulating microfilariae in their peripheral blood and the higher the biting rate, the higher the chance of a mosquito picking up microfilariae from a human host and causing transmission. Extremely high levels of microfilariae in the blood may, however, result in a substantial number of mosquito deaths as the larvae develop. Many factors contribute to the inefficient transmission of lymphatic filariasis. ? Firstly, microfilariae do not multiply in the mosquito body; hence, the number of L3 is limited by the number of microfilariae ingested. ? Second, only those mosquitoes that survive more than 10 days will contribute to transmission of the parasites. Those mosquitoes that die before the L3 develop cannot play a role in the transmission cycle. ? Third, the L3 are deposited on the skin and have to find their way into the bite wound (rather than being injected with the mosquito saliva like malaria sporozoites). In view of all these factors, the transmission of lymphatic filariasis parasites is considered to be less efficient than that of other vector-borne parasites, such as malaria and dengue. Systematic position Phylum: Nematoda Class: Secernentia Subclass: Spiruria Order: Spirurida Genus: Wuchereria Species: bancrofti

NSOU ? CC-ZO-06 68 Identifying Characters Adult 1. Hair like transparent worms. 2. Filiform and both ends are tapering. 3. Body curved without kinks 4. The posterior end of male is curved ventrally and with two unequal spicules. 5. The posterior end of-female is narrow, straight and abruptly pointed. 6. Male and females usually remain coiled. Microfilaria 1. Each microfilaria is about 0.2 to 0.3 mm in length. It is surrounded by loose cuticular sheath. This cuticular sheath is also known as egg membrane. 2. The surface of this larva is covered by flattened epidermal cells. 3. Its body contains columns of cytoplasm with a number of nuclei. 4. An oral style is present at the anterior end where the mouth develops in the future. 5. Microfilaria also bears nerve ring around the pharynx, excretory pore, renette cells, four large germinal cells, future anal pore, inner cell mass, and somatic cell mass. 3.9 Questions 1. What is amoebiasis? What are the causative agents and symptoms for such disease. 2. State the identifying characters of the infective stage of Entamoeba histolytica. 3. Name some types of Leishmania sp. parasite. What is the stage of Leishmanie sp. which lies inside the human cells? 4. What is the stage of Leishmania found in the vector. State their characters for identification.
NSOU ? CC-ZO-06 69 5. Mention different stages of material parasite. Which stage is found where to identify the infection in human body? State the identifying characters of that stage. 6. What is cysticercosis? What is the causative agent and stage of cysticercosis? State its systematic position and identifying character. 7. Identify the causative agent of Ascariasis with characters. Distinguish between male and female worm. State its systematic position. 8. State the identifying characters and systematic position of 'hook worm'. 9. What is 'filariasis'? What is the causative agent and symptoms of the disease? How can we identify the causative agent?
NSOU ? CC-ZO-06 70 Unit 4 Study of Pediculus humanus, Ctenocephalides spp. and Cimex lectularis Structure 4.0 Objectives 4.1 Introduction 4.2 Pediculus humanus 4.3 Ctenocephalides sp 4.4 Cimex lectularis (Bed bug) 4.5 Questions 4.0 Objectives This unit is designed to introduce the learners with different arthropodes which act either as parasite (ecto) on vector of some other pathogens. After stydying this unit learners will be able to identify such harmful arthropodes and their mode of action to develop disease or pathogenicity in human. 4.1 Introduction Ectoparasites are organism which are mostly arthropoda in nature. They generally include lice, fleas, bedbugs, mites and ticks and act as human ectoparasites. In many occasion these organisms act as vectors prother pathogens. They are typically regarded as vexing disorders initially, therefore attain less clinical attention. However, depending or socio-economic status and population setup such infections may cause significant morbidity and affect large portion of population. Infestation of these arthropodes are more prominent in developing countries and related with population density, weather condition and poor personal hygiene. Human body has some distinct ectoparasite defence system that includes cutancous sensory mechanisms, itch-generation mechanism and grooming behaviours. Overall, a general idea about these organisms will help us to understand better about our living, health and hygiene.

NSOU ? CC-ZO-06 71 4.2 Pediculus humanus The 3 types of human lice include the head louse (Pediculus humanu scapitis), the body louse (Pediculus humanus corporis), and the crab louse (Pthirus pubis). Body lice infest clothing, laying their eggs on fibers in the fabric seams. Head and pubic lice infest hair, laying their eggs at the base of hair fibers. Lice have simple or gradual metamorphosis. The immatures and adults look similar, except for size. Lice do not have wings or powerful jumping legs so they move about by clinging to hairs with their claw-like legs. Head lice prefer to live on the hair of the head although they have been known to wander to other parts of the body. Head lice do not normally live within rugs, carpet, or school buses. Body lice live in the seams of clothing, generally where it touches the skin, and only contact the body to feed, usually holding on to the clothing while they do this. However, sometimes they will move to the body itself. The eggs of lice are called nits. They are oval white cylinders (1/16 inch long). The eggs of head lice are usually glued to hairs of the head near the scalp. The favourite areas for females to glue their eggs are near the ears and back of the head. The eggs of body lice are laid on clothing fibers and occasionally on human body hairs. Under normal conditions the eggs will hatch in seven to 11 days. The young lice which escape from the egg must feed within 24 hours or they will die. Newly hatched lice will periodically take blood meals and moult three times before becoming sexually mature adults. Normally a young louse will mature in 10 to 12 days to an adult (1/8 inch in length). Adults range in colour from white to brown to dark grey. Female lice lay six to seven eggs (nits) per day and may lay a total of 50 to 100 eggs during their life which may last up to to days. Adults can only survive one to two days without a blood meal. The nymphs and adults all have piercing-sucking mouthparts which pierce the skin for a blood meal. The reaction of humans to louse bites can vary considerably. Persons previously unexposed to lice experience little irritation from their first bite. After a short time, individuals may become sensitized to the bites, and may react with a general allergic reaction including reddening of the skin, itching, and overall inflammation. Both the immature or nymphal forms and adult lice feed on human blood. To feed, the louse bites through the skin and injects saliva which prevents blood from clotting; it then sucks blood into its digestive tract. Bloodsucking may continue for a long period if the louse is not disturbed. While feeding, lice may excrete dark red faeces onto the skin.
NSOU ? CC-ZO-06 72 The body louse is the vector of three human diseases—eqidemic or louse-borne typhus, caused by Rickettsia prowazeki de Rocha-Lima; trench fever, caused by Rochalimaea quintana (Schmincke) Krieg (long known as Rickettsia quintana); and louse-borne relapsing fever, caused by Borrellia recurrentis (Lebert). Systematic position Phylum: Arthropoda Subphylum: Mandibulata Fig. 4.1 : Pediculus humanus, male (wikimedia commons)
NSOU ? CC-ZO-06 73 Class: Insecta Subclass: Pterygota Order: Siphunculata Genus: Pediculus Species: humanus Identifying Characters Phylum-Arthropoda 1. Bilaterally symmetrical and metamerically segmented 2. Majority of the segments bear a pair of jointed appendages. 3. Body is covered with a thick chitinous exo-skeleton. Sub-phylum-Mandibulata 1. Body usually divided into head, thorax and abdomen. 2. One or two pairs of antennae present. 3. One pair of mandibles present. Class-Insecta 1. Body is divided into head, thorax and abdomen 2. Three pairs of thoracie legs 3. Antenna one pair. Sub-class-Pterygota 1. With wings or secondarily wingless. Order-Siphunculata 1. Small wingless insect. 2. Dorsoventrally flattened with dark markings along the side. 3. Antennae short. 4. Thoracic segments fused and contains clawed legs. 5. Abdomen swollen. 6. Eyes reduced or absent. Characters 1. Small head bears a pair of antennae and a pair of feebly developed compound eyes. Normally 1-2 mm long.

NSOU ? CC-ZO-06 74 2. Piercing and sucking mouthparts for digging into the skin for blood. 3. Abdomen sowlen with small bristles on the side. 4. Legs equipped with sharp claws. Habit and Habitat P. humanus are transmitted by direct contact, by clothes or a brush, or by fallen hair. They prefer to lay them behind the ears or on the back of the head, near the neck line. The habitat of the human louse is solely on the human body or in the clothes and can only survive away from the host for a few days. Lice are obligate ectoparasites and live off of the blood of humans. They have specially designed mouth parts for piercing the skin of human and retrieving the blood that is present. Economic Importance for Humans: P. humanus has relatively little direct effect on its hosts and can be the vectors for important diseases. The three most important diseases they can carry are typhus, trench fever (both caused by bacteria in the genus Rickettsia), and relapsing fever (caused by another bacteria species Borrelia recurrentis). 7.2 Ctenocephalides sp Fleas are tiny, wingless insects arc capable of long jumps and hitch hiking a ride around the world sticking to an animal's fur belongs to the Order - Siphonoptera. Sucking on blood like tiny vampires, fleas are able to transfer many serious diseases to their host. There are different types who survive by sucking the blood of mammals and birds. Let us learn about these flea types. Fleas are divided according to the type of host species they live on. However, some fleas are very well capable of jumping over from one animal species to another. Till date, there are over 2,000 species of tleas found in the world. Some of the important fleas are;- Dog Flea (Ctenocephalides canis) These fleas feed on the blood of dogs. They are capable of feeding on cat blood too and are able to bite humans sometimes. These fleas can survive for months without a meal. Their mouth parts are well adapted to be able to pierce the skin and suck the blood of the dog. Their body is flat from side to side and is covered in spines and hair. This helps them get a grip on the dog hair while traveling. Their hind legs are very long, that help them to jump onto a suitable host body.

NSOU ? CC-ZO-06 75 Cat Flea (Ctenocephalides-felis) These are the most found fleas on the earth. These fleas feed on the blood of their feline host, but may even enjoy a dog blood meal. Cat fleas can bite humans, but cannot cause an infestation. These fleas can transmit diseases like murine typhus as well as parasites like tapeworms into the host body. Moorhen Flea (Dasypsyllus gallinulae) These are large fleas that are found in birds. They are easy to identify due to the horn- like spines on the genital flaps of male fleas. These are common parasites for many birds that include the grouse, European Robin, Willow Tit, common Moorhen, etc. Northern Rat Flea (Nosopsyllus-fasciatus) This is a flea type that inhabits the fur of domestic rats and house mice. These fleas have an elongated body that is about 4 mm in length. They are normally parasites of the Norway rat. But, they may occasionally feed on the blood of wild rodents as well as humans. They are known to be carriers of the rat tapeworm as well as serve as a vector for plague. Oriental Rat Flea (Xenopsylla cheopis) Also called the tropical rat flea, they are one of the most dangerous fleas in the world. They are the primary vectors for murine typhus and bubonic plague. When this flea feeds on the blood of the infected rat and then bites a human, it spreads the diseases. These fleas look very similar to the dog and cat fleas. The oriental rat fleas are responsible for the spread of Black Plague. Human Flea (Pulex irritans) They prefer feeding on human blood. However, it has no qualms feeding on other mammals like cats, dogs and in particular swine blood. They can bite anyone and everyone at home. These are brownish black fleas that are about 4 mm long. They are a nuisance for the human population and can transmit diseases like tularaemia, murine typhus, diseases caused by tapeworm, etc. Systematic position Phulum: Arthropoda Sub-phylum: Mandibulata Class: Insecta

NSOU ? CC-ZO-06 76 Fig. 4.2 : Ctenocephalides felis (pinterest.com) Sub-Class: Pterygota Order: Siphonaptera Genus: Ctenocephalides Order-Siphonaptera 1. Ectoparasite on birds and mammals. 2. Mouthparts piercing and sucking type. 3. Antennae short, eyes simple, no ocelli. 4. Long legs, adopted for jumping.

NSOU ? CC-ZO-06 77 5. Wingless. 6. Abdomen without cerci. Identifying Characters 1. Laterally compressed and wingless 3. It has a pronotal ctenidium and a genal ctenidium with more than 5 teeth. 4. The hind tibia lacks an outer apical tooth. 5. Presence of complex, snail-shaped genitalia in males. 6. Two mm long and reddish-brown to black, with the females being a bit larger than males and a slightly different in color. Habits & Habitat After piercing the skin of the host, adult fleas use their mouth parts to suck up blood. The blood-meal then passes through epithelial cells in the gut that are elongated into spines, collectively called the proventriculus, where it is broken up. They are known to bite humans in the absence of other hosts. In contrast to adult Ctenocephalides sp., larvae feed on the faeces of the adult fleas and detritus in the environment. Cosmopolitan, live in the nests and resting places of their hosts (cats, dogs, rabbits, horses, skunks, foxes, mongooses, koalas, poultry) when they are not feeding, and on their hosts when they are feeding. They live in just about any type of habitat, as long as it is warm and humid enough to promote development. Economic Importance for Humans: Ctencephalides sp. is a vector of murine typhus in humans, caused by Rickettsia mooseri. 7.3 Cimex lectularis (Bed bug) Common bed bugs, Cimex lectularius L., and a few closely-related species of blood feeding true bugs (Hemiptera: Cimicidae) have been persistent pests of humans throughout recorded history. They may have evolved from cave-dwelling ectoparasites of mammals (especially bats). As humans moved from caves to tents and then into houses, the bugs went with them. Bed bugs have been mentioned in the literature and folk remedies of many cultures and countries since the times of ancient Greece. Bed bugs became very rare in many industrialized countries soon after World War II because of the widespread use of synthetic insecticides. By 1997, they were so scarce in the United States that it was hard

NSOU ? CC-ZO-06 78 to find specimens to use in college entomology classes. Adult bugs are 6-7 mm long, broadly oval, flat, brown to reddish-brown true bugs, with a 3-segmented beak, 4- segmented antennae, and vestigial wings. They have dorso-ventrally flattened bodies covered with short, golden-coloured hairs. They give off a distinctive, musty, sweetish odour containing various aldehydes which are produced by glands located in the ventral metathorax. They deposit undigested parts of prior blood meals in their harbourages as tarry or "rusty" spots. The tips of the abdomen are usually pointed in males and more rounded in females. Bed bugs feed only on the blood of mammals or birds and mate by traumatic insemination. One life cycle from egg to egg is 5 weeks at 75-80% RH and 28- 32°C. They can survive and remain active at temperatures as low as 7°C. Bed bugs are nocturnal but they can feed in day time if they are starved. Bed bug bites can cause physical and psychological discomfort. Although their feeding usually is never felt, the saliva contains biologically active proteins, which may cause progressive, allergenic, visible symptomatic skin reactions to repeated bites. Typical symptoms include a raised, inflamed, reddish weal at each bite site, which may itch intensely for several days. Immediate reactions may appear from 1 to 24 h after a bite and may last 1-2 d; delayed reactions usually appear 1-3 d (or more) after a bite and may last 2-5 d. There can also be a social stigma attached with having a bed bug infestation. Systematic position Phulum: Arthropoda Sub-phylum: Mandibulata Class: Insecta Sub-Class: Pterygota Order: Hemiptera Genus: Cimex Species: Cimex lectularis Identifying Characters Order-Hemiptera 1. Usually two pairs of wings, fore wing modified as hemi elytra, with membranous apex and leathery base to cover membranous hind wings. 2. Legs absent or adopted for running, jumping, digging, grasping pray or swimming. 3. Mouth parts piercing or sucking type.

NSOU ? CC-ZO-06 79 Characters 1. Body flat and oval covered with bristle and hairs. 2. Head small and bears distinct, paired compound eyes and a pair of four jointed antennae. 3. Piercing and sucking type of mouth parts 4. Prothorax semilunar, mesothorax triangular 5. Fore wing present as atrophied condition 6. Abdomen flat and eight segmented Fig. 4.3A : Cimex lectularis life-cycle (cdc.gov) Fourth nymphal instar Fifth nymphal instar Third nymphal instar Second nymphal instar First nymphal instar Eggs Adult

NSOU ? CC-ZO-06 80 Fig. 4.3B : Cimex lectularis life-cycle (pathologyantlines.com) Habit and habitat Bed bugs are obligatory bloodsuckers. They have mouth parts that saw through the skin, and inject saliva with anticoagulants and painkillers. Sensitivity of humans varies from extreme allergic reaction to no reaction at all (about 20%). The bite usually produces a swelling with no red spot, but when many bugs feed on a small area, reddish spots may appear after the swelling subsides. Bedbugs prefer exposed skin, preferably the face, neck, and arms of a sleeping person. Economic importance for humans Bed bugs bites are not known to transmit any infectious disease.

NSOU ? CC-ZO-06 81 4.5 Questions 1. State the scientific name and systematic position of human lice. Identify the specimen with characters. Name few disease and pathogens where human lice acts as vector. 2. What are fleas and how they cause harm to human and other associated species? 3. Identify the human flea with characters. State its systematic position, habit and habitats. How it can cause harm to human? 4. What is common bed bug? Mention its identifying character and systematic position. How they are harmful to human?

NSOU ? CC-ZO-06 82 Unit 5 Study of Nematode/Cestode Parasites from the intestine of Poultry Bird Structure 5.0 Objectives 5.1 Introduction 5.2 Materials and Method 5.2.1 From intestine (Protocol) 5.2.2 From faecal matter (Protocol) 5.3 Common Nematodes 5.3.1 Ascaridia galli 5.3.2 Identifying Characters 5.3.3 Pathogenicity 5.4 Heterakis gallinarum 5.4.1 Systematic position 5.4.2 Identifying Characters 5.4.3 Pathogenicity 5.5 Common cestode 5.5.1 Systematic position 5.5.2 Identifying Characters 5.5.3 Thymus 5.5.4 Pathogenicity 5.0 Objectives The objective of the present unit is to aware the learners about the common causes of parasitic infections in the intestine of poultry birds. They can identify the infective parasites in poultry birds. Also such knowledge will help us to take remedial measures when farming.
NSOU ? CC-ZO-06 83 5.1 Introduction Poultry birds are important farm animal and rich source of protein supply to human population. Therefore, the health issues of poultry birds are important for us. It has been found that different parasites infect these birds and affect their health and many of which reside in their intestine. In intensive and semi-intensive poultry farming, the control of such parasite infection is important to maintain the quality of poultony products. Mostly, these birds are infected in Helminthiasis, the infection by the members of Nematoda (round worm) and cestoda (tape worms on flat worms). The common internal parasitic infections occur in poultry include cestodes, nematodes and coccidia. These worm infections may cause considerable damage and great economic loss to the poultry industry due to malnutrition, decreased feed conversion ratio, weight loss, lowered egg production and death in young birds. Generally, four species of cestodes namely Raillietina echinobothridia, R. tetragona, R. cesticillus and Choanotaenia infundibulum and two species of nematodes namely, Ascaridia galli and Heterakis gallinarum are the causative agents. 5.2 Materials and Method 5.2.1 From intestine (Protocol) 1. For the collection of endoparsites from the body of the hosts need to dissect open midventrally and different organs including alimentary canal were removed and kept in separate desired size petridishes where these organs were teased and cut open to search for parasites if any. 2. Cestodes may be collected by the help of dropper and preserved in 10% formalin or conoy's fluid for the identification. 3. Morphology of cestodes was studied by preparing permanent slide. 4. After washing, nematodes were collected by the help of curved needle and kept in glycerin alcohol. Nematodes were best killed in steaming hot 70% alcohol, and stored in the same solution. Later, a few drops of glycerin are to be added. 5. Thorough morphological study of nematodes may performed by the preparation of sub-permanent slide by adding one drop of lactophenol. The other steps in this
NSOU ? CC-ZO-06 84 were fixation, staining, dehydration, de-alcoholisation and clearing, mounting and labeling. 5.2.2 From faecal matter (Protocol) 1. Freshly passed out faecal matter are collected and a small amount is placed on 3- 4 glass slides precoated with mayer's albumen. 2. Few drops of normal saline is put on the faecal matter and mixed thoroughly to obtain a thin suspension. 3. The suspension is spread uniformly over a small area of the glass slide. 4. Schaudin's fluid is put over it immediately and then transferred to 90% alcohol in a coupling jar for 15 minutes. 5. The slide is then passed through 70% and 50% alcohol and then to distilled water. 6. Then dipped into haematoxylin and then into eosin. 7. It is then dehydrated through 50%, 70%,90% and 100% alcohol and mounted in DPX. 5.3 Common Nematodes 5.3.1 Ascaridia galli Systematic position Phylum: Nematoda Class: Secernentia Order: Ascaridida Genus: Ascaridia Species: Ascaridia galli 5.3.2 Identifying Characters 1. The body is semitransparent, creamy-white, and cylindrical, body is entirely covered with a thick cuticle. The cuticle is striated transversely through the length of the body
NSOU ? CC-ZO-06 85 2. The anterior end is characterized by a prominent mouth, which is surrounded by three large, trilobed lips. The edges of the lips bear teeth- like denticles. 3. Two conspicuous papillae on the dorsal lip and one on each of the sub ventral lips. 4. Distinct sexual dimorphism. Females are considerably longer measuring 72 to 112 mm long with a vulva opening at the middle portion of the body and anus at the posterior end of the body. The tail end of females is characteristically blunt and straight. 5. Males are relatively shorter and smaller, measuring 50 to 76 mm long, with a distinct pointed and curved tail. Ten pairs of caudal papillae are found towards the tail region of the body. 5.3.3 Pathogenicity The nematode infects fowl of all ages, but the greatest degree of damage is often found in birds less than 12 weeks of age. Heavy infection is the major cause of weight depression and reduced egg production in poultry husbandry, adult worms may move up the oviduct and be found in hens' eggs, and sometimes they are also found in the birds' feces. Fig. 5.1 : Camera Lucida drawing of A galli

NSOU ? CC-ZO-06 86 5.4 Heterakis gallinarum 5.4.1 Systematic position Phylum: Nematoda Class: Secementia Order:Ascaridida Genus: Heterakis Species: Heterakis gallinarum Fig. 5.2 : Heterakis gallinarum camera lucida drawing. 1. Anterior end of female (ventral view); 2. Posterior end of male (dorsal view); 3. Valval region of female (lateral view); 4. eggs; 5. Posterior end of female (lateral view) (omiesonline.org). 5.4.2 Identifying Characters 1. Typical roundworm, body covered with cuticle, three papillae-lined lips and alae, are ridges formed by the thickening of the cuticle that may act as receptors. 2. The parasite is a dioecious species with marked sexual dimorphism. 3. Males are smaller and shorter, measuring around 9 mm in length, with a unique bent tail, having a pre cloacal sucker at the posterior end
NSOU ? CC-ZO-06 87 4. Females are stouter and longer, measuring roughly 13 mm in length, with a straight tail end. 5.4.3 Pathogenicity H. gallinarum infection is itself is mildly pathogenic. However, H. gallinarum plays the role of carrier in the lifecycle of Histomonas meleagridis, the causal pathogen of entero hepatitis "blackhead" of turkeys. Heavy infection indicated gross lesions character- ized by congestion, thickening, petechial haemorrhages of the mucosa, and nodules in the caecal wall. 5.5 Common cestode 5.5.1 Systematic position Phylum: Platyhelminthes Class: Cestoda Order: Cyclophyllidea Genus: Raillietina Species: Raillietina tetragona 5.5.2 Identifying Characters 1. It is whitish in colour, highly elongated, dorso-ventrally flattened, and entirely covered with a tegument, measuring up to 30 cm in length and 1-1.5 cm in breadth. 2. The body is divisible into the head region called 'scolex', followed by an unsegmented 'neck', and then by highly segmented body proper called strobila. 3. The strobila is composed of a series of ribbon-like body segments called proglottids, gradually enlarging from the anterior end towards the posterior. 4. The scolex bears an apical rounded rostellum, which is armed with 100 minute hooks, arranged in single row. This is surrounded by four suckers which are lined with 5-6 rows of spines. 5. Hermaphroditic having a complete reproductive system in itself.
NSOU ? CC-ZO-06 88 Fig. 5.3 : Morphology of Raillietina tetragona. (A) Scolex bearing the rostellum (R) Surrounded by 4 ovoid suckers (S). (B) Small hammershaped hook. (C) Mature proglottid showing unilateral opening of the genital pore (GP). (D) Gravid proglottid showing several eggs (E) per egg capsule (EC). (researchgate.net) 6. Each mature proglottid has a set of male and female reproductive organ and genital pores on one side. 7. Testes are located on both sides of the ovary and behind vitellarium. 5.5.3 Pathogenicity The adult parasite infects the small intestine of fowl, from where it obtains nutrition from the digested food of the host. Generally the parasite is quite harmless, and does not cause serious lesions under natural conditions. However, instances of reduced weight loss and decreased production of eggs are observed.
NSOU ? CC-ZO-06 89 5.6 Questions 1. State the method to collect and observe endoparasites from poultry bird—a) from intestine and b) from faecal matter. 2. Mention the chemicals used to preserve endoparasitic nematodes and cestodes from poultry bird intestine. 3. Give example of a common cestoda parasite which affect poultry birds. Name the causative parasites. Which may cause weight loss and decreased egg production. State their identifying characters. 4. Who is the host of the pathogen for entero-hepatitis "black head" of turkeys? From where and how such hosts can be collected? How they can be identified? 5. How can you identify Ascaridia galli? State its systematic position and pathogenicity.
NSOU ? CC-ZO-06 90 Unit 6 Histological study of Spleen, Thymus and Lymph node Structure 6.0 Objectives 6.1 Introduction 6.2 Spleen 6.2.1 Identifying Characters 6.3 Thymus 6.3.1 Identifying Characters 6.4 Lymph node 6.4.1 Identifying Characters 6.5 Questions 6.0 Objectives The aim of this unit is— ? To give an idea about the tissue organization of some of the specific organs of our body which are directly involved in the immune system of the body. ? This will provide primary knowledge of histological architecture of these immune organs and the observable features of nascent and maturing immune cells in the tissue. ? Also learners receive the ideas about the clustering features and zonations of different immune cells in the tissue with their functional significance. 6.1 Introduction The cells involved in the immune response of our body are organized within our body in a special system of organs and tissues. Such organization is needed to perform their functions effectively. These organs and tissue structures are collectively called Lymphoid system. With the immune cells, such system possesses some encapsulated tissues which

NSOU ? CC-ZO-06 91 form organs. These oprgans are divided into primary and secondary organs. Primarily, lymphocytes are produced and matured in primary lymphoid organs and function in secondary lymphoid organs. The primary lymphoid organs are bone marrow and thymms, whereas, secondary lymphoid organs are spleen, lymph nodes etc. In the following section we will discuss about the tissue organization of some of these lymphoid organs and how they appear under microscope in standard histological preparation. 6.2 Spleen The spleen is the largest organ in the lymphatic system. It is an important organ for keeping bodily fluids balanced, but it is possible to live without it.The spleen is located under the ribcage and above the stomach in the left upper quadrant of the abdomen. A spleen is soft and generally looks purple. It is made up of two different types of tissue. The red pulp tissue filters the blood and gets rid of old or damaged red blood cells. The white pulp tissue consists of immune cells (T cells and B cells) and helps the immune system fight infection. Fig. 6.1A : H/E Stained histological section of spleen [T.S] (pinterest.com) Capsule Trabecula White pulp Central arteriole Red pulp

NSOU ? CC-ZO-06 92 Although it varies in size between individuals, a spleen is typically around 3-5.5 inches long and weighs 5.3-7.1 ounces (Oz). The spleen is a soft organ with a thin outer covering of tough connective tissue, called a capsule. The spleen's primary job is to filter the blood. As blood flows into the spleen, it performs a quality control service, detecting any red blood cells that are old or damaged. Blood flows through a maze of passages in the spleen. Healthy cells flow straight through, but those considered to be unhealthy are broken down by large white blood cells called macrophages. The spleen also stores blood - the blood vessels of the spleen can expand significantly. In humans, around 1 cup of blood is kept in the spleen, ready to be released if there is a significant loss of blood, after an accident, for instance.The spleen also plays a role in the immune response by detecting pathogens (bacteria, for instance), and producing white blood cells in response. Around one-quarter of our lymphocytes (a type of white blood cell) are stored in the spleen at anyone time.The spleen also produces compounds called opsonins, such as properdin and tufts in, that help the immune system. Fig. 6.1B : Histological drawing of spleen (slideplayer.com)

NSOU ? CC-ZO-06 93 6.2.1 Identifying Characters 1. The capsule enclosing the spleen is covered by single layer of mesothelial cells and consists of a dense connective tissue containing many elastic fibres and a few smooth muscle fibres. 2. Scattered throughout the spleen are lymphoid follicles separated by splenic pulp; the white and red pulp. 3. White pulp is cylindrical or fusiform in shape and consists of reticular fibres, reticular cells and lymphocytes. 4. Red pulp is a reticular network honeycombed by sinuses and consists of nongranular leucocytes, splenic cells, granular leucocytes and erythrocytes. Fig. 6.2 : H/E Staining of T.S of mammalian Thymus (researchgate.net) cortex cortex cortex cortex cortex cortex cortex cortex capsule trabecula (septa) Thymus (young) medulla medulla medulla medulla medulla medulla cortex septa (connective tissue)

NSOU ? CC-ZO-06 94 6.3 Thymus The thymus is a small, irregular-shaped gland in the top part of the chest, just under the breastbone and between the lungs. It is located in an area of the body called the mediastinum. The thymus is part of both the lymphatic system and the endocrine system. The thymus is divided into 2 main parts - a right lobe and a left lobe. Each lobe is divided into smaller sections called lobules that give the thymus its bumpy appearance. Each lobule is made up of a centre part (called the medulla) and an outer layer (called the cortex). A thin covering (capsule) surrounds and protects the thymus. The thymus is mainly made up of epithelial cells, immature and mature lymphocytes and fat tissue. The thymus changes in size as you get older. It is large in new born and toddlers. It is biggest during puberty then slowly begins to shrink as adulthood approaches. The thymus is most active during childhood and youth. By late adulthood, most of the thymus is made up of fat tissue. The thymus makes T cells (T lymphocytes) that travel throughout the body to help fight infection, disease and foreign substances. The thymus also makes hormones to help T cells develop and keep the immune system working properly.Lymphocytes travel from the bone marrow to the thymus, where they mature into T cells. Once T cells mature, they are able to leave the thymus and enter the blood so they can help the immune system. T cells also travel to lymph nodes and the spleen where they continue to mature. 6.3.1 Identifying Characters 1. It is divided into a morphologically distinct cortex and medulla separated by a vascular corticomedullary zone. 2. A thin connective tissue capsule surrounds each lobe and, in most species, gives rise to septae, that partially subdivide the thymus into interconnecting lobules of variable size and orientation. 3. The capsule is composed of an outer and inner layer of collagen and reticular fibres between which are occasional clusters of lymphocytes. 4. The darkly staining cortex contains densely packed, small, immature lymphocytes. 5. The medulla is paler staining, less densely cullular than the cortex, and contains more mature T-cells, prominent epithelial cells.

NSOU ? CC-ZO-06 95 6. Plentiful blood cessels (predominantly arterioles) with scant perivascular connective tissue and mature and immature T lymphocytes characterize the corticomedullary junction. 6.4 Lymph node Lymph nodes, also known as lymph glands, are oval-shaped masses of tissue in the body that serve an important role in protecting the body from infection and cancer. Every vertebrate animal has an extensive lymphatic system in their body, which consists of lymph nodes and lymph vessels. The lymph vessels carry a clear fluid called lymph that is collected from tissues throughout the body. Lymph contains cell wastes like cancer cells, bacteria, and viruses. This fluid then drains into lymph nodes where it's filtered by infection- fighting cells within the lymph nodes. These infection-fighting cells, also called white blood Fig. 6.3A : H/E Stained histological section of mamalian Lymph node (medcell.med.yale.edu)

NSOU ? CC-ZO-06 96 cells, destroy these foreign or "bad" cancer and infection-related cells. Lymph nodes are scattered throughout the body and located in groups, like in the armpit, groin, neck, pelvis, and abdomen. In some areas like the neck, the lymph nodes are located superficially and may be palpated—they feel like a pea or small bean. In other areas, like the abdomen or the chest, lymph nodes are located deeper and cannot be felt. 6.4.1 Identifying Characters 1. The structure includes the capsule, subcapsular sinus, cortex (B cell zone with follicles and germinal centers), paracortex (T cell zone), medullary sinuses, medullary cords and hilus. Fig. 6.3B : H/E Stained histological section of mamalian Lymph node at high resolution (nature-microscope-photo-video-com)

NSOU ? CC-ZO-06 97 2. The darker cortex at the periphery of the node has nodules, some of which show pale, mitotically active germinal centers. 3. In the middle of the lymph node is the medulla with its dark cords of dense lymphocyte population. 4. Paler lymph channels (the medullary sinuses) which have relatively fewer lympho- cytes surround the medullary cords. 6.5 Questions 1. State the identifying characters of spleen. Mention their significance. 2. Mention the anatomical position of thymas. State that how could you identify a thymus tissue. 3. Discuss the general histological features of a lymph node. Mention about the zonation in the tissue. 4. What is red pulp? Differentiate between red and white pulp. 5. Differentiate between cortex and medulla of thymus.

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Preparation of Stained Blood Film to study Various types of White

Blood Cells Structure 7.0 Objectives 7.1 Introduction 7.2 Collection of Sample 7.3 Preparation of Blood Film 7.4 Staining 7.5 Precautions/Comments 7.6 Questions 7.0 Objectives In this unit learners will learn how to prepare a blood film to observe different blood cells. Learnears will receive the practical knowledge of how different blood cell appear under microscope in standard staining technique. Most importantly they will learn how different WBC appear under microscope and will be able to identify them for further analysis. 7.1 Introduction There are two types of blood smears which are thick and thin blood smears. This two types of blood smear are prepared for different purposes. Thick blood smear is generally used for the detection of different blood parasites present in the blood. Preparation of thick blood smear Thick smears consist of a thick layer of dehemoglobinized (lysed) red blood cells (RBCs). The blood elements (including parasites, if any) are more concentrated (app. 30 x)

than in an equal area of a thin smear. Thus, thick smears allow a more efficient detection of parasites (increased sensitivity). However, they do not permit an optimal review of

NSOU ? CC-ZO-06 99 parasite morphology. For example, they are often not adequate for species identification of malaria parasites: if the thick smear is positive for malaria parasites, the thin smear should be used for species identification. 1. Place a small drop of blood in the centre of the pre-cleaned, labelled slide. 2. Using the corner of another slide or an applicator stick, spread the drop in a circular pattern until it is the size of a diameter (1.5 cm 2). 3. A thick smear of proper density is one which, if placed (wet) over newsprint, allows you to barely read the words. Fig. 7.1 : Procedure of blood smear preparation (researchgate.net)

NSOU ? CC-ZO-06 100 4. Lay the slides flat and allow the smears to dry thoroughly (protect from dust and insects). Insufficiently dried smears (and/or smears that are too thick) can detach from the slides during staining. The risk is increased in smears made with anticoagulated blood. At room temperature, drying can take several hours; 30 minutes is the minimum; in the latter case, handle the smear very delicately during staining. You can accelerate the drying by using a fan or hair dryer (use cool setting). Protect thick smears from hot environments to prevent heat-fixing the smear. 5. Do not fix thick smears with methanol or heat. If there will be a delay in staining smears, dip the thick smear briefly in water to haemolyse the RBCs. Fig. 7.2 : Blood film under microscope (at low magnification) with RBC (austince.edu)

NSOU ? CC-ZO-06 101 Scratch Method for Thick smears The scratch method is an alternate method for making thick films that allows for improved adherence and faster turnaround times. The process is similar to making a normal thick film, but instead of using a stick to spread the blood, the edge of a glass microscope slide is used, while applying firm pressure to create small scratches in the underlying slide. The scratches allow for improved adherence of the blood film to the slide without affecting the smear morphology. The smear can then be stained as soon as it is dry, generally within 20-30 minutes of smear preparation. Preparation of thin blood smear A well prepared thin blood smear is necessary for microscopic examination of blood. Blood smears are used to determine leukocyte differentials, to evaluate erythrocyte, platelet and leukocyte morphology, and, if necessary, to estimate platelet and leukocyte counts. 7.2 Collection of Sample 1. Finger Prick or 2. E.D.T.A. blood (within 1 hr. of collection) 7.3 Preparation of Blood Film 1. Place a small drop of blood, or one side about 1-2 cm from one end of a clean slide. 2. Without delay place a spreader at an angle of 45° from the slide and move it back to make contact with the drop. The drop should spread out quickly along the line of contact of spreader with the slide. 3. The moment this occurs, spread the film by rapid smooth forward movement of the spreader. 4. The film should be 3-4 cm in length. The ideal thickness is such that there is some overlap of R.B.C. throughout most of its length with proper separation and lack of distortion of RBC's. The end from where the spread had ended is called tail end.

NSOU ? CC-ZO-06 102 Fig. 7.3 : Different types of WBC observed under microscope at high magnification in a blood smear preparation (nature.com) 7.4 Staining The slide is covered with Leishman stain for 2 mins. This much time is required for fixation. After 2 mins it is diluted with double the volume of buffer water. On adding buffer water a metallic shin will be formed, if the stain is dry. Allow this to stand for 15 min. after min, flood the slide with water to remove stain. Then wash under tap water wiping the back of slide with finger or cotton. Dry in air. 7.5 Precautions/Comments 1. Angle should be maintained at 45°. 2. Blood drop should be of proper size. Lymphocyte Monocyte Neutrophil Basophil Eosinophil

NSOU ? CC-ZO-06 103 Fig. 7.4 : Different W.B.C 3. Spreader's edges should be smooth and it should be smaller than the slide on which smear is being made. 4. Pressure applied should be proper. 5. Drop should be pulled with spreader not pushed with it. 6. Preparation should be in one single stroke. 7. Initial staining time 2 minutes, is important. After dilution increase of 1-2 minutes, does not alter staining. 8. Never let the stain dry on the slide otherwise stain deposits will make it impossible to count leucocytes (DLC). 9. Staining should be deposit free. 10.For washing the smear -let the water stream replace the stain. Do not throws the stain first. 7.6 Questions 1. State the differences and utility of thick and thin smear preparation of blood. 2. Describe thick blood smear preparation and seratch method. 3. Describe thin blood smeare preparation and staining methods. 4. What precautions should be maintained in blood smear preparation to observe WBCs? 5. How can we identity—a) eosinophils, b) monocytes, c) neutrophils, d) lympho- cytes. Lymphocyte Monocyte Eosinophil Basophil Neutrophil

NSOU ? CC-ZO-06 104 Unit 8 Demonstration of ELISA Structure 8.0 Objectives 8.1 Introduction 8.2 Materials and Method (Protocols) 8.3 Comments 8.4 Questions 8.0 Objectives ELISA is an immuneassay where monoclonal antibodies are used to detect specific antiges/biomolecules and prominantly used in clinical diagnosis and research. Therefore, with the practical knowledge of this technique learners will learn— ? How an immune technique can be used to detect and quantity specific target proteins of our body precisely. ? How monoclonal antibodies and their conjugates can be used in diagnosis. ? How the protocol of ELISA can be performed. 8.1 Introduction Enzyme-linked immunosorbent assayes (ELISA) is a fundamental tool of clinical immunology, and is used as an initial screen for HIV detection. Based on the principle of antigen-antibody interaction. This test allows for easy visualization of results. ELISA utilizes the enzyme immobilized in antibodies or antigens. It is used to quantify the antigen or antibody concentration. It is the common serological test used for the detection of a specific antigen or antibody. ELISA has been used as a diagnostic tool in medicine and plant pathology, as well as quality control check in various industries. ELISAs can be performed with a number of modifications to the basic procedure: direct, indirect, sandwich or competitive. The key step, immobilization of the antigen of

NSOU ? CC-ZO-06 105 interest, can be accomplished by direct adsorption to the assay plate or indirectly via a capture antibody that has been attached to the plate. The antigen is then detected either directly (enzyrne-labeled primary antibody) or indirectly (enzyme-labeled secondary anti- body). The detection antibodies are usually labeled with alkaline phosphatase (AP) or horseradish peroxidase (HRP). A large selection of substrates is available for performing the ELISA with an HRP or AP conjugate. The choice of substrate depends upon the required assay sensitivity and the instrumentation available for signal-detection (spectro- photometer, fluorometer or luminometer). Among the standard assay formats discussed and illustrated below, where differences in both capture and detection were the concern, it is important to differentiate between the particular strategies that exist specifically for the detection step. However an antigen is captured to the plate (by direct adsorption to the surface or through a pre-coated "capture" antibody, as in a sandwich ELISA), it is the detection step (as either direct or indirect detection) that largely determines the sensitivity of an ELISA. 1. Direct ELISA For direct detection, an antigen coated to a multi-well plate is detected by an antibody that has been directly conjugated to an enzyme. This detection method is a good option if there is no commercially available ELISA kits for your target protein. Advantages ? Quick because only one antibody and fewer steps are used. ? Cross-reactivity of secondary antibody is eliminated. Disadvantages ? Immune reactivity of the primary antibody might be adversely affected by labeling with enzymes or tags. ? Labeling primary antibodies for each specific ELISA system is time-consuming and expensive. ? No flexibility in choice of primary antibody label from one experiment to another. ? Minimal signal amplification. 2. Indirect ELISA For indirect detection, the antigen coated to a multi-well plate is detected in two stages or layers. First an unlabeled primary antibody, which is specific for the antigen, is applied.
NSOU ? CC-ZO-06 106 Next, an enzyme-labeled secondary antibody is bound to the first antibody. The secondary antibody is usually an anti-species antibody and is often polyclonal. The indirect assay, the most popular format for ELISA, has the advantages and disadvantages: Advantages ? A wide variety of labeled secondary antibodies are available commercially. ? Versatile because many primary antibodies can be made in one species and the same labeled secondary antibody can be used for detection. ? Maximum immuno-reactivity of the primary antibody is retained because it is not labeled. ? Sensitivity is increased because each primary antibody contains several epitopes that can be bound by the labeled secondary antibody, allowing for signal amplifi- cation. Disadvantages ? Cross-reactivity might occur with the secondary antibody, resulting in nonspecific signal. ? An extra incubation step is required in the procedure. 3. Sandwich ELISA Sandwich ELISAs typically require the use of matched antibody pairs, where each antibody is specific for a different, non-overlapping part (epitope) of the antigen molecule. A first antibody (known as capture antibody) is coated to the wells. The sample solution is then added to the well. A second antibody (known as detection antibody) follows this step in order to measure the concentration of the sample. This type of ELISA has the following advantages: ? High specificity :the antigen/analyze is specifically captured and detected ? Suitable for complex (or crude/impure) samples: the antigen does not require purification prior to measurement ? Flexibility and sensitivity: both direct or indirect detection methods can be used. 4. Competitive ELISA The key event of competitive ELISA (also known as inhibition ELISA) is the process of competitive reaction between the sample antigen and antigen bound to the wells of a

NSOU ? CC-ZO-06 107 micro titer plate with the primary antibody. First, the primary antibody is incubated with the sample antigen and the resulting antibody-antigen complexes are added to wells that have been coated with the same antigen. After an incubation period, any unbound antibody is washed off. The more antigen in the sample, the more primary antibody will be bound to the sample antigen. Therefore, there will be a smaller amount of primary antibody available to bind to the antigen coated on the well, resulting in a signal reduction. The main advantage of this type of ELISA arises from its high sensitivity to compositional differences in complex antigen mixtures, even when the specific detecting antibody is present in relatively small amounts. 8.2 Materials and Method Sample Preparation The procedure below provides a general guidance for the preparation of commonly tested samples for use in ELISA assays. Generally: ? Protein extract concentration is at least 1-2 mg/mL. ? Cell and tissue extracts are diluted by 50% with binding buffer. ? Samples are centrifuged at 10,000 rpm for 5 min at 4°C to remove any precipitate before use. 1. Cell Culture Supernatants Centrifuge cell culture media at 1,500 rpm for 10 min at 4°C. Aliquot supernatant immediately and hold at -80°C, avoiding freeze/thaw cycles. 2. Cell Extracts Place tissue culture plates on ice. Remove the media and gently wash cells once with ice-cold PBS. Remove the PBS and add 0.5 ml extraction buffer per 100 mm plate. Tilt the plate and scrape the cells into a pre-chilled tube. Vortex briefly and incubate on ice for 15-30 min. Centrifuge at 13,000 rpm for 10 min at 4°C (this creates a pellet from the insoluble content). Aliquot the supernatant into clean, chilled tubes (on ice) and store samples at -80°C, avoiding freeze/thaw cycles. 3. Conditioned Media Plate the cells in complete growth media (with serum) until the desired level of confluence is achieved. Remove the growth media and gently wash cells using 2-3 mL of
NSOU ? CC-ZO-06 108 warm PBS. Repeat the wash step. Remove the PBS and gently add serum-free growth media. Incubate for 1-2 days. Remove the media into a centrifuge tube. Centrifuge at 1,500 rpm for 10 min at 4°C. Aliquot the supematant and keep samples at -80°C, avoiding freeze/thaw cycles. 4. Tissue Extract Mince tissue on ice in ice-cold buffer, preferably in the presence of protease inhibitors. Place the tissue in micro-centrifuge tubes and dip into liquid nitrogen to snap freeze. Keep samples at -80°C for later use or keep on ice for immediate homogenization. For every 5 mg of tissue, add 300 ul, of extraction buffer to the tube and homogenize: ? l00 mM Tris, pH 7.4 ? 150 mM NaCI ? 1 mM EGTA ? 1 mM EDTA ? 1% Triton X-l00 0.5% ? 0.5% sodium deoxy cholate (This portion of the buffer can be prepared ahead of time and stored at 4°C. Immediately before use, the buffer must be supplemented with phosphatase inhibitor cocktail [as directed by manufacturer), protease inhibitor cocktail [as directed by manufacturerjand PMSF to 1 mM to generate a complete extraction buffer solution.) Rinse the blade of the homogenizer twice with 300 ul, extraction buffer. Place the sample on a shaker at 4°C for 2 hours. Centrifuge the sample for 20 min at 13,000 rpm at 4°C. Aliquot the supematant into pre-chilled tubes sitting in ice. Keep the samples at -80°C, avoiding freeze/thaw cycles. Rinse the blade of the homogenizer twice with 300 ul, extraction buffer. Place the sample on a shaker at 4°C for 2 hours. Centrifuge the sample for 20 min at 13,000rpm at 4°C. Aliquot the supematant into pre-chilled tubes sitting in ice. Keep the samples at –80°C, avoiding freeze/thaw cycles.
NSOU ? CC-ZO-06 109 Note: Lysis buffer volume must be determined according to the amount of tissue present. Typical concentration of final protein extract is at least 1 mg/mL. Reagent Preparation 1. Standard Solutions ? 10,000 pg/mL: Add 1 mL of sample diluents buffer into one tube of standard (10 ng per tube) and mixthoroughly. Note: Store this solution at 4°C for up to 12 hours (or – 20°C for 48 hours)and avoid freezethaw cycles. ? 5,000 pg/mL: Mix 0.3 mL of 10,000 pg/mL with 0.3 mL of sample diluent buffer and mix thoroughly. ? 2,500 pg/mL: Mix 0.3 mL of 5,000 pg/mL with 0.3 mL of sample diluent buffer and mix thoroughly. ? Perform similar dilutions until the standard solutions with these concentrations (pg/ mL) are made: 1,250,625,312, 156 and 78. ? Add 100 ?L of each of the diluted standard solutions to the appropriate empty wells. Repeat in duplicate or triplicate for accuracy. Note: The standard solutions are best used within 2 hours. 2. Biotinylated Antibody ? Calculate the total volume needed for the assay by multiplying 0.1 mL/well and the number of wells required. Add 2-3 extra wells to the calculated number of wells to account for possible pipetting errors. ? Generate the required volume of diluted antibody by performing a l : 100 dilution (For each l ?L concentrated antibody, add 99 ?L antibody dilution buffer) and mixing thoroughly. 3. Avidin-Biotin-Peroxidase (ABC) ? Calculate the total volume needed for the assay by multiplying 0.1 mL/well and the number of wells required. Add 2-3 extra wells to the calculated number of wells to account for possible pipetting errors. ? Generate the required volume of diluted ABC solution by performing a 1 : 100 dilution (For each 1 ?L concentrated ABC solution, add 99 ?L ABC dilution buffer) and mixing thoroughly. Note: The diluted ABC solution should not be prepared more than 1 hour prior to the experiment.

NSOU ? CC-ZO-06 110 8.2.1 Materials and Method Protocols 1. Add diluted antibody to each well of a 96-well ELISA plate. Seal the plate to prevent evaporation, and allow it to incubate at 4°C for 15-18 hours to immobilize the antibody. 2. Remove the diluted antibody, and wash 3 times with washing solution. 3. Add blocking buffer to each well, and allow it to incubate at 37°C for 1 hour to reduce non-specific binding of the target protein to the well. 4. Remove the blocking buffer, and wash 3 times with washing solution. 5. Dilute the samples with sample dilution buffer, and add 100 ?l, of each sample to each well. For the calibration curve, prepare a dilution series of the standard on the same plate. Allow it to incubate at 37°C for 1 hour. 6. Remove the samples, and wash 5 times with washing solution. 7. Dilute the detection antibody in sample dilution buffer, and add 100 ?l, to each well. Allow it to incubate at 37°C for 1 hour. 8. After reaction, remove the detection antibody, and wash 5 times with washing solution. 9. Dilute an enzyme-labeled secondary antibody with sample dilution buffer, and add 100 ?l, to each well. Allow it to incubate at 37°C for 1 hour. 10. After reaction, remove the secondary antibody, and wash 5 times with washing solution. 11. Allow it to incubate as the color develops. 12. Add a stop solution to stop the reaction when the color IS sufficiently developed. 13. Measure the absorption at 450 nm by a plate reader. Substrate Substrate Substrate Substrate Primary antibody conjugate Secondary antibody conjugate Inhibitor antigen Capture antibody Direct ELISA Indirect ELISA Sandwich ELISA Competitive ELISA Ag NSOU ? CC-ZO-06 111 12-Channel pipetto Adding slop solution After the addition of slop solution Dilution series of a standard for the calibration curve Plate reader 10 minutes after the addition of the substrate 1 minute after the addition of the substrate 96-well plate Reservols Dilution series of a standard for the calibration curve (1) (2) (3) (4-5) (8) (6-7) NSOU ? CC-ZO-06 112 8.3 Comments To perform ELISA of unknown samples a calibration process is needed which require dilution of standard reference serum. Different combination of enzyme-substrate systems may be used like avidin-biotin- peroxidase or alkaline phosphatase lebelled enzyme system to develop the color reaction to detect and quantity target protein or biomolecule in the photometric reaction. The ELISA plate-reader is the essential instrument to perform this technique which is a modified form of spectrophotometric device to read the color intensity generated in each well of ELISA plate or microtiter plate. 8.4 Questions 1. Describe the methodology to perform sandwich ELISA. 2. Briefly state the procedure for preparation of tissue extract to perform ELISA. 3. Why standard solution is necessary. Describe its preparation and use in ELISA. 4. State the procedure of preparing working solutions of different antibodies and enzyme substrate solution to utilize in ELISA. 5. How can be utilize cell extract or conditioned media in ELISA technique?

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PREFACE In a bid to standardise higher education in the country, the University Grants Commission (UGC) has introduced Choice Based Credit System (CBCS) based on five types of courses viz. core, discipline specific, generic elective, ability and skill enhancement for graduate students of all programmes at Honours level. This brings in the semester pattern, which finds efficacy in sync with credit system, credit transfer, comprehensive continuous assessments and a graded pattern of evaluation. The objective is to offer learners ample flexibility to choose from a wide gamut of courses, as also to provide them lateral mobility between various educational institutions in the country where they can carry acquired credits. I am happy to note that the University has been accredited by NAAC with grade 'A'. UGC (Open and Distance Learning Programmes and Online Learning Programmes) Regulations, 2020 have mandated compliance with CBCS for U.G. programmes for all the HEIs in this mode. Welcoming this paradigm shift in higher education, Netaji Subhas Open University (NSOU) has resolved to adopt CBCS from the academic session 2021-22 at the Under Graduate Degree Programme level. The present syllabus, framed in the spirit of syllabi recommended by UGC, lays due stress on all aspects envisaged in the curricular framework of the apex body on higher education. It will be imparted to learners over the six semesters of the Programme. Self Learning Materials (SLMs) are the mainstay of Student Support Services (SSS) of an Open University. From a logistic point of view, NSOU has embarked upon CBCS presently with SLMs in English / Bengali. Eventually, the English version SLMs will be translated into Bengali too, for the benefit of learners. As always, all of our teaching faculties contributed in this process. In addition to this we have also requisitioned the services of best academics in each domain in preparation of the new SLMs. I am sure they will be of commendable academic support. We look forward to proactive feedback from all stakeholders who will participate in the teaching-learning based on these study materials. It has been a very challenging task well executed, and I congratulate all concerned in the preparation of these SLMs. I wish the venture a grand success. Professor (Dr.) Subha Sankar Sarkar Vice-Chancellor
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Unit-1 Biological Macromolecules Structure 1.0. Obectives 1.1. Introduction to biological macromolecules 1.2. Carbohydrates 1.2.1 Introduction to carbohydrates 1.2.2 Classification of carbohydrates 1.2.3 Some additional information 1.2.4 Isomerism in monosaccharides 1.2.5 Mutarotation shown by glucose (monosaccharide) 1.2.6 Some chemical properties of carbohydrates 1.2.7 Physiological importance of carbohydrates 1.3. Proteins 1.3.1 Introduction to proteins 1.3.2 Classification of proteins 1.3.3 Protein structure 1.3.4 Some important properties of proteins 1.3.5 Physiological importance of proteins 1.4. Lipids 1.4.1 Introduction to lipids 1.4.2 Classification of lipids 1.4.3 Properties of fats 1.4.4 Physiological importance of lipids 1.5. Nucleic acids 1.5.1 Introduction to nucleic acids 1.5.2 Watson and Crick's model of DNA structure 1.5.3 Types of DNA 7
8 ____ NSOU ● CC-ZO- 08 1.5.4 Function of DNA 1.5.5 RNA – structure and function 1.6. Questions 1.7 References 1.0 Objectives After studying this Unit-I, one will be able to: ● Understand the meaning of 'biological macromolecules'. ● Define and classify carbohydrates. ● Explain isomerism in monosaccharides. ● Understand mutarotation shown by glucose. ● Have an idea of the chemical properties of carbohydrates. ● Understand the physiological importance of carbohydrates. ● Define and classify proteins. ● Understand various orders of protein structure. ● Understand the important properties of proteins. ● Understand the physiological importance of proteins. ● Define and classify lipids. ● Define and classify fatty acids. ● Have an idea of the chemical properties of lipids. ● Understand the physiological importance of lipids. ● Understand Watson and Crick's model of DNA structure. ● Understand the characteristics of different forms of DNA. ● Understand the function of DNA. ● Have an idea of different types of RNA and their function. 1.1 Introduction to biological macromolecules Macromolecules are giant molecules in which at least a thousand atoms are linked together by covalent bonds. Moreover, macromolecules are long repetitive sequences of an elementary chemical structure called the monomer. Cells and tissues of living organisms are made up of four kinds of biological macromolecules, viz. carbohydrates, proteins, lipids and nucleic acids; the latter are again of two types, viz.

NSOU ● CC-ZO- 08 ____ 9 DNA or deoxyribonucleic acid and RNA or ribonucleic acid. The monomer units of carbohydrates are called mono saccharides; those of proteins are called amino acids; those of lipids include fatty acids and alcohol; those of nucleic acids are called nucleotides. A macromolecule is called a homopolymer, if it is formed by joining of monomers having the same chemical structure, e.g. the carbohydrate called starch is formed by joining of numerous glucose units. On the other hand,a macromolecule is called a heteropolymer, if it is formed by joining of monomers having different chemical structure, e.g.Hyaluronic acid of connective tissue consists of alternating units of glucuronic acid and acetyl glucosamine. Biological macromolecules are important for not only constituting cells and tissues, but also for serving different physiological functions in the body of living beings. In this chapter, learners will know about the structure, properties and functions of different biological macromolecules. 1.2 CARBOHYDRATES : 1.2.1 Introduction to carbohydrates : Carbohydrates are widely distributed in both plant and animal tissues. Carbohydrates have profound biological importance: they serve as major source of energy for vital activities in both plants and animals; many carbohydrates form structural components of cells and tissues; some carbohydrates are essential components of other biological macromolecules of cells and tissues; some carbohydrates serve specific physiological functions in animal body. Definition of carbohydrates : Carbohydrates are derivatives of polyhydroxy alcohols, bearing one or more, free or bound, aldehyde – C O H ( ) or ketone (< C = 0) group. Generally, carbohydrates are composed of carbon, hydrogen and oxygen and have a 2 : 1 ratio of hydrogen and oxygen atoms, as in case of water. However, there are some exceptions. All compounds that are composed of C, H and O and that have a 2 : 1 ratio of hydrogen and oxygen may not be carbohydrates: It should be noted that : (i) All substances that consists of C, H and O and that have a 2 : 1 ratio of hydrogen and oxygen atoms, may not necessarily be carbohydrates,e.g. Formaldehyde (HCHO or CH 2 O) and Acetic acid (CH 3 COOH or C 2 H 4 O 2). (ii) There are carbohydrates where the ratio of hydrogen and oxygen atoms is not 2 : 1, e.g. Fucose (C 6 H 12 O 5).
10 ____ NSOU ● CC-ZO- 08 (iii) Some carbohydrates contain substances other than C, H and O, e.g. Glucosamine (C 6 H 11 O 5 NH 2) contains nitrogen in addition to C, H and O. 1.2.2 Classification of carbohydrates : Carbohydrates may be classified into the following classes : (A) Monosaccharide : Monosaccharides are the simplest carbohydrates, which cannot be hydrolyzed any further and which usually have the empirical formula C n (H 2 O) n . According to the number of carbon atoms, monosaccharides can be subdivided into the following types : Type No. of Empirical Example Occurrence carbon formula atoms Triose 3 C 3 H 6 O 3 Glyceraldehyde EMP pathway Tetrose 4 C 4 H 8 O 4 Erythrose HMP pathway Pentose 5 C 5 H 10 O 5 Ribose Ribonucleic acid Hexose 6 C 6 H 12 O 6 Glucose Blood sugar Heptose 7 C 7 H 14 O 7 Sedoheptulose HMP pathway Octose 8 C 8 H 16 O 8 Glucooctose Metabolic pathway in plants Nonose 9 C 9 H 18 O 9 Gluconononse Metabolic pathway in plants Decose 10 C 10 H 20 O 10 Glucodecose Metabolic pathway in plants Again, monosacharides may be subdivided into 2 groups according to the nature of the sugar-group present in the molecules: (i) Aldose: Monosaccharides having an aldehyde group at the first carbon (C 1) of their carbon skeleton, e.g. Glucose, Galactose. (ii) Ketose: Monosaccharides having a ketone group (<C = 0) at a position other than the first carbon in their carbon skeleton, e.g. Fructose.
NSOU ● CC-ZO- 08 ____ 11 Ring Structures of five important monosaccharide [Source : Wikimedia Commons (CC 3.0)] (B) Disaccharide : Disaccharides are carbohydrates which are composed of two similar or dissimilar monosaccharide units, joined by glycosidic linkage, with the loss of one molecule of water. Upon hydrolysis, disaccharides yield the two constituent monos accharide residues. The general formula of disaccharide is C 2n (H 2 O) 2n−1 . Examples Constituent monosaccharide units Occurrence Maltose Glucose + Glucose Malt and germinating (linked by ?-1,4 glycosidic bond) cereals Lactose Galactose + Glucose Milk (linked by ?-1,4 glycosidic bond) Sucrose Gluctose + Fructose Sugarcane and Beet (linked ?-1,2 glycosidic bond) Isomaltose Glucose + Glucose Sugarcane and Beet (linked by ?-1,6 glycosidic bond)

12 ____ NSOU ● CC-ZO- 08 (C) Oligosaccharide : Oligosaccharides are carbohydrates composed of more than two but less than ten monosaccharide residues, joined together by glycosidic linkages : Type and Constituent monosaccharide residues Occurrence Examples Trisaccharide Raffinose = Galactose + glucose + fructose Sugar-beet Tetrasaccharide Stachyose = 2 Galactose + 1 glucose + 1 fructose Some plant tubers Pentasaccharide Verbascose = 3 Galactose + 1 glucose + 1 fructose Some plant roots (D) Polysaccharide: Polysaccharides are carbohydrates composed of ten or more monosaccharide units,joined by glycosidic linkages. While mono-, di- and oligosaccharides are soluble in water and sweet in taste, most polysaccharides are insoluble in water and devoid of sweet taste. The empirical formula is [C n (H 2 O) n1] x where x is 10 or larger. Polysaccharides are subdivided into: (i)Homopolysaccharide or Homoglycan: When the constituent monosaccharides are all similar, e.g. Starch of plant tissues and glycogen of animal bodies are composed of innumerable glucose units only. (ii) Heteropolysaccharide or Heteroglycan: When a polysaccharide consists of more than one type of monosaccharide units, e.g. Hyaluronic acid of connective tissue consists of alternating units of glucuronic acid and acetyl glucosamine. Besides, polysaccharides are sometimes, divided into (i) Structural polysaccharides and (ii) Storage polysaccharides. Structural polysaccharides serve as components of different structural parts of organisms,e.g. Hyaluronic acid is a component of connective tissues of animals. Cellulose is a part of cell-wall in plants. Storage polysaccharides are stored in animal or plant bodies for obtaining energy during necessity,e.g. Starch in plants and glycogen in animals. 1.2.3 Some additional information 1.2.3.1 Lowest number of carbon atoms in a carbohydrate : By definition, a carbohydrate is derivative of polyhydroxy alcohol, having one or more, free or bound CHO or CO group. Hence, a compound must have (i) at least two OH groups and (ii) at least one CHO or CO group. In other words, a carbohydrate molecule cannot have less than 3 carbon atoms.

NSOU ● CC-ZO- 08 ____ 13 1.2.3.2 Distinction between a triose and a trisaccharide : Ans. (i) A triose is a monosaccharide having 3 carbon atoms in its carbon- skeleton. E.g. Glyceraldehyde. On the other hand, a trisaccharide is a bigger carbohydrate molecule, composed of 3 monosaccharide units which are joined with one another by glycosidic linkage. E.g. Raffinose – it is a trisaccharide formed by joining of 1 galactose, 1 glucose and 1 fructose residues. (ii) A triose being a monosaccharide cannot be hydrolysed any further. But, a trisaccharide, when hydrolysed, is broken into 3 monosaccharide residues. 1.2.3.3 The smallest carbohydrates : Smallest carbohydrates are called as 'triose' which means monosaccharide with 3 carbon atoms,e.g. (i) Glyceraldehyde is an 'aldose' type of triose and (ii) Dihydroxyacetone is a 'ketose' type of triose : Starch 1. It is a storage polysaccharide of plants. 2. It consists of many glucose units joined by ?-1,4-glycosidic linkage. Moreover, a starch molecule has a branched structure; branching occurs in every 24- 30 glucose units; one branch remains joined to another branch by ?-1,6- glycosidic linkage. 3. It forms a blue adsorption complex with iodine. Glycogen 1. It is a storage polysaccharide of animals. 2. It is also composed of many glucose units joined by ?-1,4-glycosidic linkage. A glycogen molecule has a highly branched structure ; branching occurs in every 10-15 glucose units; one branch remains joined to another branch by ?-1,6-glycosidic linkage. 3. It forms a reddish adsorption complex with iodine. 1.2.3.4 Distinction between two polysaccharides – starch and glycogen :

14 ____ NSOU ● CC-ZO- 08 1.2.4 Isomerism in monosaccharides : Isomerism : The existence of a compound in different forms that retain the same molecular formula but differ in physical and chemical properties is called isomerism while such different forms are called isomers. Monosaccharides show different types of isomerism: 1.2.4.1 Stereoisomerism : It refers to the existence of a compound in such different forms that have the same empirical and structural formula but that differ in their spatial configuration (arrangement of constituent atoms in space). Monosaccharides show stereoisomerism due to the presence of asymmetric carbon atoms in their molecules. An asymmetric carbon atom is such a carbon atom which has four different groups or atoms satisfying its four valencies. Monosaccharides are considered as 'chiral molecules', i.e. the spatial arrangement of different groups around the asymmetric carbon atoms may be variable, which forms the basis of stereoisomerism of different kinds. (i) D- and L-isomerism : The most commonly described stereoisomers are D- and L-isomers, which appear as exact mirror-image of each other. The designation of an isomer as D- or L-isomer depends on its spatial relationship to the parental compound of carbohydrate family, the 3-carbon sugar glyceraldehyde. The structure of D-glyceraldehyde and its mirror-image, the L-glyceraldehyde are as follows : When the highest asymmetric carbon atom i.e. the penultimate carbon atom lying before the terminal primary alcohol carbon has an OH group at its right and a H at its left as in D-glyceraldehyde, the sugar is called D-sugar or D-isomer. But, when the penultimate carbon has OH at its left and H at its right as in L-glyceraldehyde, the sugar is called L-sugar or L-isomer. For instance, glucose is a hexose with the 5 th carbon as its penultimate carbon; the structures of D- and L-glucose are as follows : NSOU ● CC-ZO- 08 ____ 15 The D- and L-isomers being mirror-images of each other cannot be superimposed on each other. The 2 isomers together are called an enantiomeric pair, and each isomer is said to be an enantiomer to the other. It may be further added here that most sugars occur as D-isomers in living beings, e.g. D-glucose, D-galactose etc. as aldoses and D-fructose, D-ribulose etc. as ketoses. However, some sugars occur predominantly as L-isomers, e.g. the aldose L- fucose and the ketose L-rhamnose. (ii) Epimerization: Stereoisomerism with respect to variation in the arrangement of -OH and -H attached to any single asymmetric carbon atom in molecules that have more than one asymmetric carbon atoms is called epimerization. For instance, D- glucose and D-galactose are epimers differing in configuration around only the 4 th carbon. Again, D-glucose and D-mannose are epimers differing in configuration around only the 2 nd carbon. Their structures are as follows:

16 ____ NSOU ● CC-ZO- 08 (iii) Anomerism: Stereoisomerism with respect to change in configuration of groups or atoms around the anomeric carbon atom is called anomerism. In solution, the sugars occur almost exclusively in the form of a ring instead of a chain-structure. In case of an aldose, the ring is a hemiacetal ring, i.e. the ring is formed due to hemiacetal formation or by condensation of the -OH group of C 5 (carbon 5) with the aldehyde group of C 1 (carbon 1). In case of a ketose, the ring is a hemiketal ring, i.e. the ring is formed due to hemiketal formation or by condensation of -OH group of C 5 with the ketone group of C 2 . The hemiacetal carbon or C 1 in an aldose and the hemiketal carbon or C 2 in a ketose are called anomeric carbons. During the formation of the ring structure of a sugar, 2 stereoisomers can be formed: the a- and b-anomers, which differ in configuration of groups or atoms around the anomeric carbon. For instance, in case of D-glucose, in the a-anomer, -H lies above and -OH lies below the C 1 while -H lies below and O -H lies above the C 1 in the â-anomer. The structures are shown below : The a- and b- anomers of glucose differ in many of their properties, e.g. (i) a- glucose has a melting point of 146 0 C while b-glucose melts at 150 0 C, (ii) a-glucose has a solubility of 82.5 g/100 ml of water while b-glucose dissolves at a rate of 178 g/100 ml of water and (iii) the a-anomer of D-glucose shows an initial dextrorotation of +112.2 0 which gradually decreases to +52.7 0 on standing and the b-anomer shows an initial dextrorotation of +18.7 0 which increases to +52.7 0 on standing. This type of gradual change in optical activity of a sugar until a stability is reached, is called as mutarotation. Mutarotation occurs due to partial inter-conversion between the a- and b-anomers. The optical activity becomes stable when an equilibrium mixture of the 2 anomers is produced, e.g. In case of D-glucose, the 'equilibrium mixture' contains 38% a-anomer and 62% b-anomer and this mixture shows a stable dextrorotation of +52.7 0 only. 1.2.4.2 Optical Isomerism: Monosaccharides possess optical activity, i.e. they can rotate the plane of polarized light either to the right or to the left, when polarized light is passed through

NSOU ● CC-ZO- 08 ____ 17 their solutions. The optical activity is due to the presence of asymmetric carbon atoms in their molecules. The electromagnetic fields of atoms or groups around the asymmetric carbons act on polarized light to cause rotation of its plane. A monosaccharide can exist as two optical isomers: (i) dextrorotatory or d- isomer or (+) isomer which rotates the plane of polarized light to the right and (ii) levorotatory or l-isomer or (-) isomer which rotates the plane of polarized light to the left, e.g. Two optical isomers of glucose are d-glucose or (+) glucose and 1-glucose or (-) glucose respectively. The rotation of polarized light by an isomer is measured by an instrument called Polarimeter. In this instrument, ordinary monochromatic light is passed through a Nicol prism at a specified angle. The prism gives out polarized light that oscillates in one plane only. The polarized light is passed through the glass-tube containing the sugar solution which rotates the plane of the light. The rotated beam coming out of the solution is passed through an 'analyzer Nicol prism' and a 'lens system' to fall on the eyes or a screen. The 'specific optical rotation' is then calculated as follows: r= obs 100 1 c (Where, r = specific optical rotation at a specific temperature and a specific wave-length; obs = observed rotation (in degree); 1 = length of the tube containing sugar solution (in decimeter); c = g of sugar/100 ml of solution.) In case of most sugars, the d-and l-isomers correspond to the D- and L- stereoisomers, respectively, e.g. D-glucose is dextrorotatory and L-glucose is levorotatory and therefore, the 2 isomers can be written as D (+) glucose and L(-) glucose. However, in some sugars, the 2 optical isomers do not correspond to the two stereoisomers, e.g. D-fructose is levorotatory and should be written as D (-) fructose. Working principle of Polarimeter Finally, an equimolar mixture of the d- and l-isomers of a sugar is optically inactive and does not rotate the plane of polarized light at all. Such a mixture is called racemic mixture. The two components of a racemic mixture can be separated by specific techniques only.

18 ____ NSOU ● CC-ZO- 08 Schematic representation of different types of isomers [Source : Wikimedia Commons (CC 3.0)] 1.2.4.3. Structural Isomerism : Compounds that have the same molecular formula but differ in molecular structure are called structural isomers and the phenomenon is called structural isomerism, Monosaccharides show structural isomerism as described below: (i) Aldose-ketose isomerism: The aldohexose glucose and the ketohexose fructose have the same empirical formula of C 6 H 12 O 6 , but they differ in their molecular structures. Glucose has an aldehyde group at the 1 st carbon while fructose has a ketone group at the 2 nd carbon; glucose has no ketone group and fructose has no aldehyde group. Thus, glucose and fructose are 2 structural isomers. Their structures have been shown in classification of carbohydrates (Section 1.2.2). (ii) Pyranose-furanose isomerism: In solution, the sugars exist as ring-structure instead of chain-structure, when the ring is a 6-membered ring having 5 carbons and 1 oxygen like a pyran ring, the sugar is said to be in pyranose form and when the ring is a 5-membered ring with 4 carbons and 1 oxygen like a furan ring, the sugar is said to be in furanose form. The basic structures of pyran and furan rings are as follows :

NSOU ● CC-ZO- 08 ____ 19 1.2.5 Mutarotation shown by glucose Definition : The optical activity of a freshly prepared solution of a monosaccharide, with the exception of a few ketoses, shows a gradual change until it becomes stable on standing. This is known as mutarotation. Mutarotation in glucose : Mutarotation has been studied best in case of glucose. If D-glucose is crystallized from water or dilute alcohol at room temperature, an isomer separates, which in solution shows an initial specific rotation of +112.2 o . However, the specific rotation gradually decreases to +52.7 o on standing. This isomer is called as a-anomer of glucose. On the other hand, if D-glucose is crystallized from water or pyridine at 98 0 C or higher temperatures, an isomer separates, which in solution shows an initial specific rotation of +18.7 o . The specific rotation gradually increases to +52.7 o on standing. This isomer is called b-anomer of glucose. Mechanism of mutarotation: In solution, a sugar molecule mainly exists in a ring form which, in turn, may exist in 2 stereoisomeric forms called as a-anomer and and b-anomer. The structure of the 2 anomers of D-glucose are shown below; the a- anomer has a 'H' above and a 'OH' below the plane of the ring at C 1 , while the arrangement of 'H' and 'OH' at C 1 is just the opposite in case of the ?-anomer : Mutarotation occurs due to partial inter-conversion between the alpha- and beta- anomers through an intermediate open-chain form of the molecule. So long as this inter-conversion goes on, mutarotation or change in optical activity of the sugar solution continues. Finally, an equilibrium mixture of the 2 anomers is established and the optical activity also becomes stable. An equilibrium mixture of D-glucose contains nearly 38% of the a-anomer and 62% of the ?-anomer. Mutarotation in case of glucose

20 ____ NSOU ● CC-ZO- 08 1.2.6 Some chemical properties of carbohydrates: 1.2.6.1 Molisch test : Carbohydrates, in general, respond positively to a colour reaction known as Molisch test. The test is based on the following principle: On treating with a strong mineral acid, a sugar loses water and forms furfural or furfural-derivative, e.g. when the sugar is a pentose, furtural is formed and when the sugar is a hexose, hydroxymethyl furfural is formed. The furfural or furfural- derivative then condenses with phenolic compounds like a-napthol, thymol etc. to yield coloured complexes. When Molisch test is carried out, a few drops of an alcoholic solution of a- naphthol is added to the sugar solution. To this mixture, concentrated H_2SO_4 is added very slowly so that the heavy acid forms a separate layer below the previous mixture. A reddish-violet ring appears at the junction of the two layers. Carbohydrates consisting of more than one or many monosaccharide units also give a positive response to Molisch test, because the treatment with acid hydrolyzes them into monosaccharides. 1.2.6.2 Reducing sugars and reduction test : Sugars possessing a free -CHO or <CO group changes into an enediol in presence of alkali and the enediol, in turn, reduces a metallic ion like Cu^{++} (Cupric) ion or Fe^{+++} (Ferric) ion into a Cu^{+} (Cuprous) ion or Fe^{++} (Ferrous) ion. Due to such reducing action on metallic ion, a sugar with a free -CHO or <CO group is called a reducing sugar. All monosaccharides are reducing sugars, as they possess a free -CHO or <CO group. Among disaccharides, lactose and maltose are reducing sugars, as they possess a free -CHO group. A reduction test is a chemical test to identify a reducing sugar. Benedict's test is a common reduction test. Benedict's qualitative reagent contains (i) $CuSO_4$ Reactions in Molisch test
NSOU ● CC-ZO- 08 ____ 21 (Cupric sulphate as a source of Cu^{++} ions), (ii) Na_2CO_3 (an alkali) and (iii) Sodium citrate (which promotes ionization of $CuSO_4$). Upon heating with Benedict's reagent, a reducing sugar reacts with the alkali and changes into an enediol. The enediol reduces Cu^{++} ions into Cu^{+} ions, which combine with OH^{-} ions of water to give yellow CuOH (Cuprous hydroxide). Due to heat, CuOH changes into a brick-red precipitate of Cu_2O or Cuprous oxide ($2CuOH = Cu_2O + H_2O$). Lactose and maltose are reducing sugars but sucrose in a non-reducing sugar. For showing a reducing action, a sugar must possess a free -CHO or <CO group. Among disaccharides, lactose and maltose have a free -CHO group and they are reducing sugars, but sucrose has no free -CHO or <CO group and sucrose is a non-reducing sugar. In case of maltose, the -CHO group at C_1 of one glucose residue is linked with the C_4 of the second glucose residue. So, the -CHO group at C_1 of the 2nd glucose remains free to make maltose a reducing sugar. In case of lactose, the -CHO group at C_1 of the galactose residue is linked with the C_4 of the glucose residue. So, the -CHO group at C_1 of the glucose remains free to make lactose a reducing sugar. In case of sucrose, the CHO group at C_1 of thee glucose residue is linked with the <CO group at C_2 of the fructose residue. So, there is no free -CHO or <CO group in a sucrose molecule and sucrose cannot have any reducing action. 1.2.6.3 Osazone test : When reducing sugars are treated with phenylhydrazine in acetic acid at 100^{o}C, the sugar group, i.e. the free -CHO or free <CO group of the sugar reacts with penylhydrazine and sugar-phenylhydrazone is produced. Sugar-phenylhydrazone then reacts further with the excess phenylhydrazine to produce sugar-phenylosazone that precipitates as yellowish or orange crystals with characteristic shape. All monsaccharides and reducing disaccharides like lactose and maltose give a positive Osazone test. The crystals are commonly called as Osazone crystals. Sugar + Phenylhydrazine Sugar-phenylhydrazone Sugar-phenylhydrazone + Phenylhydrazine Sugar-phenylosazone Glucose and fructose give elongated needle-like crystals. Lactose gives cotton-ball shaped crystals and maltose gives sunflower-shaped crystals.

22 ____ NSOU ● CC-ZO- 08 Glucose/Fructose Lactose Maltose 1.2.7 Physiological importance of carbohydrates Monosaccharides : (i) Blood glucose enters into the cells of animal body and is oxidized inside cells for production of energy. (ii) Pentose sugars like ribose and deoxyribose are structural components of RNA and DNA, respectively. Disaccharides : Milk-sugar or lactose is an essential nutrient for the new-born babies of all mammals. Lactose is hydrolyzed into glucose and galactose by intestinal lactase. Then, glucose and galactose are absorbed into blood and these sugars are oxidized inside cells for production of energy. Homopolysaccharides : (i) Starch is a storage homopolysaccharide in plant body while glycogen is a storage homopolysaccharide in liver and muscle of animals. Both starch and glycogen are homopolymers of numerous glucose units joined by ?- 1,4-glycosidic linkage. Both starch and glycogen are broken into glucose whenever required for production of energy in cells. (ii) Cellulose is an insoluble homopolymer of numerous glucose units joined by ?-1,4-glycosidic linkage. Cellulose is a structural homopolysaccharide; it is an essential structural component of cell-wall of plant cells. (iii) Chitin is an insoluble homopolymer of numerous N-acetyl- glucosamine units joined by ?-1,4-glycosidic linkage. Chitin is a structural homopolysaccharide; it is an essential structural component of exoskeleton of arthropods and wings of insects. Heteropolysaccharides: (i) Heparin is an acid mucopolysaccharide consisting of alternating units of 2-O-sulphated iduronic acid and glucosamine sulfate. Heparin is secreted from basophils of blood and mast cells of connective tissue. Heparin acts an anticoagulant which prevents clotting of blood in blood vessels. (ii) Hyaluronic acid is a structural heteropolysaccharide cum acid mucopolysaccharide consisting of alternating units of Glucuronic acid and N-acetyl glucosamine. Hyaluronic acid is an essential component of the intercellular matrix of loose connective tissues, synovial fluid and vitreous humor. (iii) Chondroitin sulfate is a structural heteropolysaccharide cum acid mucopolysaccharide consisting

of alternating units of Glucuronic acid and N-acetyl galactosamine sulfate.

Chondroitin sulfate is an essential component of the intercellular matrix of bone, cartilage, tendon and lung. Osazone crystals of different sugars

NSOU ● CC-ZO- 08 ____ 23 1.3 Proteins 1.3.1 Introduction to proteins Proteins are polymers of the monomers called as amino acids. Proteins are major structural components of cellular membranes, various cell organelles, chromosomes, cytoskeletal structures, extracellular matrix and connective tissue fibers. Besides, proteins in the form of different enzymes, hormones, respiratory proteins and immunoglobulins perform various important physiological functions in the body of living beings. 1.3.2 Classification of proteins (A) On the basis of molecular shape : On the basis of molecular configuration or shape, proteins are classified into globular and fibrous proteins. (i) Globular proteins have their peptide chains compactly folded, exposing polar amino acid side- chains on the surface and hiding non-polar amino acid side-chains within the folds. This makes them soluble in polar solvents like water. The axial ratio (length: diameter ratio) of these molecules ranges from 1 to 4, e.g. Albumin, Globulin. (ii) Fibrous proteins have elongated molecules with axial ratios above 10. Non-polar amino acid side-chains lie on their surface, which makes them less soluble in water, e.g. Keratin, Collagen. (B) On the basis of physiological function : On the basis of physiological role, proteins may be classified into:(i) Structural proteins (e.g. Keratin, Collagen, Elastin), (ii) Contractile proteins (e.g. Actin, Myosin), (iii) Carrier proteins (e.g. Transferrin, Ceruloplasmin), (iv) Informational proteins (e.g. Neurotransmitter peptides, Protein hormones and Peptide hormones), (v) Storage proteins (e.g. Ferritin, Calsequestrin), (vi) Enzymes (e.g. Pepsin, Trypsin), (vii) Respiratory proteins (e.g. Cytochromes, Haemoglobin, Haemocyanin), (viii) Body defense proteins (Immunoglobulins, Complements). The same protein may sometimes belong to more than one class. (C) On the basis of solubility: An age-old classification of proteins is based on their solubility in various solvents: 1. Simple proteins: They are composed of amino acids only and have no non- protein part in their molecules. Simple proteins are further classified into : (a) Protamines: (i) These are the smallest proteins having globular shape. (ii) They are soluble in water, dilute acid or alkali and dilute ammonia. (iii) Protamines are not coagulated by heat. (iv) Protamines do not contain cysteine, cystine, tyrosine and tryptophan, but have a large number of the

24 ____ NSOU ● CC-ZO- 08 cationic, polar amino acid arginine. So, their isoelectric pH is above the normal blood pH 7.4. Consequently, they exist as cationic or basic proteins in the body and combine with nucleic acids, e.g. Protamines like Salmine, Sardinine and Iridine combine with DNA to form Nucleoprotein of fish sperms. (b) Histones : (i) Histones have globular and larger molecules than protamines. (ii) Their solubility is lower than that of protamines. They dissolve in water, dilute acid or dilute alkali, but not in dilute ammonia. (iii) They are not coagulated by heat. (iv) They are rich in cationic, polar amino acids like arginine and histidine. So, their isoelectric pH is above the normal blood pH 7.4. Consequently, they exist as cationic or basic proteins in the body and combine with nucleic acids and porphyrins. E.g. Histones combine with DNA to form nucleohistone of eukaryotic chromosomes and a histone called globin combines with the porphyrin haem to form haemoglobin of vertebrate RBC. (c) Albumins : (i) They are large globular proteins. (ii) They dissolve in water, dilute acid or alkali. From solutions, they are precipitated by full saturation with (NH 4) 2 SO 4 , but not by half-saturation. (iii) They are easily thermo- coagulated. (iv) They are deficient in glycine and they have low isoelectric pH, compared to blood pH. Consequently, they are anionic or acidic proteins, e.g. Ovalbumin (egg-white) and lactalbumin (milk albumin) are glycoproteins, but plasma albumin carries no attached oligosaccharides. (d) Globulins : (i) They have globular and still larger molecules, as compared to albumins. (ii) They have quite low solubility. They are insoluble in water, acid or alkali, but they dissolve in dilute neutral salt solutions (salting in). Globulins are precipitated by half-saturation with (NH 4) 2 SO 4 (salting out) (iii) They are easily thermo-coagulated. (iv) Many globulins bind with lipids to form lipoproteins (e.g. plasma VLDL or Very Low-Density Lipoproteins), with metals to form metalloproteins (e.g. Transferrin and ceruloplasmin of plasma), and with oligosaccharides to form glycoproteins (e.g. Immunoglobulins of plasma). (e) Glutelins: These are plant proteins of large size, insoluble in water or salt solution, but soluble in dilute acid or alkali. Having sufficiently big molecules, they are coagulated by heat, e.g. Oryzenin of rice and glutenin of wheat. (f) Prolamines: They are plant proteins of large size. They are insoluble in water, salt solution and absolute alcohol, but they dissolve in dilute alcohol and dilute acid or alkali. They are coagulated by heat.They are very rich in proline, but poor in lysine, e.g. Gliadin of wheat and hordein of barley).

NSOU ● CC-ZO- 08 ____ 25 (g) Scleroproteins: These are fibrous animal proteins with very lowsolubility : (i) Keratins are very insoluble and indigestible. Keratins occur in skin, hair, nail and wool. Keratins are rich in cystine which accounts for interchain S-S linkages, but are poor in proline and hydroxyproline. (ii) Collagens occur in cartilage, bone, tendon and white fibres of areolar tissue. They dissolve in strong acids and changed to sticky gelatin by heating in water. They are rich in glycine, proline and hydroxyproline, but deficient in tryptophan, tyrosine, cysteine, cystine and methionine. (iii) Elastins are present in ligaments, tendons and yellow elastic fibres of areolar tissue. They are not gelatinized on heating with water. They are rich in alanine, leucine, valine and proline, but deficient in cysteine, cystine, methionine, hydroxylysine and histidine. 2. Conjugated proteins : These are complexes of simple proteins with non- proteins. The protein part is called apoprotein; the non-protein part is called prosthetic group while the entire molecule is known as a holoprotein. Conjugated proteins are classified according to the prosthetic group: (a) Chromoproteins: Their prosthetic groups are pigments like porphyrins, carotenoids, melanins and flavins, e.g. Hemoproteins like haemoglobin and cytochromes contain the iron-porphyrin haem. Rhodopsin and iodopsin of retinal rods and cones contain the carotenoid pigment retinol. (b) Metalloproteins : These are metal-protein complexes, e.g. Carbonic anhydrase of RBC contains Zn 2+ , ceruloplasmin of plasma contains Cu 2+ and ferritin of intestinal mucosa contains Fe 3+ . (c) Nucleoproteins : Deoxyribonucleoproteins occur in chromosomes, chloroplast stroma and mitochondrial matrix. They have DNA as the prosthetic group while their apoprotein part consists of histones (basic proteins) and non- histones (acidic proteins). Ribonucleoproteins occur in nucleoli and ribosomes. They have RNA as the prosthetic group. (d) Phosphoproteins : Their prosthetic groups contain phosphates, e.g. Casein of milk and ovovitellin of egg-yolk. (e) Lipoproteins: Their prosthetic groups are formed of triglycerides, phospholipids, sphingolipids, fatty acids and cholesterol. They are abundant in cellular membranes, plasma and milk. Plasma lipoproteins are classified into VLDL, LDL, HDL etc. according to their densities. The density varies inversely with the percentage of lipids in the molecule. (f) Glycoproteins: Oligosaccharide chains form the prosthetic groups in these proteins. Oligosaccharide chains are bound either by O-glycosidic linkages with the sidechain-OH of the apoprotein or by N-glycosidic linkages with the

26 ____ NSOU ● CC-ZO- 08 sidechain-NH (of asparagine residues) of the apoprotein. Two major classes are glycoproteins and proteoglycans. Glycoproteins carry hexoses (e.g. galactose, mannose, fucose), N-acetylhexosamines and sialic acid but no hexuronic acid in their oligosaccharide chains. Glycoproteins include mucin, immunoglobulins and some hormones like TSH, FSH and LH. Oligosaccharides of proteoglycan are made of mainly hexuronic acids and N-acetylhexosamines. Proteoglycans occur in extracellular matrix of bones and cartilages. 3. Derived proteins: These are produced from native proteins by various physical and chemical factors: (a) Denatured proteins or Primary derived proteins: Heat, radiation, acid and alkali can change native proteins non-hydrolytically into denatured proteins. They possess same molecular weight as the original protein, but differ from the latter in solubility, precipitation and crystallization. E.g. Heat, X-ray, UV ray, alcohol or urea change the soluble globular protein ovalbumin into fibrous, insoluble, coagulated protein. This coagulation or clumping of protein occurs due to denaturation or breaking of intra-chain hydrogen bonds in the polypeptide chains. (b) Secondary derived proteins: Progressive hydrolysis of peptide bonds breaks a protein into smaller molecules: Protein à Peptone à Peptide. They are generally soluble in water and not coagulated by heat. 1.3.3 Protein structure: Proteins are made up of one or more polypeptide chains, which in turn are formed by polymerization of many amino acid residues. However, many intra-and interchain connections are formed so that protein molecules assume different higher orders of structure, rather than occurring as simple and discrete polypeptide chains. The formation of higher-order structure fulfils two important purposes: (a) large protein molecules can be accommodated within a limited space in and out of cells and (b) proteins assume the necessary configurations so that they can interact with or act upon other biomolecules. Different orders of proteins structure are described below: 1.3.3.1 Primary structure: (1) The primary structure of a protein denotes the amino acid sequence of its constituent polypeptide chain or chains. (2) The primary structure of each polypeptide chain is mainly formed by the formation of covalent bonds called peptide bonds or CONH bonds in between the successive amino acid residues.

NSOU ● CC-ZO- 08 ____ 27 (3) A peptide bond links the a-carboxyl carbon of one amino acid with the ?-amino nitrogen of the next amino acid while one molecule of water is lost during the formation of a peptide bond. Peptide bond formation [Source : Wikimedia Commons]

28 ____ NSOU ● CC-ZO- 08 (4) The amino acid residue at one terminal end of a polypeptide chain retains a free ?-NH 2 group. This amino acid is called as the first amino acid of a polypeptide chain and this end of the chain is called as the N-terminal end. The amino acid residue at the opposite terminal end of a polypeptide chain retains a free ?-COOH group. This amino acid is called as the last amino acid of the chain and this end of the chain is called as the C-terminal end. (5) The amino acid residues in a polypeptide chain are given serial numbers and shown by respective symbols, starting from the N-terminal end and finishing at the C terminal end, e.g. (6) The backbone of each polypeptide chain is constituted by the a-carbon (C a), the a-carbonyl carbon (C o) and the a-amide N of the amino acid residues of the chain while the side-chains (R groups) and the H of the amino acids project outwards from the backbone. Comment: Primary structure of proteins is extremely important for functioning of proteins. Some evidences in favour of this statement are as follows: (i) Bovine pancreatic ribonuclear is a monomeric protein having a single polypeptide chain with four intrachain disulphide links. If it is treated with 8M urea and â-mercaptoethanol, the hydrogen bonds are disrupted by urea and the disulphide links are disrupted by b-mercaptoethanol. Thus, the secondary and tertiary structure of the protein, which in turn was dependent on the primary structure, is impaired and the enzymatic protein becomes inactive. However, the inactive protein gets reactivated when the denaturing agents are removed and the SH groups are reoxidized with atmospheric O 2 . (ii) In a genetic disease called sickle cell anaemia, the 6 th amino acid glutamic acid in each of the two b-chains of haemoglobin is replaced by valine. This abnormal Hb is called HbS and that of normal subjects is called HbA. HbS with nonpolar valine has low solubility; it crystallizes, resulting in sickling of RBCs. The sickle-shaped RBCs rupture easily during their passage through the splenic red pulp. 1.3.3.2 Secondary Structure of Proteins: The folding or coiling of the polypeptide chain or chains of a protein, due to the formation of intrachain or interchain hydrogen-bonds is called as secondary structure of a protein. 1 2 3 4 5 6 N terminal end Ala Gly Lys Asp Glu Val C terminalend

NSOU ● CC-ZO- 08 ____ 29 Hydrogen bonding as the cause of secondary structure formation: (i) The secondary structure of a protein is formed due to formation of intrachain or interchain hydrogen bonds. (ii) Hydrogen bonds are weak electrostatic bonds formed by sharing of a H + ion between 2 electron donor groups lying at a distance of about 2.4 to 3.7 Å. Hydrogen bonds require only 4.5 Kcal of energy per mole to get disrupted. (iii) The secondary structure of a protein is formed by hydrogen bonds between the carbonyl (=CO) group of one peptide linkage and the amide (–NH) group of another peptide linkage (or between the =CO group of one peptide linkage and the OH or NH 2 group in the side-chain of an amino acid residue. 1.3.3.3 Different types of secondary structure : (a) ?????-helix : (i) This type of secondary structure is common in some fibrous proteins like - keratin of hair, wool, nail and skin. It is also found in some regions of some globular proteins like haemoglobin and myoglobin. (ii) The polypeptide chain forms a helix around a long axis. It is generally a right- handed helix (since the amino acids in body-proteins are L-stereoisomers only). Each complete turn of the helix has a pitch of 5.4 Å). Each turn contains about 3.6 amino acid residues and the angle of the helix is about 26 0). ?????-helix
30 ____ NSOU ● CC-ZO- 08 Triple-helix (iii) The helical shape of the chain is maintained by intra-chain H-bonds. (iv) H-bond runs between the NH group of one peptide bond in one turn of the coil and the =CO group of another peptide bond in the next turn of the coil. (v) The H-bonds lie parallel to the long axis of the helix. (vi) The side-chains of amino acid residues project outward from the helix. (vii) All peptide linkages are involved in H-bond formation. (b) Triple helix : (i) This type of secondary structure is found in case of the fibrous protein collagen which consists of 3 polypeptide chains. (ii) Each of the 3 polypeptide chains occurs as a left-handed helix around a long axis common to all the 3 chains. Thus, the 3 chains together form a triple helix. (iii) The triple helical organization is maintained by inter-chain H-bonds. (iv) H-bonds are established between the -NH and =CO groups of peptide linkages located on the different polypeptide chains. (v) The H-bonds lie perpendicularly with the long axis of the triple helix. (vi) The side-chains of amino acid residues project outward from the polypeptide chains. (vii) Unlike the a-helix, all peptide linkages are not involved in H-bond formation.
NSOU ● CC-ZO- 08 ____ 31 (c) ?????-pleated sheet: (i) This type of secondary structure is found in certain fibrous proteins like - keratin of silk and spider's web, which consists of several polypeptide chains. (ii) The polypeptide chains occur in the form of zigzag chains lying side by side. Two adjacent chains may lie parallel to each other, i.e. their NH 2 -terminals lie at the same end and the COOH-terminals lie on the other end. Two adjacent chains may lie in anti-parallel manner also, i.e. the NH 2 - and COOH-terminals of 2 adjacent chains lie in the same side. (iii) The zigzag chains are held together by means of inter-chain H-bonds. (iv) H-bonds run between -NH and =CO groups of peptide linkages lying on adjacent chains. (v) The H-bonds lie perpendicular to the long axis of each chain. (vi) The side-chains of amino acid residues project either upward or downward from the individual chains. (vii) Like the alpha-helix and unlike the triple helix, all peptide linkages are involved in H-bond formation. ?????-pleated sheet
32 ____ NSOU ● CC-ZO- 08 Secondary Structure of Protein [Source : Wikimedia Commons (CC 4.0)] 1.3.3.4 Tertiary structure of proteins: In case of globular proteins, the polypeptide chains with the coiled secondary structures again become folded or twisted about themselves due to different types of intra-molecular bonds and forces. Such folding of the secondary structure itself is called tertiary structure of a protein. This is the highest order of structure of a monomeric protein (= a protein having a single polypeptide chain). The following intra-molecular forces and bonds are responsible for tertiary structure formation: (i) van der Walls forces: These are very weak attractive forces between atoms, resulting from fluctuations in the distributions of electrons. Such weak forces operating between the side-chains of neutral amino acids help in formation of tertiary structure. (ii) Hydrogen bonds: These are weak electrostatic bonds formed by sharing of a H + ion between 2 electron-donor groups. The formation of the tertiary structure of proteins may be helped by the formation of H-bonds between the CO group of the peptide linkage or the COOH group of the side-chains and the OH and NH 2 groups of the side-chains. (iii) Ionic bonds: These are strong electrostatic bonds between a +vely charged group and a -vely charged group of the side-chains of amino acids. (iv) Hydropbobic interaction: This is an attractive interaction between the non- polar side-chains of different amino acids. (v) Covalent disulphide linkage: Disulphide linkage (-S-S-) is a very strong covalent linkage which can be formed between 2 cysteine residues of a

NSOU ● CC-ZO- 08 ____ 33 polypeptide chain. It is formed by sharing of electron pairs between 2 sulphur atoms of 2 cysteine residues of a polypeptide chain. Tertiary structure of a globular protein 1.3.3.5 Quaternary structure : Many proteins are oligomeric or possess 2 or more identical or non-idendical poly peptide chains called as subunits. These chains remain held together by non- covalent bonds. This assembly is called as quaternary structure of proteins, e.g. Haemoglobin is a tetrameric protein with two ? and two ? chains. These chains or subunits remain held together by mainly H-bonds and some ionic bonds between side-chains of polar amino acids of the different polypeptide chains. Besides, SH (Sulphydril) groups of cysteine residues of different polypeptide chains may be linked by disulphide (-S-S-) linkage. Primary to Quaternary Protein Structure Formation [Source : Wikimedia Commons]

34 ____ NSOU ● CC-ZO- 08 1.3.4 Some important properties of proteins: 1.3.4.1 Biuret test for proteins: Biuret test is a colour reaction to detect any compound which bears at least two peptide linkages (-CONH) in its molecule. Hence, proteins, peptones and peptides give a positive response to this test. When an alkaline solution of protein, peptone or peptide is added with very dilute copper sulphate solution, a violet or pinkish colour develops due to formation of a complex between the cupric ion (Cu ++), peptide nitrogen and oxygen of water. The colour depends on the complexity of size of the reactant molecules, e.g. Proteins give a purplish violet colour. Peptones have a smaller size than proteins and give a pink colour. Peptides have a further smaller size and give a light pink colour. It may be added here that 'Biuret' which is formed by union of 2 molecules of urea on heating also gives a +ve response (pink colour formation) to biruet test, because 'Biuret' also contains two -CONH linkages in its molecule. 1.3.4.2 pH and protein structure and function : At a particular pH, called as the isoelectric pH or pI, a protein exists as a 'zwitterion' or carries equal numbers of +vely and –vely charged groups. In other words, at its pI, a protein bears a net charge of '0'. Hence, at its pI, a protein remains least soluble and also, does not show any migration towards either the cathode or the anode in an electric field, e.g. pI of egg albumin is 4.6 and pI of haemoglobin is 6.8. On the acidic side of the pI, a protein accepts H + ions from the medium and converts into a cation. On the alkaline side of the pI, a protein donates H + ions to the medium and converts into an anion. In this way, a significant change of pH of the medium may influence the ionic status of proteins, which in turn may influence the solubility of proteins. Moreover, the 3-dimensional structure and activity of proteins may be affected by changes of pH, as the intra- and inter-chain bond formation may be affected by changes of pH.

NSOU ● CC-ZO- 08 ____ 35 Effect of pH change on proteins 1.3.4.3 Salting in: The solubility of several proteins like globulins increases in presence of traces of electrolyte ions. In a dilute solution of a mineral salt, one particular type of electrolyte ion is adsorbed on the protein particles, in preference to the other type of ion from that electrolyte or salt. This increases the like-charges on the protein particles, which then repel one another and remain dispersed in the aqueous medium. However, a concentrated mineral salt solution giving a higher concentration of its ions may precipitate a protein from its solution. 1.3.4.4 Salting out : Concentrated solutions of neutral mineral salts such as (NH 4) 2 SO 4 , MgSO 4 and Na 2 SO 4 can precipitate a protein from its solution. This 'salting out' of protein requires a higher concentration of the mineral slat than what is needed for 'salting in'. Firstly, the higher concentration of mineral ions osmotically removes water from the solvation layer around protein particles. Secondly, at high concentrations, both cations and anions from the mineral salt bind with the respective counter-ionic groups on the protein particles to reduce the surface charges of the latter. Both these phenomena enhance the aggregation and precipitation of protein particles. Salting out is most effective near the isoelectric pH of the relevant protein. (Moreover, if a protein solution containing a low concentration of mineral salt is frozen, the protein is salted out from it, because the formation of ice crystals raises the concentration of the mineral ions in the remaining solution and thus precipitates the protein). 1.3.5 Physiological importance of proteins : (a) Proteins are major structural components of cellular membranes, organelles, cytoskeletal structures, extracellular matrix and connective tissue fibres. (b) Some structural proteins such as actin and myosin are contractile proteins; they cause contractions of muscle fibres. (c) Some cytoplasmic or membrane proteins function as molecular receptors. They bind with specific molecules, reaching or entering the cell, so as to mediate in the cellular actions of those molecules.

36 ____ NSOU ● CC-ZO- 08 (d) Some proteins like histones and protamines combine with DNA and RNA to form nucleoproteins of respectively chromosomes and ribosomes. (e) Carrier proteins bind with specific substances and transport them either across the membranes or in the body fluids, e.g. 'Sodium pump for transmembrane Na+ transport, and transferring for transporting Fe 3+ in plasma. (f) Specific proteins may bind with and store specific substances in the cell or in the extracellular fluid, e.g. Ferritin stores iron in spleen and liver cells. (g) Most enzymes are proteins. Enzymes catalyze various reactions in the body of living beings. (h) Immunoglobulins and complements are plasma proteins which help in body immunity. (i) Some proteins are constituents of respiratory pigments like haemoglobin, myoglobin and cytochromes. (f) When necessary, proteins may be catabolized to produce energy. (k) Proteins influence and control the osmotic pressure of body fluids. (l) Proteins influence and maintain ionic and fluid distributions on two sides of membranes. (m) Some of the hormones are either peptides (e.g. hypothalamic and gastrointestinal hormones) or proteins (e.g. pituitary, pancreatic and parathyroid hormones). 1.4 Lipids 1.4.1 Introduction to lipids Lipids are esters of aliphatic mono-carboxylic organic acids called fatty acids with different alcohols. They are non-polar organic compounds which are insoluble in water, but soluble in non-poalar organic solvents like chloroform and benzene. They are compounds of mainly C, H and O, but may also contain P, N and S. The ratio of H and O in lipids is quite greater than 2 : 1, which is found in water and many carbohydrates. Lipids may serve as energy in living beings; lipids are structural components of cellular membranes; lipids may also serve different physiological functions. 1.4.2 Classification of lipids Lipids are classified into 3 broad categories: 1. Simple lipids: These are esters of fatty acids with different alcohols and do not contain any other substances. Simple lipids are divisible into 2 types:

NSOU ● CC-ZO- 08 ____ 37 (A) Glycerides or acylglycerols: (i) These are esters of fatty acids with a trihydroxy alcohol called glycerol. Schematic Representation of Tri-glyceride Structure [Source: Wikimedia Commons (CC 3.0)] (iii) Triglycerides are again divisible into simple and mixed triglycerides depending on whether the three OH-groups of the glycerol moiety are esterified with only one type of fatty acid or more than one type of fatty acid, respectively. Glycerol (ii) Glycerides are further divisible into mono-, di- and triglycerides (or mono, di- and triacylglycerols), depending on whether they contain 1, 2 or 3 fatty acid residues, respectively. Simple (left) and mixed (right) triglycerides (iv) Triglycerides are commonly called as fats; fats remaining solid at room temperature are called solid fats (e.g. Lard and butter of animal origin and 'Vanaspati' of plant origin) and fats remaining liquid at room temperature are called oils (e.g. Mustard oil, Soya bean oil etc. plant oils and Cod liver oil of Cod fish).

38 ____ NSOU ● CC-ZO- 08 Solid fats are triglycerides containing saturated fatty acids while oils are triglycerides containing unsaturated fatty acids whose melting points are lower than those of saturated fatty acids due to the presence of double-bonds in their carbon-chains. (B) Waxes : (i) Waxes are solid esters of long-chain fatty acids (C 16 -C 34) with long-chain monohydroxy alcohols (C 16 -C 34). (ii) Waxes in which the alcohol is an aliphatic alcohol are called aliphatic waxes, e.g. Bee-wax is an ester of palmitic acid (C 15 H 31 COOH) with myricyl alcohol (C 30 H 61 OH) or bee-wax is myricyl palmitate (C 15 H 31 COOC 30 H 61). (iii) Waxes in which the alcohol is an alicyclic alcohol are called alicyclic waxes, e.g. Lanolin secreted by the skin of sheep is an ester of fatty acids with alicyclic alcohol commonly called as 'sterol'. 2. Compound lipids: These are also esters of fatty acids with different alcohols, but their molecules contain additional substances like phosphate, nitrogenous base, carbohydrate, protein etc. They are of 3 types: (A) Phospholipids: These are not only esters of fatty acids with alcohols, but also contain a phosphate and a nitrogenous or non-nitrogenous molecule. Phospholipids may be divided into 2 types: (a) Phosphoglycerides: Phospholipids in which the alcohol part is the trihydroxy alcohol glycerol are called phosphoglycerides. Phospglycerides are of different types: (i) Cephalin or phosphatidylethanolamine : Here, the ?-OH of glycerol is esterified with a phosphoric acid which in turn remains bound with a nitrogenous base called ethanolamine; the ?-OH of glycerol is esterified with an unsaturated fatty acid; the ? ? -OH of glycerol is esterified with a saturated fatty acid. Cephalin is found in brain and liver. [Remember, ? = C 3, ? = C 2, ? ?? ?= C 1]. Cephalin [NH 2 CH 2 CH 2 OH = Ethanolamine] (ii) Lecithin or phosphatidylcholine: Its structure is comparable with that of cephalin, but it contains a nitrogenous base called choline instead of ethanolamine. Lecithin occurs in brain, liver and cardiac muscle.

NSOU ● CC-ZO- 08 ____ 39 Lecithin (Choline = trimethylethanolamine with N +) (iii) Lipoamino acids: Their structure is comparable with that lecithin, but they contain a hydroxy amino acid like serine or threonine in place of the nitrogenous base choline. Accordingly, they are called as phosphatidylserine or phosphatidylthreonine. Lipo-amino acids occur in brain and RBC. Phosphatidylserine (iv) Plasmalogens: Here, the a-OH of glycerol is esterified with a phosphoric acid which in turn remains bound with either choline or ethanolamine; the b-OH of glycerol is esterified with an unsaturated fatty acid; the a / -C of glycerol is linked by an ether linkage with an unsaturated alcohol. Plasmalogens occur in brain, RBC and cardiac muscles. (v) Nitrogen-free phosphoglycerides: Their structure is comparable to that of lecithin, but they contain a non-nitrogenous substance like either an inositol (a vitamin) or a glycerol or a phosphatidic acid in the place of choline. They are named as phospha tidylinositol, phosphatidylglycerol and cardiolipin, respectively. These phospholipids are found in brain, cardiac muscle and liver. [Phosphatidic acid = 1 glycerol + 2 fatty acids + 1 H 3 PO 4]. (b) Sphingomyelins: Phospholipids in which the alcohol part is a monoamino, dihydroxy, unsaturated, C 18 alcohol sphingosine are called as sphingomyelins. The NH 2 -group of sphingosine remains combined with a fatty acid while the CH 2 OH part of sphingosine remains esterified with a phosphoric acid which in turn remains is linked with a choline. Sphingomyelins occur in brain, cardiac muscle and liver. 40 ____ NSOU ● CC-ZO- 08 (B) Glycolipids: They are not only esters of fatty acids with the nitrogenous alcohol sphingosine, but also contain a carbohydrate moiety. They are of different types : (a) Carebrosides: Here, the NH 2 -group of sphingosine remains combined with a fatty acid while the CH 2 OH part of sphingosine remains linked with a galactose or glucose. Accordingly, they are called as galactocerebrosides and glucocerebrosides, respectively and they occur in nervous and non-nervous tissues, respectively. (b) Sulfatides: Here, the NH 2 -group of sphingosine remains combined with a fatty acid while the CH 2 OH part of sphingosine remains linked with a galactose which in turn is sulphated. Sulfatides occur in liver, kidney and salivary glands. (c) Gangliosides: Here, the NH 2 group of sphingosine remains combined with a fatty acid and the CH 2 OH part of sphingosine remains linked with an oligosaccharide chain containing hexose, acetylhexosamine and sialic acid. Gangliosides occur in the membranes of neurons and RBC. (C) Lipoproteins : These are lipid-protein complexes that assume the shape of small to large rounded particles. Lipids found in lipoprotein particles include triglycerides, phospholipids, cholesterol and free fatty acids. Lipoprotein particles of various size and density occur in blood plasma and help in transport of fats, fatty acids, cholesterol between the liver and the extrahepatic tissues. 3. Derived lipids: Substances derived from simple or compound lipids by their hydrolysis are called as derived lipids. Derived lipids are as follows:
NSOU ● CC-ZO- 08 ____ 41 (A) Fatty acids : Fatty acids are aliphatic mono-carboxylic organic acids that occur in lipid molecules of animal or plant body. Fatty acids are classified as follows: (a) Straight-chain fatty acids : In these fatty acids, carbon atoms are arranged linearly. These fatty acids are divided into 2 types: (i) Saturated fatty acids : They have no double-bond between the constituent carbon atoms. All valencies of their carbons, except the carboxyl-C, are saturated with hydrogens. They have a general fomula of CnH (2n+1) COOH and a structure of CH 3 (CH 2) x COOH. They are again subdivided into 2 groups: Even-C fatty acids: Saturated fatty acids with an even number of carbons are very common in animal lipids. Even-C fatty acids with 10 or fewer carbons are called as lower fatty acids. E.g. Butyric acid [C 4 : C 3 H 7 COOH or CH 3 (CH 2) 2 COOH]. Even-C fatty acids with more than 10 carbons are called as higher fatty acids. E.g. Palmitic acid [C 16 : C 15 H 31 COOH or CH 3 (CH 2) 14 COOH] and Stearicacid [C 18 : C 17 H 35 COOH or CH 3 (CH 2) 16 COOH]. Odd-C fatty acids: Saturated fatty acids with an odd number of carbons are more common in plant lipids than in animal lipids. E.g. Valeric acid [C 5 : C 4 H 9 COOH or CH 3 (CH 2) 3 COOH]. (ii) Unsaturated fatty acids: Straight-chain fatty acids containing double-bonds in the carbon-chain are unsaturated fatty acids. They are generally even-C fatty acids. They are subdivided into: Monoenoic fatty acids: They have a single double-bond in the carbon-chain. E.g. Oleic acid found (C 17 H 33 COOH) in both animal and plant lipids is a D 9 -cis- monoenoic fatty acid, i.e. it has a double-bond after C 9 and the double-bond is in cis-configuration. Oleic acid (D 9 -cis-monoenoic) Polyenoic fatty acids: Fatty acids with more than one double-bond in the carbon-chain are called polyenoic fatty acids or polyunsaturated fatty acids (PUFA). E.g. Linoleic acid (C 17 H 31 COOH) of Saffola and Soya bean oils is a D 9, 12 -cis- dienoic acid having two double-bonds in cis-configuration after C 9 and C 12 , respectively. Arachidonic acid (C 19 H 31 COOH) of Peanut and Groundnut oils is a D 5, 8, 11, 14 -cis-tetraenoic acid with four double-bonds in cis-configuration after C 5 , C 8 , C 11 and C 14 , respectively.

42 ____ NSOU ● CC-ZO- 08 Arachidonic acid (D 5, 8, 11, 14 -cis-tetraenoic) (b) Branched-chain fatty acids: Some fatty acids have a branched carbon- chain; these are not found in fats but may be present in waxes. Examples of such fatty acids are Isobutyric acid and Isovaleric acid. (d) Cyclic fatty acids: These are fatty acids with cyclic ring in their carbon- chain, e.g. Prostaglandins found in different animal tissues are polyunsaturated fatty acids with a cyclopentane ring. (B) Aliphatic alcohols : The aliphatic alcohol, Glycerol is derived from hydrolysis of glycerides and phosphoglycerides. Another aliphatic alcohol, sphingosine is derived from hydrolysis of sphingomyelins and glycolipids. Some others like myricyl alcohol and cetyl alcohol are derived from hydrolysis of aliphatic waxes. Palmitic Acid – Straight Chain Fatty Acid 13-methyltetradecanoic acid (iso-pentadecanoic acid) – Branched Chain Fatty Acid Palmitoic Acid – Unsaturated Fatty Acid [Source: Wikimedia Commons] (c) Substitued fatty acids: These are saturated or unsaturated fatty acids in which one or more H-atoms of the hydrocarbon chain are replaced by hydroxyl (OH) or methyl (CH 3) or halide groups, e.g. 3-Methylbutyric acid found in brain.

NSOU ● CC-ZO- 08 ____ 43 (C) Steroids and sterols: Steroids and sterols are present in association with fat within animal body and can be separated as an 'unsaponifiable residue' after saponification of fat. Moreover, sterols may be derived from hydrolysis or some waxes. All steroids contain a characteristic 17-carbon, fused, tetracyclic ring-system designated as 'cyclopentanoperhydrophenanthrene nucleus'. Cyclopentanoperhydrophenanthrene nucleus The first three rings of this nucleus are cyclohexanes or 6-carbon rings and called as A, B and C, respectively while the 4 th ring called as D is a cyclopentane or 5- carbon ring. Fusion of A, B, C and D produces a 17-carbon ring system or nucleus. Besides, 2 methyl (CH 3) groups remain attached with C 13 and C 10 of the nucleus and those methyl carbons are designated as C 18 and C 19 , respectively. Moreover, other groups may remain attached with different carbons of the nucleus in different steroids. Basic structure of a steroid Those steroids which not only carry CH 3 -groups at C 13 and C 10 of the cyclopentanoperhydrophenanthrene nucleus, but also carry a hydroxyl (OH) group at C 3 and a 8-10 carbon-long side-chain at C 17 , but no carboxyl or ketonyl oxygen at any carbon, are called sterols,e.g. Cholesterol and lanosterol are two important sterols of animal body. Cholesterol is the precursor of gonadal and adrenocortical steroid hormones; cholesterol carries a 3'-OH, a 8-carbon side-chain at C 17 and a double-bond between C 5 and C 6 .

44 ____ NSOU ● CC-ZO- 08 Cholesterol 1.4.3 Properties of fats : 1. Melting point: Fats containing saturated fatty acids have high melting point and remain solid at room temperature (e.g. Lard and butter) while fats containing unsaturated fatty acids have low melting point and remain liquid at room temperature (e.g. Mustard oil, soya bean oil). The former are called solid fats and the latter are called oils. The low melting point of oils is due to their possession of unsaturated fatty acids having cis double-bonds in the carbon-chain; the cis double-bonds prevent the close-packing of the carbon-chains and also reduce the hydrophobic interaction in between those chains. 2. Hydrogenation: When oils, i.e. fats with unsaturated fatty acids are exposed to hydrogen at 155 o -220 o C in presence of nickel or platinum catalyst, hydrogen is added to the double-bonds in the unsaturated fatty acid residues. One atom of hydrogen is added to each side of a double-bond. As a result, the oil gets reduced into a solid, saturated fat,e.g. Cottonseed oil is changed into margarine and sunflower oil is changed into 'Vanaspati' or 'Dalda' by means of hydrogenation: Hydrogenation of oil 3. Rancidity: An unpleasant odour and taste is often developed by fats left out for a long period in contact with air and light. This is called rancidity of fats. It is due to two causes: (a) Hydrolytic action of lipases from contaminating microbes, resulting in release of glycerol and free fatty acids with characteristic odour; this is called 'hydrolytic rancidification'. (b) Oxidation of unsaturated fatty acids at their double-bonds by atmospheric oxygen, resulting in formation of peroxides which then decompose to form aldehydes with unpleasant odour and taste; this is called 'oxidative rancidification'.

NSOU ● CC-ZO- 08 ____ 45 4. Hydrolysis: Fats get hydrolysed into glycerol and constituent fatty acids, when acted upon by the enzyme lipase or when boiled with acidified water under high temperature and pressure. 5. Saponification and saponification number: (i) When boiled with a solution of strong metallic alkali like KOH or NaOH, fats quickly decompose into glycerol and fatty acids. The released fatty acids soon react with the alkali to form metallic salts and water. Those metallic salts of fatty acids are called 'soaps' and the overall process of soap formation is called 'saponification', e.g. If a triglyceride containing glycerol and palmitic acid is boiled with KOH, a soap called 'potassium palmitate' and glycerol are produced. The reaction is facilitated upon addition of an alcohol to the mixture of fat and alkali, as fats are quickly dissolved in alcohol. Saponification of fat (ii) In addition to fats, the waxes, phospholipids and glycolipids can also undergo saponification upon boiling with an alkali. However, in these instances, the alcohol being produced is often different from glycerol. All these lipids are called saponifiable lipids. On the other hand, Steroids and sterols are unsaponifiable lipids. (iii) The number of milligrams of KOH required to saponify 1 g of a fat is called as the 'saponification number' of that fat, e.g. Saponification number of butter is 210-230 and that of castor oil is 175-180. (iv) Significance of saponification number: (a) The higher is the saponification number of a fat, the lower are the chain-length and molecular weight of the fatty acids in that fat and also, the lower is the molecular weight of the fat itself, e.g. Butter is rich in shorter fatty acids and has a lower molecular weight while castor oil is rich in longer fatty acids and has a higher molecular weight. (b) Since 3 molecules of KOH (MW = 56000 mg) are required to saponify 3 fatty acid residues of a triglyceride, saponification number = 3 56000 × M mg of KOH (M = average molecular weight of the triglyceride) or M = 168000 saponification number .
46 ____ NSOU ● CC-ZO- 08 6. Iodination and iodine number: (i) When fats with unsaturated fatty acids are treated with halides like IBr (iodine bromide) or ICI (iodine chloride), iodine is added to the double-bonds of the unsaturated fatty acid residues of a fat molecule. One atom of iodine is added to each side of a double-bond resulting in the formation of a saturated halogenated fat. Iodination of fat (ii) The number of grams of iodine absorbed by 100 g of a fat is called as the iodine number of that fat, e.g. Iodine number of coconut oil is 6-10 and butter is 25-28 but that of saffola oil is as high as 140-155. (iii) Significance of iodine number : A high iodine number of a fat indicates that the fat is rich in unsaturated fatty acids. In other words, iodine number is an index of the degree of unsaturation of fat, e.g. Saffola oil has a much higher degree of unsaturation than coconut oil and butter. 7. Reichert-Meissl number: Reichert-Meissl number or Volatile fatty acid number is a measure of the amount of steam-volatile, lower fatty acids (C 2 -C 10) present in a fat. A fat sample is first saponified and then treated with a mineral acid to liberate free fatty acids from the soaps. Thereafter, steam is passed through this mixture to let the lower fatty acids get volatilized and carried away with the steam to condense in a receptacle. The number of milliliters of N/10 KOH required to neutralize the volatile fatty acids liberated from 5 g of a fat is called as Reichert- Meissl number of that fat,e.g. Reichert-Meissl number of butter is 26-33, but that of olive oil is only 0.5-1.5, indicating that butter contains a much larger amount of volatile fatty acids than olive oil. 1.4.4 Physiological importance of lipids: (i) Fats stored in adipose tissues may act as a source of energy whenever required by the body. (ii) Fats deposited under the skin and around the vital organs act as thermo- insulator and shock-absorbing cushion. (iii) Phospholipids, glycolipids, lipoproteins and sterols form different cellular structures like plasma membrane, nuclear membrane, organelle membranes and myelin sheath.

NSOU ● CC-ZO- 08 ____ 47 (iv) Lipoprotein particles of blood plasma help in transport of fats, fatty acids, cholesterol and other non-polar substances between the liver and the extrahepatic tissues. (v) Sterols are used in the biosynthesis of steroid hormones and vitamin D. (vi) Phospholipids help in intestinal absorption of fat-soluble vitamins and excretion of cholesterol in bile. (vii) Prostaglandins, which are modified fatty acids, act as local hormones that influence the functioning of different tissues or organs of the body (contraction and relaxation of smooth muscle, the dilation and constriction of blood vessels, control of blood pressure). 1.5 Nucleic Acids 1.5.1 Introduction to nucleic acids Nucleic acids are non-protein, nitrogenous, acidic substances in living cells. These are polymers of numerous small units or monomers called as nucleotides. There are two kinds of nucleic acids: DNA or deoxyribonucleic acid and RNA or ribonucleic acid. DNA molecules transmit all the hereditary characters of an organism from one generation to another while RNA molecules carry out protein synthesis in living cells. DNA or deoxyribonucleic acid occurs in chromosomes and mitochondria of all eukaryotic cells, chloroplasts of plant cells, bacterial chromosome and plasmids. Moreover, DNA is found in the genetic material of DNA viruses. The second type of nucleic acids includes the RNAs or ribonucleic acids which occur in both nucleus and cytoplasm of all eukaryotic cells. In prokaryotes, RNAs are associated with DNA of chromosome and also, in the cytoplasm. Moreover, RNA occurs in the genetic material of RNA viruses. 1.5.2 Watson and Crick's model of DNA structure A DNA molecule has a double-helical structure and the double-helix model of DNA structure was proposed by James Watson and Francis Crick in 1953; the model was proposed on the basis of X-ray diffraction studies. The basic postulates of the model are as follows: 1. A DNA molecule consists of two long strands called polynucleotide strands. The two strands remain helically coiled around each other. 2. Each polynucleotide strand is a polymer of numerous small units called nucleotides. Each nucleotide is made up of a nucleoside and a phosphoric acid residue; thus, each nucleotide is a nucleoside phosphate. Again, a 48 ____ NSOU ● CC-ZO- 08 nucleoside consists of a nitrogenous base and a pentose sugar called deoxyribose which lacks oxygen at its C 2 . Since the pentose sugar in DNA is deoxyribose, the nucleosides of DNA are more precisely called as deoxyribonucleosides and the nucleotides of DNA are more precisely called as deoxyribonucleotides. 3. The two polynucleotide strands bear two kinds of nitrogenous bases: purines and pyrimidines. Purines possess a purine ring with different substituent groups while pyrimidines possess a pyrimidine ring with different substituent groups. DNA contains two types of purines, viz. adenine and guanine (commonly abbreviated as A and G), and two types of pyrimidines, viz. cytosine and thymine (commonly abbreviated as C and T). Accordingly, the deoxyribonucleosides containing purines (A and G) are called deoxy- adenosine and deoxyguanosine, respectively while the deoxyribo-nucleosides containing pyrimidines (C and T) are called deoxycytidine and deoxy- thymidine, respectively. Moreover, the deoxyribonu cleotides containing purines (A and G) are called deoxyadenosine monophosphate (dAMP) or deoxyadenylic acid and deoxyguanosine monophosphate (dGMP) or deoxyguanylic acid, respectively while the deoxyribonucleotides containing pyrimidines (C and T) are called deoxycytidine monophosphate (dCMP) or deoxycytidylic acid and deoxythymidine monophosphate (dTMP) or deoxyt hymidylic acid, respectively 4. The deoxyribonucleotides of each polynucleotide strand are connected to each other by covalent 3′,5′-phosphodiester bond in between the 3′-OH of the deoxyribose of one deoxyribonucleotide and the 5′-OH of the deoxyribose of the next deoxyribonucleotide. Consequently, the two poly- nucleotide strands lie anti-parallel to each other: in one strand, the 3′-OH of the terminal deoxyribonucleotide remains free and at the same end, the other polynucleotide strand has a free 5′-OH of the terminal deoxyribonucleotide. 5. It can be added here that a deoxyribose sugar remains covalently linked by a glycosidic bond with a nitrogenous base within each nucleoside. In case of a purine nucleoside, the glycosidic bond runs in between the N 9 of a purine base (A or G) and the anomeric OH group on C 1 of deoxyribose. In case of a pyrimidine nucleoside, the glycosidic bond runs in between the N 1 of a pyrimidine base (C or T) and the anomeric OH group on C 1 of deoxyribose. 6. Further, the two polynucleotide strands are not free from each other, but instead, remain connected with each other by means of hydrogen bonds that run in between the nitrogenous bases of the opposite polynucleotide strands. The base pairing occurs in a complimentary and very specific manner: two

NSOU ● CC-ZO- 08 ____ 49 hydrogen bonds lie in between A and T of the opposite strands and three hydrogen bonds lie in between G and C of the opposite strands. Consequently, the sum of A and G residues in a double-helical DNA molecule equals the sum of T and C residues, or (A + G) : (T + C) = 1 : 1. This is called as Chargaff's rule. Triple hydrogen bonding between complementary nucleotides Guanine and Cytosine [Source: Wikimedia Commons] 1.5.3 Types of DNA : In course of time, different forms of DNA have been discovered. The most commonly described forms are B-DNA, Z-DNA and A-DNA. Their characteristics are as follows: Feature B-DNA Z-DNA A-DNA B-DNA was vividly described by James Watson and Francis Crick in 1953. It is the prevalent type of DNA found in all living cells. The two strands of B-DNA form right- handed helix around each other. Z-DNA was discovered by Andrew Wang and Alexander Rich in 1979. It is found in all living cells, but in a much less quantity, as compared to B- DNA. The two strands of Z- DNA form left- handed helix around each other. A-DNA was discovered by Rosalind Franklin in 1953. It is derived from B-DNA under d e h y d r a t i n g conditions. In nature, it is found in bacterial spores. The two strands of A-DNA form right- handed helix around each other. Occurrence Helix nature

50 ____ NSOU ● CC-ZO- 08 Sketch diagram of B-DNA double-helix Simple DNA double-helix structure (Source: Wikimedia Commons) Diameter of DNA double helix is 20 Angstrom units. The length of each turn of DNA double-helix is 34 Angstrom units. 10 3.4 Angstrom units. Diameter Pitch Base-pairs per turn Length of nucleotide Diameter of DNA double helix is 26 Angstrom units. The length of each turn of DNA double- helix is 28.6 Angstrom units. 11 2.6 Angstrom units. Diameter of DNA double helix is 18 Angstrom units. The length of each turn of DNA double-helix is 45 Angstrom units. 12 3.75 Angstrom units.

NSOU ● CC-ZO- 08 ____ 51 1.5.4 Function of DNA : Functionally, DNA carries the genetic information (= information for carrying out protein synthesis) of a cell. The genetic information is engraved within the base sequence in the polynucleotide strands of DNA. The genetic information passes from DNA to messenger RNA (mRNA) when the latter is synthesized from the DNA strands by complementary base-pairing. Thereafter, mRNA participates in the synthesis of a particular type of protein. Moreover, DNA serves as the hereditary material of cells, i.e. DNA transmits genetic information from one generation of a cell to the next. In fact, DNA is a self- duplicating molecule or a DNA produces two identical copies of itself before cell Detailed Structure of DNA with its structural components [Source : Wikimedia Commons (CC 4.0)]

52 ____ NSOU ● CC-ZO- 08 division. During duplication of DNA, the two strands of a DNA separate from each other and along each of the two separated strands a new strand is synthesized by complementary base-pairing. In this way, from one parental DNA molecule are produced two daughter DNA molecules which are structurally identical to each other as well as with the parental DNA molecule. In other words, identical genetic information is transmitted from one parental DNA molecules to the two daughter DNA molecules. 1.5.5 RNA – structure and function: The second type of nucleic acids includes the RNAs or ribonucleic acids which occur in both nucleus and cytoplasm of all eukaryotic cells. In nucleus, RNA molecules remain associated with DNA of chromosomes and also, in the nucleolus. In prokaryotes, RNAs are associated with DNA of chromosome and also, in the cytoplasm. Moreover, RNA occurs in the genetic material of RNA viruses. While DNA is double-stranded RNAs are made up of single polynucleotide strands. In DNA, the pentose sugar is deoxyribose but that in RNA is ribose. Besides, the pyrimidine bases in DNA are cytosine and thymine while those in RNA are cytosine and uracil. Purines are similar in both DNA and RNA. However, it may be added here that certain parts of two types of RNA molecules (viz. tRNA and rRNA) are double-stranded due to complementary base pairing in between A and U in one hand and G and C on the other. RNAs are divisible into three main types: ribosomal RNA or rRNA, messenger RNA or mRNA and transfer RNA or tRNA. About 60-80% of cellular RNAs are rRNA. These RNA molecules remain associated with proteins, forming small cytoplasmic particles called ribosomes which act as the site of protein synthesis inside cells. About 10-20% of cellular RNAs are tRNA. These RNA molecules bind amino acids and carry them to the site of protein synthesis (ribosomes) during protein synthesis. Another 10-20% of cellular RNAs include the mRNA. These RNA molecules accept the message necessary for the cellular synthesis of different protein from DNA and then bind to the ribosomes so that the tRNA molecules can bring the appropriate amino acids for protein synthesis to the ribosomes. Comparison between general structure of DNA and RNA

NSOU ● CC-ZO- 08 ____ 53 [(Source: Wikimedia Commons (CC 4.0)] 1.6 Questions (with hints to answers) 1. Classify monosaccharides (see Section 1.2.2). 2. What are polysaccharides? Classify polysaccharides (see Section 1.2.2). 3. Distinguish between a triose and a trisaccharide (see Section 1.2.3.2). 4. Distiguish between starch and glycogen (see Section 1.2.3.4). 5. Give an account of D- and L-isomerism in sugars (see Section 1.2.4.1). 6. Give an account of optical isomerism in sugars (see Section 1.2.4.2). 7. Explain the phenomenon of mutarotation shown by glucose (see Section 1.2.5).
54 ____ NSOU ● CC-ZO- 08 8. What are reducing sugars and reduction tests? Lactose and maltose are reducing sugars but sucrose is not – explain (see Section 1.2.3.4). 9. What do you mean by osazone test? (see Section 1.2.6.3.). 10. State the physiological importance of carbohydrates (see Section 1.2.7). 11. Classify simple proteins (see Section 1.3.2). 12. Classify conjugated proteins (see Section 1.3.2). 13. Describe á-helix and triple helix types of protein structure (see Section 1.3.3.3). 14. What do you mean by â-pleated sheet of protein structure? (see Section 1.3.3.3). 15. What is biuet test? (see Section 1.3.4.1). 16. What is isoelectric pH of proteins? How does change of pH influence the ionic status of proteins? (see Section 1.3.4.2). 17. What do you mean by salting in and salting out of proteins? (see Sections 1..3.4.3 and 1.3.4.4). 18. Classify phosphoglycerides (see Section 1.4.2). 19. Write notes on lecithin and cephalin (see Section 1.4.2). 20. Define and classify fatty acids (see Section 1.4.2). 21. Write notes on saponification number and Reichert-Meissl number of fat(see Section 1.4.3). 22. Distinguish between fat and oil. Add a note on hydrogenation of fat (see Section 1.4.3). 23. State the physiological importance of lipids (see Section 1.4.4) 24. Describe Watson and Crick's model of DNA structure(see Section 1.5.2). 25. Tabulate the salient features of B-DNA, Z-DNA and A-DNA (see Section 1.5.3). 26. Write a note on structure and function of RNA(see Section 1.5.5). 1.7 References 1. Biochemistry – A. H. Lehninger (1975), Worth Publishers, New York. 2. Biochemistry – Debajyoti Das (2005), Academic Publishers, Kolkata. 3. Harper's Illustrated Biochemistry – V. W. Rodwell, D. A. Bender and K. M. Botham (2018), Lange, New York. 4. Outlines of Biochemistry – E. E. Conn and P. K. Stumpf (1972), John Wiley, New York.
NSOU ● CC-ZO- 08 ____ 55 5. Principles of Biochemistry – D. L. Nelson and M. M. Cox (2005), Freeman & Co., New York. 6. Textbook of Biochemistry – E. S. West and W. R. Todd (1966), Macmillan, New York.
56 ____ NSOU ● CC-ZO- 08 Unit-2 Bioenergetics Structure 2.0. Obectives 2.1. Introduction 2.2. First law of thermodynamics 2.2.1 Basic postulate of the law 2.2.2 Mathematical presentation of the law 2.2.3 Enthalpy 2.2.4 Enthalpy change (DH) 2.2.5 Citation of a situation when DH = DE (or DW = 0) 2.2.6 Example of numerical problem 2.3. Second law of thermodynamics 2.3.1 Second law and its explanation 2.3.2 Entropy 2.4. Third law of thermodynamics 2.5. Relevance of laws of thermodynamics to biological systems 2.6. High-energy bonds and high-energy compounds 2.6.1 Definition of high-energy compounds 2.6.2 Examples of high-energy compounds 2.6.3 Energy transfer (utilization) from high-energy compounds in cells 2.6.4 Energy capture (storage) in high-energy compounds in cells 2.7. Questions 2.8. Reference 56
NSOU ● CC-ZO- 08 ____ 57 2.0 Objectives Upon going through this Unit II, one will be able to : ● Understand the meaning of thermodynamics. ● Understand the features of different types of systems. ● Understand the different laws of thermodynamics. ● Explain the meaning of enthalpy and enthalpy change. ● Understand the meaning and significance of entropy. ● Understand the role of high-energy compounds in living organisms. 2.1 Introduction Thermodynamics is the science that deals with (i) conservation of energy, (ii) convertibility of different forms of energy into heat energy and (iii) the relationship between energy content and properties of molecular systems. In thermodynamics, the term'system' is used to denote an assemblage of a vast number of one or more kinds of molecules and a specific amount of internal energy, separated from its surroundings by either a real and well-defined boundary or a reasonable imaginary boundary. The internal energy of any system is the sum of the kinetic energy of all its molecules. The internal energy changes with a change of the thermodynamic state of a system. Thermodynamic state of a system is a collective term that refers to the chemical constituents, pressure, volume and temperature of the system. Systems can be classified into 3 types : (a) Isolated system: An isolated system is such a system that is separated from its surrounding by a well-defined adiabatic (insulating) boundary across which neither matter nor energy can pass between the system and its surrounding. (b) Closed system: A closed system is such a system that is separated from its surrounding by a diathermal boundary across which only energy (e.g. heat or light) but no matter can pass between the system and its surrounding. (c) Open system: An open system is such a system that is separated from its surrounding by a real or imaginary boundary which allows exchange of both matter and energy between the system and its surrounding.

58 ____ NSOU ● CC-ZO- 08 Living beings represent an 'open, steady-state, non-equilibrium system'.A living being is an 'open system', because, exchange of matter (e.g. intake of food, water and O 2 ; discharge of faeces, urine and CO 2) and exchange of energy (e.g. gain and loss of heat) can occur between its body and its surroundings.A living being is an 'open, steady-state system', because it tries to maintain a balance between (i) matter and energy received from the surroundings and (ii) matter and energy lost to the surrounding. A living being is, however, a non-equilibrium system, because it tends to maintain an organized state or low-entropy state (less disorderliness) by acquiring as much energy as possible from the surrounding. In a living body, reversible chemical reactions seldom attain a stable equilibrium.In a living body, reversible chemical reactions seldom attain a stable equilibrium, because (i) the products are continuously removed by other reactions in vivo, with a constant fall in the rate of a backward reaction, (ii) the reactants are continuously added to maintain a steady forward reaction and (iii) reactions seldom occur under standard conditions inside the body of a living being. A spaceship together with an astronaut is an 'Isolated system', but the astronaut himself is not. A spaceship with an astronaut inside itself can be considered as an 'isolated system', because the spaceship is well-insulated against exchange of both matter and energy between the spaceship and the surrounding space (outside the spaceship). On the other hand, the astronaut himself should be considered as an 'open system', because considerable exchange of matter as well as energy can occur between his body and the space inside the spaceship. 2.2 First law of thermodynamics 2.2.1 Basic postulate of the law : The change in internal energy (DE) of a system equals the algebraic sum of (i) heat gained by the system from its surrounding and (ii) heat lost from the system to its surrounding and heat used by the system in doing a work. Thus, the law is virtually the law of conservation of energy – the total energy of a system and its surrounding remains unchanged. 2.2.2 Mathematical presentation of the law : The first law of thermodynamics can be represented by the equation : ?E = ?Q – ?W (?E = change in internal energy ; ?Q = heat absorbed by a system or released from the system; ?W = work done by a system or work done on a system). ?W is positive when a work is done by the system (e.g. expansion in volume) and ?W is negative, NSOU ● CC-ZO- 08 ____ 59 when a work is done on the system (e.g. contraction in volume). ?Q is positive when heat is absorbed by a system and it is negative when heat is released by the system. A positive value of ?E indicates a rise in internal energy and a negative value of ?E indicates a fall in internal energy of a system. 2.2.3 Enthalpy : It is the heat content (H) of a system and it amounts to the sum of its internal energy (E) and the product of its pressure and volume (P and V, respectively) : H = E + PV Any physical or chemical change of a system causes change of its enthalpy. Therefore, the enthalpy change (?H) calories or Joules per mole) is the change in the amount of energy of the system in the form of heat absorbed or heat released during a physical or chemical change of the system. 2.2.4 Enthalpy change (?H) : Enthalpy change may be expressed by the following equation: ?H = ?E + ?PV = ?E + ?W [because, PV= work done by a system (e.g. expansion in volume) or work done on a system (e.g. contraction in volume) during a physical or chemical change of the system)]. Now, the equation may be rewritten as ?H = ?Q (total amount of heat absorbed by a system or released from the system during a physical or chemical change), because the first law of thermodynamics tells us the DE = DQ – DW. Moreover, the value of DQ is positive, when heat is absorbed by the system and negative, when heat is released by the system and DW is positive, when a work is done by the system and DW is negative, when a work is done on the system. 2.2.5 Citation of a situation when ?????H = ?????E (or ?????W = 0) : We know, ?H = ?E + ?W. When ?W or work done by a system or done on a system is '0', we can say that ?H = ?E in such a situation, e.g. Metabolic reactions take place in a living body at an almost constant pressure and in aqueous solutions. These reactions involve negligible changes in P (Pressure) and V (Volume), or ?PV = 0 = W for such reactions. In other words, ?H = ?E + 0 = ?E (apparent heat absorbed or released) for metabolic reactions occurring in vivo. 2.2.6. Example of numerical problem : The latent heat of evaporation of water is 536 cal/g. Calculate DH in converting 1 mole of water at 100 o C into steam at the same temperature, assuming water to behave as an ideal gas :

60 ____ NSOU ● CC-ZO- 08 ?H or heat absorbed by 1 mole (18 g) of water = 536 × 18 cal/mole = 9648 cal/ mole. Now, the work done in converting 1 mole of water at 100 o C into steam (gas) at the same temperature = PV = RT = 2 × 373 = 746 cal. [because, R or molar gas constant = 2 and T or absolute temperature = (100+ 273) Kelvin; PV = RT (ideal gas equation)]. Now, ?H = ?E + ?PV, or 9648 cal = ?E + 746 cal. ? ?E = 9648 – 746 = 8902 cal. 2.3 Second law of thermodynamics 2.3.1 Second law and its explanation : The second law of thermodynamics states that each system, given the freedom, always changes spontaneously to increase the randomness or disorder in it; the magnitude of this disorder is called as'entropy'. In other words, the energy of a closed system has always a persistent tendency to get progressively diluted or randomized, thus tending constantly to enhance its entropy[entropy is that proportion of the total energy of a system which is unavailable for work]. Higher Entropy Lower Entropy Higher Disorder/ Higher Order/ More Randomness Less Randomness Conceptual representation of Entropy and System Order [Source: Wikimedia Commons] It appears from the second law of thermodynamics that if orderliness is created in any part of a system, a greater or equivalent degree of disorder must simultaneously
NSOU ● CC-ZO- 08 ____ 61 appear in another part of that system or in its surrounding so that the overall entropy either rises or at least remains undiminished. Further, the second law asserts that a process can take place spontaneously, only if the total entropy of a system and its surrounding increases during that process. As a system spontaneously attains equilibrium, its entropy reaches a maximum level for its existing state so that the system can change no further unless some energy (heat) is supplied to it from its surroundings. However, even when energy is supplied to a system, the total amount of the supplied energy fails to be changed to an equivalent amount of work.A part of the supplied energy remains unavailable to work and adds up to entropy. The second law, therefore, envisages the tendency for an increase in entropy as the driving force for all physicochemical changes in an isolated system. In essence, the following equation may be held to be true for a system at equilibrium at the absolute temperature T : 2.3.2 Entropy : Entropy (S) refers to the magnitude of randomness or disorder in a system and is expressed in either joules or calories per degree Kelvin per mole. Entropy increases with the increase in randomness or disorderliness in a system. Therefore, entropy can be held to represent that part of the total energy of the system which cannot be transformed into work and is instead, spent in creating disorder in the system. Entropy is a function of the state of a system, viz., its temperature, chemical constitution, pressure and volume. Whenever the state of a system gets altered, it suffers from an entropy change (?S). Entropy does not change instantly, but tends to increase progressively. So, a system left to itself changes spontaneously towards rising entropy, until its entropy reaches a maximum level or equilibrium for the existing state. After attaining equilibrium with maximum disorder, the system then stays as such, unless it absorbs some further energy from its surrounding. The stability of a system depends on its entropy.The lower its entropy, the greater is its tendency to change towards the maximum entropy and so. The higher is its tendency for spontaneous changes. It follows from the second law of thermodynamics that addition of energy or heat (DQ) raises the entropy of a system because a part of the supplied energy must go to enhance the disorder instead of being available for work. At equilibrium, Δ Δ Δ Δ Q T S S Q T = = ; , or
62 ____ NSOU ● CC-ZO- 08 But so long as the system has not attained equilibrium and is undergoing a thermodynamically irreversible process, the following condition prevails: T?S < ?Q Again, as ?Q equals the enthalpy change (?H) of the system, it can be rewritten that : T?S < ?Q, or, T?S < ?H; or, ?H = T?S – ?W Ordinarily, a reaction proceeds spontaneously towards the goal of maximum entropy. Only a supply of energy from the surroundings may drive the reaction in the opposite direction against entropy.Entropy is involved in the maintenance of the physiological steady state in biological organisms. Conceptual representation of the 2 nd Law of Thermodynamics 2.4 Third law of thermodynamics The third law of thermodynamics holds that the entropy of perfect crystals of a compound rises with the increase of temperature from a minimum or zero value at Kelvin scale, i.e. –273 o C [–273 o C= –273 o + 273 = 0 o Kelvin].

NSOU ● CC-ZO- 08 ____ 63 2.5 Relevance of law of thermodynamics to biological systems The laws of thermodynamics have considerable relevance to biological systems. From the first law of thermodynamics, we know, DH = DE+DW. When DW or work done by a system or done on a system is '0', we can say that DH = DE in such a situation.This situation is quite evident during metabolic reactions taking place in living organisms. Metabolic reactions take place in a living body at an almost constant pressure and in aqueous solutions. These reactions involve negligible changes in P (Pressure) and V (Volume), or ?PV = 0 = ?W for such reactions. In other words, ?H = ?E+0 = DE (apparent heat absorbed or released) for metabolic reactions occurring in vivo. Again, the oxidation of one mole (gram molecule) of glucose yields 686 kcal of energy but the oxidation of one mole of lactic acid yields 326 kcal of energy. Now, the enthalpy as well as oxidation pathways of glucose and lactic acid are different. Therefore, the difference of enthalpy between the two (glucose and lactic acid) when two molecules of lactic acid are produced from one molecule of glucose during glycolysis may be expressed as follows : ?H glycolysis = (?H glucose – ?H lactic acid) = (686 – 2 × 326) kcal = 686 – 652 kcal = 34 kcal. In fact, the oxidation of one mole of glucose practically yields only 34 kcal of energy which is utilized for production of high-energy ATP molecules from ADP and P i in cells. In this way, as per the first law of thermodynamics, it is found that ?H = ?E during glycolysis in cells. Again, the second law of thermodynamics indicates that a system tends to progressively increase its entropy or state of disorderliness. But, it is practically found that the cells or tissues in living organisms tend to maintain a steady though non-equilibrium state. How this contradictory situation is made possible? It becomes possible as because the living organisms tend to maintain a balance between (i) matter and energy received from the surroundings and (ii) matter and energy lost to the surrounding. 2.6 High-energy bonds and high-energy compounds 2.6.1 Definition of high-energy compounds: High-energy compounds aresuch compounds that possess one or more high- energy covalent bonds that yield 7 kcal of energy during hydrolysis of each mole of the compound.On the other hand, low-energy compounds possess only ordinary

64 ____ NSOU ● CC-ZO- 08 covalent bonds; an ordinary covalent bond yields 3.4 kcal of energy during hydrolysis of each mole of a low-energy compound. 2.6.2 Examples of high-energy compounds: High-energy compounds having high-energy bonds include: (i) Phosphoric anhydrides like some purine/pyrimidine nucleotides (e.g. ATP or Adenosine triphosphate, ADP or Adenosine diphosphate, GTP or Guanosine triphosphate, GDP or Guanosine diphosphate, CTP or Cytidine triphosphate and UTP or Uridine triphosphate).The tri- and di-phosphates of purine and pyrumidine nucleosides carry two and one high-energy phosphate bonds, respectively in their molecules. The 3rdor g and the 2nd orbphosphate bonds of a nucleoside triphosphate are high-energy bonds while the 2nd orbphosphate bondof a nucleoside diphosphate is high-energy bonds. In both of these tri- and diphosphates, the 1st or aphosphate bond connected directly to the ribose sugar is only a low-energy phosphate bond. Again, adenosine monophosphate (AMP) has a single low-energy aphosphate bond (?G o ' –3.4 kcal). Similarly, the lone a phosphate bond of GMP, CMP and UMP molecules is a low-energy phosphate bond. (ii) Enol phosphates like phosphoenolpyruvate. (iii) Acyl phosphates like 1, 3-bisphosphogiycerate. (iv) Phosphoguanidines like creatine phosphate. (v) Thiol esters like succinyl-CoA. (vi) Sulfonium compounds like S-adenosylmethionine. (vii) Cyclized nucleotides like cyclic AMP. The high negative ?G o ' values of those compounds result largely from: 2.6.3 Energy transfer (utilization) from high-energy compounds in cells : (a) ATP or Adenosine triphosphate: The high-energy bonds of ATP are hydrolyzed to provide energy for driving a large number of cellular processes. Hydrolysis of 1 mole of ATP into ADP releases 30 kilo joules or 7 kilo caloriesof energy. ATP is, therefore, called as the 'energy currency' of living cells. A few roles of ATP are cited below: (i) Active transport of Na + and K + :The enzyme Na + -K + -ATPase of plasma membrane catalyzes the hydrolysis of one ATP to ADP and Pi in one hand, and the carrier-mediated active transports of three Na + ions outwardand two K + ions inward across the plasma membrane against their respective con centration gradients. This role of ATP is essential for maintaining the

NSOU ● CC-ZO- 08 ____ 65 polarized state of the membrane, higher extracellular concentration of Na + and higher intracellular concentration of K + . (ii) Phosphorylation of substrates: In many metabolic pathways, substrates or intermediates are phosphorylated into low-energy phosphate compounds such as glucose 6-phosphate, fructose 1,6-bisphosphate and glycerol 3-phosphate by respective phosphotransferase enzymes utilizing the high-energy phosphate bond of ATP. (iii) Cellular protein synthesis:The energy released from cleavage of ATP is utilized by amino acyl-tRNA synthetase enzyme for the formation of amino acyl-tRNA, which represents the first step of biosynthesis of proteins in cells. (iv) Other physiological functions:The cleavage ofATP also provides the energy necessary for contraction of muscles, movement of cilia and flagella, exocytosis and endocytosis. (b) Cyclic AMP or adenosine 3′, 5′-monophosphate: It is a high-energy phosphate formed by cyclization of ATP by adenylate cyclase.It mediates signal transduction across the cell membrane as a second messenger for the actions of many signaling molecules like peptide hormones and adrenaline. (c) High-energy ribonucleotides and deoxyribonucleotides: The high-energy g-phosphate bond of ATP, GTP, CTP and UTP are cleaved during RNA synthesis and the energy released there from is utilized in forming phosphodiester bonds between successive nucleotides of RNA. Similarly, the high-energy g-phosphate bond of dATP, dGTP, dCTP and dTTP are cleaved during DNA synthesis and the energy released there from is utilized in forming phosphodiester bonds between successive nucleotides of DNA. (d) Phosphagens: In vertebrate muscles, the enzyme creatine phosphokinase (CPK) cleaves the high-energy phosphate bond of creatine phosphate and utilizes the energy and inorganic phosphate released there from to phosphorylate ADP to ATP. In invertebrate muscles, arginine phosphokinase similarly causes cleavage of high energy phosphate bond of arginine phosphate and utilizes the energy and inorganic phosphate released there from to phosphorylate ADP to ATP. 2.6.4 Energy capture (storage) in high-energy compounds in cells : The most important high-energy compound of all living cells is ATP or adenosine triphosphate. ATP is produced during aerobic oxidation of glucose and fatty acids inside the mitochondria of cells. During aerobic oxidation, NADH and FADH 2 are produced in cells. NADH and FADH 2 enter into the mitochondria

66 ____ NSOU ● CC-ZO- 08 wherein electrons from these substances are transported through the 'electron transport chain' (ETC). The transported electrons are combined with H + ions (protons) and molecular oxygen to produce water while the energy liberated from the transport of electrons is used to produce ATP from ADP and P i (inorganic phosphate) by the help of ATP synthetase. The overall process of ATP production is called 'oxidative phosphorylation', because the substrates (viz. NADH and FADH 2) give out electrons for transport through the ETC and thus, get oxidized while ADP gets phosphorylated or added with phosphate for formation of ATP. Again, cAMP or cyclic AMP which is another important high-energy phosphate in living cells is formed by cyclization of ATP by adenylate cyclase. On the other hand, the high-energy phosphagen of vertebrate muscles, known as CP or creatine phosphate is produced from creatine by the catalytic action of creatine phosphokinase in presence of ATP which breaks into ADP and P i . The high-energy phosphagen of invertebrate muscles, known as AP or arginine phosphate is produced from arginine by the catalytic action of arginine phosphokinase in presence of ATP which breaks into ADP and P i . 2.7 Questions (with hints to answers) 1. What are systems? Define 'isolated', 'closed'and 'open' systems? [see Section 2.1]. 2. Living beings represent an 'open, steady-state, non-equilibrium system' – explain [see Section 2.1]. 3. In a living body, reversible chemical reactions seldom attain a stable equilibrium – explain [see Section 2.1]. 4. A spaceship together with an astronaut is an 'Isolated system', but the astronaut himself is not – explain [see Section 2.1]. 5. State first law of thermodynamics and give a mathematical presentation of the law [see Sections 2.2.1 and 2.2.2]. 6. What do you mean by enthalpy and enthalpy change (DH)? [see Sections 2.2.3 and 2.2.4]. 7. Cite of a situation when DH becomes equal toDE[see Section 2.2.5]. 2.2.6. The latent heat of evaporation of water is 536 cal/g. Calculate DH in converting 1 mole of water at 100 o C into steam at the same temperature, assuming water to behave as an ideal gas [see Section 2.2.6]. 8. State and explain the second law of thermodynamics [see Section 2.3.1]. 9. What is entropy? State its significance [see Section 2.3.2].

NSOU ● CC-ZO- 08 ____ 67 10. Explain the relevance of laws of thermodynamics to biological systems [see Section 2.5]. 11. What are high-energy compounds? Give at least 3 examples. Explain the role of ATP in living organisms. [see Sections 2.6.1, 2.6.2 and 2.6.3]. 12. What is oxidative phosphorylation? [see Section 2.6.4]. 2.8 References 1. Biochemistry – Debajyoti Das (2005), Academic Publishers, Kolkata. 2. Biophysics and Biophysical Chemistry – D. Das (2004), Academic Publishers, Kolkata. 3. Elementary Physical Chemistry – S. R. Palit (1975), Calcutta : Science Book Agency, Kolkata. 4. Physical Chemistry – I. N. Levine (1990), McGraw-Hill, New York.

68 ____ NSOU ● CC-ZO- 08 Unit-3 Enzymes Structure 3.0. Objective 3.1. Introduction 3.2. Nomenclature and classification 3.2.1 Different classes of enzymes 3.2.2 Some relevant terms 3.3. Coenzymes and cofactors 3.3.1 Coenzymes 3.3.2 Cofactors 3.4. Specificity of enzyme action 3.4.1 Template model or lock-and-key model 3.4.2 Induced-fit model 3.5. Isozymes, Ribozymes and Abzymes 3.5.1 Isozymes 3.5.2 Ribozymes 3.5.3 Abzymes 3.6. Mechanism of enzyme action 3.6.1 Basic principle 3.6.2 Some evidence of ES complex formation 3.6.3 Bonds in ES complex formation 3.6.4 Transition-state theory of enzyme action 3.7. Enzyme Kinetics 3.7.1 Meaning of 'enzyme kinetics'and derivation of Michaelis-Menten equation 3.7.2 Concept of K m and V max 3.8. Lineweaver-Burk plot 3.9. Multisubstrate reactions 68
NSOU ● CC-ZO- 08 ____ 69 3.10. Factors affecting rate of enzyme-catalyzed reactions 3.10.1. Enzyme concentration 3.10.2. Effect of reaction products 3.10.3 Effect of substrate concentration 3.10.4 Effect of pH 3.10.5 Effect of temperature 3.11. Enzyme inhibition 3.11.1 Competitive inhibition 3.11.2 Non-competitive inhibition 3.11.3 Uncompetitive inhibition 3.12. Allosteric enzymes and their kinetics 3.12.1 Non-covalent or Allosteric modulation (regulation) of enzymes 3.12.2 Characteristics of allosteric modulation 3.12.3 Positive and negative allosteric modulations 3.12.4 'K'and 'M' types of allosteric enzymes 3.12.5 Molecular mechanism of allosteric modulation 3.12.6 Non-competitive inhibition vs. allosteric inhibition 3.13. Covalent regulation of enzyme action 3.13.1 Irreversible covalent activation 3.13.2 Reversible covalent modification 3.14. Questions 3.15. References 3.0 Objectives : Upon going through this Unit-II, students will be able to: ● Define enzymes and distinguish between enzymes and inorganic catalysts. ● Classify enzymes. ● Define code number, turnover number and international number of enzymes. ● Distinguish between coenzymes and cofactors. ● Learn about the 'lock-and-key' and 'induced-fit' models of enzyme-substrate complex formation.
70 ____ NSOU ● CC-ZO- 08 ● Gain knowledge on isozymes, ribozymes and abzymes. ● Understand the transition-state theory of enzyme action. ● Understand the meaning of 'enzyme kinetics'and derive of Michaelis-Menten equation. ● Develop thorough concept of K m and V max . ● Understand the meaning and significance of Lineweaver-Burk plot. ● Understand the mechanisms of multisubstrate reactions. ● Gain thorough knowledge on the factors affecting rate of enzyme-catalyzed reactions. ● Understand the details of competitive, non-competitive and uncompetitive inhibitions of enzymes. ● Develop thorough concept of allosteric enzymes and their kinetics. ● Differentiate between 'K' and 'M' enzymes. ● Learn about reversible and irreversible covalent regulations of enzyme action. 3.1 Introduction Enzymes are colloidal, thermo-labile, biological catalysts, generally protein in nature and synthesized in living cells. Enzymes catalyze chemical changes of specific substances or substrates either inside or outside cells within the body of living organisms. Both inorganic catalysts and enzymes bind to their substrate molecules to form transient binary complexes and both remain unchanged after their catalytic action and both catalyze changes of only covalent bonds in their substrates. However, enzymes are macromolecular entities while inorganic catalysts have small molecular size. Again, an inorganic catalyst can bind to several substrates but an enzyme has a specific three-dimensional substrate-binding site which can bind to a single or a very few specific substrates. Besides, enzymes do not exist outside the body of living beings and their production is a gene-regulated phenomenon. On the other hand, inorganic catalysts are available outside the body of living beings and their production is not any cellular phenomenon. 3.2 Nomenclature and classification 3.2.1 Different classes of enzymes: Enzymes are broadly classified into 6 classes. The classification as well as the nomenclature of each class is done according to the types of reaction catalyzed by the enzymes :
NSOU ● CC-ZO- 08 ____ 71 Class 1. Oxidoreductases : Enzymes of this class catalyze oxidation or reduction of their substrates. Oxidation is carried out by the removal of electron (often along with H +) from a specific group or by addition of oxygen to specific group. Reduction is just the opposite change, e.g. Lactate dehydrogenase remove two electrons (along with two H +) from CH(OH) group of lactic acid and converts it into pyruvic acid : Class 2. Transferses: Enzymes of this class catalyze the transfer of a particular group from one substrate to another, e.g. Hexokinase transfers a phosphate from ATP to glucose, resulting in production of glucose-6-phosphate and ADP: Class 3. Hydrolases: They catalyze hydrolysis of their respective substrates,e.g. Acetylcholinesterase hydrolyses acetylcholine; Glucose-6-phosphatase hydrolyses glucose-6-phosphate:

72 ____ NSOU ● CC-ZO- 08 Class 4. Lyases: An enzyme of this class cleaves a covalent bond in the substrate non-hydrolytically and converts it to more than one product. Moreover, the enzyme action also produces a double bond in one of the products, e.g. Aspartate ammonia lyase cleaves a C-N bond in L-aspartic acid to produce fumaric acid along with ammonia; this is an example of non-oxidative deamination of amino acid : Class 5. Isomerases: An enzyme of this class catalyzes the change of the substrate into another isomeric form by way of intra-molecular rearrangement, e.g. Phosphohexose isomers is an aldoseketose isomerase and isomerizes glucose-6- phosphate into fructose-5-phosphate: Class 6. Ligases: These enzymes catalyze the formation of a covalent bond between two substrates, which thereby get joined together. Such reaction is endergonic; the necessary energy is derived from a simultaneous cleavage of ATP. Pyruvate carboxylase cause a C-C bond formation between pyruvic acid and CO 2 , resulting in formation of oxaloacetic acid :
NSOU ● CC-ZO- 08 ____ 73 Remarks: However, each class of enzyme is subdivided into some subclasses and each subclass is again divided into sub-subclasses, depending on particulars of their catalytic action. For instance, Glucose-6-phosphatase of the class 'hydrolases' belongs to the subclass 'esterases', as it hydrolyses an ester bond, but pepsin of the same class belongs to another subclass called 'peptide hydrolases', as it hydrolyses a peptide bond. 3.2.2 Some relevant terms : (a) Enzyme Code Number: Every enzyme has been given an EC No. or Enzyme Code Number in 4 digits by 'The 1972 Recommendations of the Commission on Enzyme Nomenclature'. The first digit indicates its class; the second digit indicates its subclass; the third digit indicates its sub-subclass and the fourth digit indicates its serial number in sub-subclass, e.g. The EC No. of the gastric enzyme pepsin is 3.4.4.1. So, it is an enzyme with a serial number 1 in the sub-classes 4 (Animal endopeptidases) under the subclass 4 (Peptide hydrolases) under the class 3 (Hydroclases). (b) Enzyme Unit (E): The Commission on Enzymes of the International Union of Biochemists holds that a unit of an enzyme is that amount of the enzyme which catalyzes the transformation of one micromole of substrate into product per minute at 25 o C under optimal conditions. (c) Turnover number: The turnover number of an enzyme refers to the number of substrate molecules transformed into product per minute by a single enzyme molecule under optimal conditions, e.g. Turnover number of b-amylase is as high as 1,100,000. 3.3 Coenzymes and cofactors 3.3.1 Coenzymes : (i) In many enzymes, a dialyzable, thermolabile, non-protein but organic compound remains bound to the main protein part of the enzymes. The whole of such an enzyme molecule is called a holoenzyme; its protein part is
74 ____ NSOU ● CC-ZO- 08 called an apoenzyme and the non-protein but organic compound attached to the apoenzyme is called as a coenzyme. A coenzyme helps in the enzyme catalyzed reaction. (ii) Coenzymes are found in several oxidoreductases, transferases and isomerases, but not in all classes of enzymes. (iii) When a coenzyme remains non-covalently linked with the apoenzyme, it gets detached from the latter after the enzyme-catalyzed reaction is over, e.g. NAD + (Nicotinamide adenine dinucleotide) is such a detachable coenzyme of different anaerobic dehydrogenases like lactate dehydrogenase and pyruvate dehydrogenase. When a coenzyme remains covalently linked with the apoenzyme, it does not dissociate from the latter after the enzyme-catalyzed reaction is over. Such coenzymes are called as prosthetic groups (Lehinger, 1975), e.g. PLP (pyridoxal phosphate) is a prosthetic group of transaminases and FAD (Flavin adenine dinucleotide) is the prosthetic group of D-amino acid oxidase). (iv) Coenzymes including prosthetic groups are mostly derivatives of vitamins, for instance, NAD + is a derivative of pyridoxine or vitamin B 6 ; FAD is derivative of riboflavin or vitamin B 2 . However, a few enzymes like peroxidase and catalase have heme, a metalloporphyrin as the prosthetic group. (v) Coenzymes help in the action of enzymes in different ways: (a) In general, the association between coenzyme and apoenzyme helps in the binding of the substrate to the active site of the enzyme, as the binding of the coenzyme provides the proper three-dimensional conformation to the active site of the enzyme. (b) A coenzyme may accept a particular atom or functional group or electron removed from the substrate by the action of an enzyme. Thus, the coenzyme gets chemically changed but its original form is reproduced later by other cellular reactions, e.g. NAD + gets reduced to NADH while it acts as a coenzyme of some anaerobic dehydrogenases. NADH is later re-oxidized to NAD + by mitochondrial NADH dehydrogenase : 2 . Anaerobicdehydrogenase NAD A H NADH H A

NSOU ● CC-ZO- 08 ____ 75 (c) A conenzyme may donate a particular group or atom to be added to the substrate by an enzyme, e.g. Tetrahydrobiopterin donates H 2 when tryptophan hydroxylase causes oxidation of tryptophan into 5-hydroxy-tryptophan and it itself changes into dihydrobiopterin. Dihydrobiopterin is later reduced back to tetrahydrobiopterin by dihydrobiopterin reductase. (d) A coenzyme may form an intermediate complex with the substrate during an enzyme-catalysed reaction, e.g. PLP, the coenzyme of a transaminase form a Schiff base intermediate with a substrate amino acid. Later, the Schiff base undergoes various chemical changes with the conversion of the amino acid into its corresponding keto acid and reproduction of PLP. 3.3.2 Cofactors : Sometimes, a metal ion instead of non-protein organic compound remains attached with the holoenzyme. Such a metal ion is called a cofactor. Enzymes to which the metal ions remain loosely bound are called metal-activated enzymes and enzymes to which the metal ions remain tightly bound are called metalloenzymes. Metal-activated enzymes contain alkali metals like Na + and K + or alkaline earth metals like Ca ++ and Mg ++ , but metalloenzymes contain transitional metals like Cu ++ , Cu + , Zn ++ etc. Metal ions help in the action of enzymes in different ways: (i) Metal ions may provide the proper three-dimensional conformation to the active site of an enzyme for binding to a substrate, e.g. pyruvate kinase requires Mg ++ ions while it transfers the phosphate group from phosphoenolpyruvate to ADP for production of ATP. (ii) A metal may help in substrate-binding by binding to the enzyme in one hand and to the substrate on the other, e.g. Enolase requires the help of Mg ++ ions when it binds to 2-phosphoglycerate to produce phosphoenolpyruvate. (iii) A metal ion may act as a donor or acceptor of electron to and from a substrate during an enzyme-catalyzed reaction, e.g. Cu ++ ions of plasma ceruloplasmin (an enzyme) can oxidize Fe ++ ions entering the plasma into Fe +++ ions. 3.4 Specificity of enzyme action Enzymes bind to specific substrate or substrates only. Biochemists have proposed two different models for explaining the binding of an enzyme with its specific substrate:

76 ____ NSOU ● CC-ZO- 08 3.4.1 Template model or lock-and-key model : According to Emil Fischer (1894), the active site of an enzyme always remains in the proper conformation even in absence of its substrate. Thereby, the active site provides a pre-shaped permanent template which fits with the size, shape and groups of the substrate. The binding of the substrate with the active site is like a lock-and-key interaction. The conformation of the active site is not changed after the catalytic action of the enzyme is accomplished. Merit : (i) This model fits with the simple substrate-saturation kinetics (hyperbolic substrate-saturation curve)of enzymes. (ii) This model can explain how certain enzymes can act on a particular stereoisomer, but not on another stereoisomer of the respective substrate. (iii) The model can also explain the sequential binding of a coenzyme and a substrate to an enzyme. Demerit : A major demerit of this model is that it cannot explain the change in enzyme activity in presence of allosteric modulators. 3.4.2 Induced-fit model : A second model upheld by D. E. Koshland (1958) states that the active site of an enzyme is not a rigid structure and instead, it has a flexible three-dimensional structure. The active site does not bear its fully and complementary conformation in absence of the substrate. Either on approach of the substrate or following an initial loose binding with the substrate, the flexible active site changes its conformation to attain its fully functional form, which binds the substrate more tightly and starts catalytic action. After the catalytic activity is over, the active site returns to its original flexible form. Merits : (i) The induced-fit model has received support from X-ray crystallographic studies on the conformation of native enzymes and ES complexes. (ii) It can explain changes in enzyme activity in presence of an allosteric modulator which binds to an enzyme at a site other than the active site. (iii) This model can explain complex substrate-saturation kinetics of allosteric enzymes in presence of allosteric modulators.

NSOU ● CC-ZO- 08 ____ 77 3.5 Isozymes, Ribozymes and Abzymes 3.5.1 Isozymes : Some enzymes exist in more than one molecular form in the same species. In other words, these different forms are different proteins catalyzing an identical reaction involving the same substrate. Such different molecular forms of the same enzyme are called isozymes or isoenzymes. Isozymes of an enzyme differ from each other in their physicochemical properties like (i) primary structure or amino acid sequence, (ii) isoelectric pH, (iii) electrophoretic mobility, (iv) thermolability, (v) sensitivity to different denaturing agents and (vi) sedimentation coefficient. They also differ from each other in their biological properties like (i) optimum pH and temperature for activity, (ii) allosteric property and (iii) immunological reactions. Isozymes can be separated precisely from one another by isoelectric focusing. Different isozymes of an enzyme may occur in different tissues of an organism, e.g. Lactate dehydrogenase which acts on lactate and converts it into pyruvate, occurs as five different isozyme in rats: LDH-I 1 occurs in heart; LDH-I 2 in brain, kidney and RBC; LDH-I 3 in lungs; LDH-I 4 in WBC, and LDH-I 5 in liver and muscle. Different isozymes may occur in a cell also, e.g. Two distinct isozymes of transaminase occur in cytosol and mitochondria of hepatic cells. 3.5.2 Ribozymes : Almost all enzymes are basically protein in nature. However, a few RNA with the ability of catalyzing the cleavage of specific RNA molecules have been
78 ____ NSOU ● CC-ZO- 08 discovered in both prokaryotes and eukaryotes in the last two decades. Such RNA molecules acting as biological catalysts are called as 'ribozymes'. A ribozyme may have a protein moiety associated with itself, but the attached protein moiety is not a must for the catalytic action of the ribozyme. The catalytic site lies in the RNA part of the ribozyme and not in the associated protein part. e.g.(i) The precursor or primary transcript of t-RNA of E. coli contains an extra RNA sequence (leader sequence) at the 5′ end. During the processing of the precursor of t-RNA, the extra RNA sequence at the 5′ end is cut off by the catalytic action (endonuclease action) of a ribozyme called as RNAse P. This ribozyme consists of a 377 nucleotide-long RNA molecule called M1 RNA and a closely attached protein molecule with a molecular weight of 17.5 kD (Nelson and Cox, 2005). The removal of the attached 17.5 kD protein cannot prevent the endonuclease action of RNase P, which proves that the active site of RNase P lies in the RNA part, but not in the attached 17.5 kD protein part. The attached 17.5 kD protein may however, somehow promote the enzymatic activity of RNAse P. It may be added here that the precursor of t-RNA contains as extra RNA sequence (trailer sequence) at the 3′ end also. However, during the processing of the precursor molecule, the 3′extra sequence is cut off by an exonuclease called RNase D, which is protein in nature like an ordinary enzyme. (ii) Spliceosome is a eukaryotic ribozyme. It consists of five snRNA (small nuclear RNA) molecules and some associated proteins. Spliceosome removes the introns or intervening sequences and splices or joins the exons or expressed sequences of primary transcripts of mRNA molecules. Action of RNase P on precursor of E.coli tRNA 3.5.3 Abzymes: Lerner and Tramontano (1988) discovered that some monoclonal antibodies (a monoclonal antibody is the purest form of an antibody agains a particular antigen) can act as biological catalysts. Such monoclonal antibodies are called abzymes, e.g. Lerner and Tramontano (1988) produced a hapten-carrier complex in which the

NSOU ● CC-ZO- 08 ____ 79 hapten was a partially hydrolysed ester (hapten is a small molecule; when it combines with a carrier the hapten-carrier complex becomes an antigen). Then, using the hapten-carrier complex, they produced an 'antihapten monoclonal antibody'. When this monoclonal antibody was incubated in presence of the free and unhydrolysed ester, it catalysed rapid hydrolysis of the ester. So, this monoclonal antibody was an abzyme.Research work is going on to produce abzymes that will be able to (i) dissolve blood clots and (ii) dissolve viral glycoproteins and destroy the infectivity of viruses. 3.6 Mechanism of enzyme action 3.6.1 Basic principle : An enzyme (E) at first binds with the substrate (S) to form a transient enzyme- substrate (ES) complex. The binding occurs between the active site of the enzyme and a specific group or component of the substrate. ES is an intermediate complex and it soon dissociates into the free, unaltered enzyme (E) and the changed substrate or product (P): E S ES E P + ⇔ ⇔ + 3.6.2 Some evidence of ES complex formation : (1) ES complex of glyceraldehyde-3-phosphate dehydrogenase is quite stable and has been chemically isolated. (2)ES complexes of catalase and peroxidase can be detected by spectrophotometry. (3) ES complex of RNA polymerase can be directly visualized with the help of electron microscopy. 3.6.3 Bonds in ES complex formation : The active site of an enzyme consists of several amino acid residues, located at some distance from each other in the polypeptide chain but brought close together by the folding of secondary and tertiary structures of the enzyme. Thus, the active site assumes a cleft-like three-dimensional structure. Inside this cleft, side-chains of some specific amino acids constitute a substrate-binding site and side-chains of some other specific amino acids constitute a catalytic site. [Therefore, Active site = Substrate- binding site + Catalytic-site]. ES complex is formed mainly by non-covalent bonds like (a) hydrogen bonds, (b) electrostatic bonds, (c) Van der Waals forces and (d) hydrophobic bonds between specific amino acid side-chain of the active site of the enzyme and particular groups or residues of the substrate. However, in case of some

80 ____ NSOU ● CC-ZO- 08 Enzyme-substrate reaction as per induced-fit model [Source: Wikimedia Commons] enzymes, ES complex is formed by covalent bonding, e.g. A covalent thioester bond is formed between the sulfhydril group of a cysteine of the active site of glyceraldehyde-3-phosphate dehydrogenase and the C1 aldehyde group of the substrate, glyceraldehyde-3-phosphate.

NSOU ● CC-ZO- 08 ____ 81 3.6.4 Transition-state theory of enzyme action : At physiological temperature, the substrate molecules cannot participate in any chemical reaction or formation/breakage of bonds, as they possess insufficient kinetic energy and as such, they fail to collide with or approach each other with sufficient energy, which is needed for formation or breakage of bonds. In other words, the substrate molecules fail to cross the 'energy barrier' for a chemical reaction. Reactant molecules occurring at physiological temperature ('physiological ground state') can be made to participate in a chemical reaction in two ways: 1. One way is to add some amount of energy to the reactant molecules and to shift them to a state of high kinetic energy, when they can collide with each other with sufficient energy and can cause formation or breakage of bonds. This reactive and high-energy state of reactant molecules is called as the 'transition-state'. The amount of energy required to shift the reactant molecules from their 'physiological ground-state' to the 'transition-state' is called as the 'activation energy'. The target energy-level which must be crossed by the reactant molecules for their escalation to the 'transition state' is called as the 'energy barrier' for a chemical reaction. At par with the kinetic theory of chemical reaction, the addition of 'activation energy' to the reactant molecules may be done by increasing the temperature of the molecules. It is obvious that enzymes cannot do so, because enzymes are not any source of heat. 2. There exists an alternative way to enable the reactant molecules to participate in a chemical reaction. This is exactly what the enzymes do with their substrate molecules. Enzymes bind their substrate molecules to their active sites. The formation of enzyme-substrate complex lowers the 'energy barrier' for a reaction to a bare minimum level. As such, a meager amount of 'activation energy' has to be added to the enzyme-bound substrate molecules to make them cross the altered 'energy barrier' and reach the 'transition-state'. This small amount of energy may be quite well provided by the physiological temperature of living beings. Consequently, the enzyme-bound substrates undergo chemical change rapidly, yielding the product. Transition-state theory

82 ____ NSOU ● CC-ZO- 08 Mechanism of enzymes action in terms of energy (?????G = change of free energy) [Source: Wikimedia Commons] 3.7 Enzyme Kinetics 3.7.1 Meaning of 'enzyme kinetics'and derivation of Michaelis-Menten equation : When the substrate concentration or [S] is very low compared to the enzyme concentration of [E], many enzyme molecules remain free or not bound with substrates, and this makes the velocity (v) of enzyme activity very low. If [S] is gradually increased without disturbing pH, temperature and [E] of the medium, more and more enzyme molecules bind with substrate molecules and 'v' also increases progressively. However, a stage soon comes when all enzyme molecules get linked with substrate molecules and 'v' reaches its maximum level of V max . A further rise in [S] fails to increase the velocity of enzyme activity beyond V max , since the free enzyme molecules are no more available in the medium for binding any more substrate molecules. The study of the quantitative relationship between the velocity of enzyme action and the substrate concentration is called as the study of enzyme kinetics. The pioneer workers on this issue were L. Michaelis and M. L. Menten. They stated in 1913 that an enzyme-catalysed reaction involves two essential steps. At first, an enzyme (E) reversibly binds to the substrate (S), resulting in formation of a transient enzyme- substrate complex (ES). Then, the ES dissociates into the enzyme and the product (P). The overall changes may be shown by the following equation : 3 1 4 2 K K ES K K E+S E+P NSOU ● CC-ZO- 08 ____ 83 Here, K 1 , K 2 , K 3 and K 4 are the rate constants for the reactions; K 1 and K 3 for the forward reactions while K 2 and K 4 are for the backward reactions. Now, at a steady state of the enzyme activity, the situation becomes : Rate of formation of [ES] = Rate of dissociation of [ES] So, from the law of mass action, it can be represented as follows : K E S K E P K ES K ES 1 4 2 3 [ ][ ] [ ][ ] [ ] [ ] + = + or, [ ]([ ] [ ]) [ ]( ) E K S K P ES K K 1 4 2 3 + = + or, [ ] [ ] [ ] [ ] E ES K K K S K P = + + 2 3 1 4 Now, at an early stage of the reaction, [P] will be very small and the backward reaction ES E P K 4 ← — — + will also be very slow. As such, we can ignore K 4 [P] from the denominator and can write that : 2 3 1 [ ] [ ] [ ] K K E ES K S or, [ ] [ ] [ ] E ES K S m = (When the 3 constants K 1 = K 2 and K 3 are condensed into a single constant Km, by the relationship, K K K K m 2 3 1 + =) The lumped constant Km of the above equation is called as Michaelis constant. Now, we suppose that the total concentration of enzyme molecules is [E] t . So, the concentration of enzyme molecules bound to the substrate will be equal to the concentration of ES molecules, i.e. [ES]. Therefore, the concentration of free enzyme molecules will be : [ ] [ ] [ ] t E E ES Hence, we can further write as follows : [ ] [ ] [ ] m K E ES S or, [ ] [ ] [ ] [ ] t m E ES K ES S or, [ ] [ ] [ ] t m E K ES ES ES S 84 ____ NSOU ● CC-ZO- 08 or, or, Now, the maximum velocity of enzyme action or V max will be reached when all the enzyme molecules or [E] t will bind to the substrate. In other words, max [ ] t V E. Again, the velocity (v) of enzyme action at any given moment is directly proportional to the concentration of enzyme molecules bound to the substrate at that particular moment. In other words, . Therefore, we can write that V v E ES t max [ ] [ ] α Again by substituting [ ] [ ] E ES t for V v max , we can write as follows : [ ] [ ] E ES K S t m = + 1 or, V v K S K S S m m max [ ] [ ] [ ] = + = + 1 or, v V S K S m max [ ] [ ] = + or, v V S K S m = + max [ ] [ ] The above equation is called as Michaelis-Menten equation for the velocity of enzyme action. Michaelis-Menten saturation curve showing relation between substrate concentration and reaction rate [Source: Wikimedia Commons]

NSOU ● CC-ZO- 08 ____ 85 3.7.2 Concept of K m and V max : Michaelis-Menten equation depicts the velocity of enzyme action at any given moment. From Michaelis-Menten equation, the value of K m for a given enzyme can be easily calculated. K m or Michaelis constant or Michaelis-Menten constant is an important and fundamental characteristic of every enzyme. K m can be defined as a measure of affinity of an enzyme for a particular substrate and it also represents the substrate concentration at which the velocity of enzyme activity reaches max 2 V or half of the maximum velocity. K m is independent of enzyme concentration and the higher is the value of K m , the lower will be affinity of the enzyme for the substrate. Michaelis-Menten equation states : max [ ] [ ] m V S v K S If we consider that max 2 V v , then we can represent the situation as follows: max max [ ] 2 [ ] m V V S K S or, max max max [ ] 2 [ ] m V K V S V S or, max max max 2 [ ] [ ] m V K V S V S or, max max [ ] [ ] m V S K S V Thus, K m is equal to the substrate concentration at which the velocity of enzyme action is half of the maximum velocity. Different enzymes have different K m , e.g. K m for catalase acting on H 2 O 2 is 25 mM/l and K m for hexokinase acting on glucose is 0.15 mM/l. The K m of an enzyme may vary with change of pH and temperature of the medium. Again, K m of an enzyme is increased in case of competitive inhibition, lowered in case of uncompetitive inhibition and remains unaffected in case of non- competitive inhibition of enzyme activity. Besides, if an enzyme acts on more than one substrate, then the enzyme will have different K m values for different substrates, e.g. Hexokinase acting on glucose has a K m value 0.15 mM/l, but the same enzyme while acting on fructose has a K m value of 1.5 mM/L. From Michaelis-Menten equation, one can easily understand the changes in velocity of enzyme activity along with changes in substrate concentrations : 86 ____ NSOU ● CC-ZO- 08 The equation states : v V S K S m = + max [ ] [ ] If [S] is very low compound to K m , then we can modify the equation into : v V S K m = max [ ] ([S], being very small, is ignored in the denominator) or, v = a very small quantity (since, [S] in the numerator is very small compared to K m in the denominator), or, velocity of enzyme action is very low. When [S] is much bigger than K m , we can modify the equation as follows : v V S S = max [ ] [ ] (K m , being very small, is ignored in the denominator) or, v V ≈ max or, velocity of enzyme action is approaching towards V max , or, velocity is very high. Finally, when 'v' is equal to V max we can represent the situation as follows : v V S S = max [ ] [ ] (here also [S] is much higher than K m and K m can be ignored) or, v = V max Thus, v is equal to irrespective of any value of [S]. In other words, once V max is reached, the velocity does not increase any further and remains steady even if [S] is increased. In this way, the graph representing velocity (v) of enzyme action in the ordinate and substrate concentration or [S] in the abscissa becomes a hyperbolic curve. 3.8 Lineweaver-Burk Plot The value of K m can be easily determined in the laboratory from 'double- reciprocal plot' or 'Lineweaver-Burk plot' devised by Lineweaver and Burk in 1934. Thus plot is derived from Michaelis-Menten equation. Michaelis-Menten equation states : v V S K S m = + max [ ] [ ] By inverting we get : 1 v K S V S m = +[ ] [ ] max NSOU ● CC-ZO- 08 ____ 87 or, 1 v K S V S S V S m = + + [ ] [ ] [ ] [ ] max max or, 1 1 1 v K V S V m = × + max max [ ] The above represents an equation for a straight line, as it may be considered as : y = ax + b (if we consider that 1 1 v y K V a S x m = = = , , [ ] max and 1 V b max =). Hence, a straight-line graph will be obtained when 1 v and 1 [ ]S are plotted on the ordinate and the abscissa respectively. The Y-intercept of the graph represents 'b' or 1 V max , because the value of 'x' at this point is 0 ; consequently, y = ax + b, or, y = a × 0 + b = b. Again, the –ve X-intercept of the graph represents – 1 K m , because the value of 'y' at this point is 0; consequently, y = ax or, 0 = ax + b, or, x b x V K V V V K K m m m = – = – + = – × = – 1 1 1 max max max max . From the value of – 1 K m , the value of K m can be easily determined.

88 ____ NSOU ● CC-ZO- 08 3.9 Multisubstrate reactions Some enzymes act on only one particular substrate, e.g. Isomerases. Here, ES complex generally has a short span of existence and the rate of product formation is proportional to the concentration of ES complex. However, many enzymes act on more than one substrate. Such enzyme actions occur as follows: (a) Single-displacement reaction: Here, two substrates S 1 and S 2 combine with the enzyme one after another, either in specific sequence or in a random sequence. After both substrates bind to the enzyme, a ternary complex 'ES 1 S 2 ' is formed. Later, ES 1 S 2 dissociates into the enzyme and two products P 1 and P 2 which are released in either a specific or a random sequence: E + S 1 ? ES 1 ES 1 + S 2 ? ES 1 S 2 ES 1 S 2 ? EP 1 P 2 ? EP 2 + P 1 EP 2 ? E + P 2 e.g. Hexokinase can phosphorylate not only D-glucose but also other D-hexoses. The hydrolase, pepsin can hydrolyse casein of milk as well as collagen of connective tissues. (b) Ping-pong reaction or double-displacement reaction: Here, each of the substrates binds singly with the enzyme in an ordered sequence, each forming only a binary ES complex. No ternary complex or ES 1 S 2 is formed, since two substrates never remain simultaneously combined with the enzyme. The first ES complex or ES 1 dissociates to release the first product (P 1) and a modified form of the enzyme (E'). Then, E' binds to the second substrate or S 2 to form a second ES complex or E'S 2 which subsequently dissociates into the second product or P 2 and the original form of the enzyme or E : E + S 1 ? ES 1 ? E' + P 1 E' + S 2 ??E'S 2 ? E + P 2 e.g. Transaminase acts on an amino acid and its corresponding keto acid, respectively, through ping-pong mode of enzyme action. 3.10 Factors affecting rate of enzyme-catalyzed reactions 3.10.1. Enzyme concentration : An increase in enzyme concentration causes a proportionate rise in the initial velocity of the enzyme action. A linear graph is obtained by plotting the velocity of enzyme action against enzyme concentration.

NSOU ● CC-ZO- 08 ____ 89 Generally, in an enzyme-catalyzed reaction, the number of substrate molecules far exceeds the number of enzyme molecules. So, many substrate molecules remain free even after all enzyme molecules have bound to substrate molecules. Therefore, if we increase the concentration of enzyme molecules, the formation of enzyme- substrate complex and the velocity of enzyme action will also increase. However, if the number of enzyme molecules is so much increased that the number of substrate molecules becomes less than the number of enzyme molecules, the velocity of enzyme action will not increase anymore and the linear graph will become hyperbolic in shape. 3.10.2. Effect of reaction products : If the reaction products continue to accumulate, the rate of enzyme action is, to some extent, depressed. This happens so because an accumulation of products stimulates the backward reaction : Enzyme-substrate ? Enzyme (free) + Product Besides, the products may mask (cover) the active sites of enzymes, which also depress the rate of enzyme action. However, within the body, enzyme actions are generally not prevented by accumulation of products, because different reactions occur in a series in the body. One reaction leads to the formation of one product, but very soon, a second enzyme starts to act on that product to produce a second product. Thus, products can hardly accumulate to depress enzyme actions. 3.10.3 Effect of substrate concentration: When the substrate concentration or [S] is very low compared to the enzyme concentration of [E], many enzyme molecules remain free or not bound with substrates, and this makes the velocity (v) of enzyme activity very low. If [S] is gradually increased without disturbing pH, temperature and [E] of the medium, more and more enzyme molecules bind with substrate molecules and 'v' also increases progressively. However, a stage soon comes when all enzyme molecules get linked with substrate molecules and 'v' reaches its maximum level of V max . A further rise in [S] fail to increase the velocity of enzyme activity beyond V max , since free enzyme molecules are no more available in the medium for binding any more substrate molecules.

90 ____ NSOU ● CC-ZO- 08 Effect of substrate concentration on velocity of enzyme action If the gradually increasing substrate concentrations and the corresponding velocities of enzymes activity are plotted in graph, a hyperbolic curve is obtained: Hyperbolic curve showing enzyme action 3.10.4. Effect of pH : Each enzyme acts best at a particular pH, which is called as the optimum pH for that enzyme. The velocity of enzyme action progressively declines, both when the pH of the medium is increased above the optimum pH and when the pH of the medium is lowered below the optimum pH. Thus, a bell-shaped curve will be obtained by plotting the velocity of enzyme action against pH of the medium. Variations of pH above and below the optimum pH, may affect ionization of different groups in the substrate and also, in the active site of an enzyme. These in turn affect enzyme-substrate complex formation.

NSOU ● CC-ZO- 08 ____ 91 Increase or decrease of pH of the medium above and below the optimal pH, may also affect the 3-dimensional structure of the enzyme, which in turn may affect enzyme-substrate complex formation. Variations of pH may cause dissociation of apoenzyme and coenzyme parts of an enzyme, which in turn may inhibit the activity of an enzyme. Some enzyme like pepsin may act on more than one substrate. In such cases, the optimum pH of the enzyme varies with substrates, e.g. Pepsin has an optimum pH of 2.2 when it digests haemoglobin, but it has on optimum pH of 1.5 when it acts on egg albumin. 3.10.5. Effect of temperature : For each enzyme, there is a particular temperature, called optimum temperature, at which the enzyme activity becomes maximum. Above and below the optimum temperature, the activity of an enzyme gets depressed. Thus, a bell-shaped graph is obtained by plotting the velocity of enzyme action against temperature of the medium. When the temperature is too low, the rate of enzyme action remains slow due to low kinetic energy of both enzyme and substrate molecules. A slow rise in temperature increases the kinetic energy of both enzyme and substrate molecules, which increases their interaction and also, the overall rate of enzyme action. But, when the temperature is raised above an optimum level, the secondary and tertiary structure of the enzyme molecule may be affected. This is turn may affect enzyme- substrate binding and enzyme activity. The increase in the rate of an enzyme's activity for every 10 o C rise of temperature, starting from an initial temperature of 0 o C, is called as Q 10 (temperature coefficient) of an enzyme. For most of the enzymes, the value of Q 10 is 2. For most of the enzymes found in mammals, the optimum temperature is about 37 o C. Most enzymes get completely denatured and lose their activity at 55 o C to 60 o C. However, the enzymes of thermophilic bacteria (hot-spring bacteria) remain active at even 85 o C.

92 ____ NSOU ● CC-ZO- 08 Effect of pH, temperature and enzyme concentration [E] on velocity of enzyme action 3.11 Enzyme inhibition : 3.11.1 Competitive inhibition: Definition : Sometimes, the activity of an enzyme is inhibited in presence of such an inhibitor, which bears a close similarity with the original substrate of the enzyme and which competes with the substrate for occupying the binding site of the enzyme. Mechanism : The inhibitor (I) binds with the enzyme by competing with the substrate to form an enzyme-inhibitor complex (EI). Consequently, the enzyme is abstained from binding with the substrate and forming enzyme-substrate complex (ES). Naturally, enzyme activity of lowered. Characteristics : (1) Effect of [I] : If the [I] or concentration of inhibitor is progressively increased, the formation of EI is also increased while the formation of ES and the enzyme activity are progressively decreased. (2) Effect of K m : A progressive rise in [I] causes a progressive lowering of the affinity of the enzyme for its substrate. Consequently, the K m value of the enzyme increases progressively. (3) Reversibility : Competitive inhibition is reversible. If the [S] is much increased relative to the [I], the substrate succeeds to force the inhibitor out from EI complex and to bind with the enzyme to form ES complex and to produce the same maximum velocity as in absence of the inhibitor.

NSOU ● CC-ZO- 08 ____ 93 (4) Effects on Lineweaver-Burk plot : (a) Slope of the curve: The slope of the graph becomes steeper in presence of the inhibitor than in absence of the inhibitor, which indicates a rise in the value of 1 v or a decrease in the velocity of enzyme action in presence of the inhibitor. (b) X-intercept : Along with the increase in [I], the X-intercept becomes reduced in size or moves closer to the Y-axis of the graph, which indicates a decrease in the absolute value of 1 K m or an increase in the value of K m . (c) Y-intercept : A rise in [I] does not affect the Y-intercept of the graph. In other words, the value of either 1 V max or V max does not change. It means that the inhibitor does not affect the rate of breakdown of whatever number of ES complex is present, into E and P. Examples: Malonate competes with succinate and inhibits the activity of succinate dehydrogenase; fluorocitrate competes with citrate and inhibits the activity of aconitase. Lineweaver-Burk plot in competitive inhibition

94 ____ NSOU ● CC-ZO- 08 3.11.2 Non-competitive inhibition: Definition: Sometimes, the activity of an enzyme is depressed in presence of such an inhibitor, which has no structural similarity with the substrate and does not compete with the substrate for occupying the binding site of the enzyme, but which combines with some other site of the enzyme and inactivates the latter. This is called non-competitive inhibition. Mechanism: The inhibitor binds to a site other than the substrate-binding site of the enzyme. The binding may occur when the enzyme is free or after the formation of enzyme-substrate complex. Thus, an enzyme-inhibitor (EI) or an enzyme-substrate- inhibitor (ESI) complex is formed. The binding of the inhibitor deforms the three-dimensional conformation of the enzyme, which thus loses its catalytic power. As a result, the enzyme subsequently fails to convert the substrate into the product. Characteristics : (1) Effect of [I] : The higher is the concentration of the inhibitor, the higher is the formation of EI or ESI complexes and the lower becomes the velocity of enzyme action. (2) Effect on K m : Since the inhibitor does not compete with the substrate for occupying the binding site of the enzyme, it does not affect the substrate- affinity of the enzyme. In other words, the K m value for the enzyme remains unaffected. (3) Irreversibility : As the inhibitor binds to the enzyme at a site other than the substrate-binding site, an increase in [I] cannot dislodge the inhibitor from EI or ESI complexes. Thus, non-competitive inhibition is not reversed by an increase of [S]. (4) Effects on Lineweaver-Burk plot : (a) Slope of the curve: The slope of the graph becomes higher than in absence of the inhibitor, indicating a rise in the value of 1 v or a decrease in the value of 'v' or velocity of the enzyme activity. (b) X-intercept: The X-intercept of the graph remains unchanged, indicating no change in the value of – 1 K m as well as K m . (c) Y-intercept: The Y-intercept of the graph is increased. In other words, the value of 1 V max is increased and the value of V max is decreased. Thus, the maximum velocity of enzyme action is decreased in presence of the inhibitor.

NSOU ● CC-ZO- 08 ____ 95 Examples : EDTA (Ethylene diamine tetra-acetate) may bind with the Mg ++ ions of Mg-dependent enzymes like enclose and inhibit them. Again, heavy metals like Ag + and Hg ++ may bind to SH groups of sulfhydril enzymes like glyceraldehydes-3- phosphate dehydrogenase and inhibit them. Lineweaver-Burk plot in non-competitive inhibition 3.11.3 Uncompetitive inhibition: Definition: In case of certain bi- or multi-substrate enzymes and in a few single- substrate enzymes, enzyme activity is inhibited in presence of such an inhibitor which has no structural similarity with the substrate and does not compete with the substrate for occupying the binding site of the enzyme, but which binds with the enzyme-substrate complex and inhibits the formation and release of the product. This is called uncompetitive inhibition. Mechanism: The inhibitor does not affect enzyme-substrate complex formation and it binds to enzyme-substrate complex only, forming an enzyme-substrate- inhibitor (ESI) complex. This deforms the conformation of the enzyme in such a way that its catalytic power is suppressed, which prevents the formation and release of the product. Characteristics: (1) Effect of [I] : An increase in the concentration of the inhibitor increase the formation of ESI complex and thus, progressively lowers the formation of the product.

96 ____ NSOU ● CC-ZO- 08 (2) Effect of K m : The inhibitor causes an apparent increase in the substrate- affinity of the enzyme, which in turn, decreases the K m value of the enzyme [Apparent increase of substrate-affinity = Accumulation of ESI without breakdown into E and P; as if, the substrate affinity of the enzyme is increased]. (3) Irresversibility : The higher is the [S], the higher are the formation of ES as well as ESI, and the inhibition cannot be reversed by increasing the [S]. (4) Effect on Lineweaver-Burk plot: (a) Slope of the curve: The slope of the graph remains unchanged. (b) X-intercept: The X-intercept becomes larger in size or moves away from the Y-axis of the graph than in absence of the inhibitor, which indicates an increase of the absolute value of 1 K m or a decrease in the value of K m in presence of the inhibitor. (c) Y-intecept : The Y-intercept of the graph is increased, indicating an increase in the value of 1 V max or a decrease in the value of V max in presence of the inhibitor. Thus, the maximum velocity of the enzyme decreases with a rise in the concentration of the inhibitor. Example: Uncompetitive inhibition may be noted in cases of bi- and multi- substrate enzymes. Lineweaver-Burk plot in uncompetitive inhibition

NSOU ● CC-ZO- 08 ____ 97 3.12 Allosteric enzymes and their kinetics The activity of enzymes vary depending on (a) physiochemical conditions of the surrounding medium, e.g. temperature and pH, (b) reaction conditions, e.g. substrate concentration, accumulation of product and (c) presence of inhibitor substances, e.g. different non-cellular chemicals applied from outside and a few cellular substances acting as substrate analogues. Besides, the activity of certain enzymes may be modified (increased or decreased) by the presence of specific cellular substances. The process is called regulation of enzymes and those enzymes are called regulatory enzymes. Regulation of enzymes by cellular substances is divisible into two types: 3.12.1 Non-covalent or Allosteric modulation (regulation) of enzymes: Sometimes, the activity of an enzyme may be either enhanced or inhibited by the non-covalent binding of some specific low-molecular weight ligands to specific sites of the enzyme, other than the isoteric site or the active site. Such modification or enzymes activity is called as allosteric modulation; the concerned regulatory substances or ligands are called allosteric modulators or effectors; the binding site of an allosteric modulator on the enzyme is called allosteric site; the enzyme thus being regulated is called an allosteric enzyme. 3.12.2 Characteristics of allosteric modulation: 1. An allosteric site is different from the active site of the enzyme. An allosteric stie possesses specificity for binding with a particular allosteric modulator only. 2. An allosteric enzyme may possess only one allosteric site for either a positive modulator or a negative modulator. Or, an allosteric enzyme may possess separate allosteric sites for the binding of a positive and a negative modulator, respectively. 3. Allosteric enzymes are generally oligaomeric enzymes and each enzyme contains more than one substrate binding sites [one on each subunit or polypeptide chain]. 3.12.3 Positive and negative allosteric modulations : When an enzyme activity is enhanced by allosteric modulation, it is called as positive allosteric modulation and the modulator is called as a positive modulator (or activator). The reverse situation is called as negative allosteric modulation and the modulator is than called as a negative modulator (or inhibitor), e.g. (a) Citrate positively modulates or enhances the activity of acetyl-CoA carboxylase, which 98 ____ NSOU ● CC-ZO- 08 produces malonyl-CoA from acetyl-CoA and (b) Palmityl-CoA negatively modulates or suppresses the activity of acetyl-CoA carboxylase. The same modulating substance may act as a positive modulator for one enzyme but as a negative modulator for another enzyme, e.g. ATP is an allosteric activator for fructose diphosphatase which hydrolyzes fructose diphosphate into fructose 6-phosphate during glucogenesis, but ATP is an allosteric inhibitor of phosphofructokinase that converts fructose 6-phosphate to fructose diphosphate during glycolysis. 3.12.4 'K'and 'M' types of allosteric enzymes : Some allosteric enzymes are called 'K' enzymes. In presence of a positive modulator, their K m values are decreased and in presence of a negative modulator, their K m values are increased than in absence of any modulator. The V max remains unchanged in both conditions,e.g. Phosphofructokinase. Some allosteric enzymes are called 'M' enzymes. No change in their K m values occurs in presence of either a positive or a negative modulator. However, V max of an 'M' enzyme rises and falls in presence of a positive and a negative modulator, respectively, e.g. Acetyl-CoA carboxylase. K m and V max of 'K' and 'M' enzyme 3.12.5 Molecular mechanism of allosteric modulation: 1. 'M' enzymes: 'M' enzymes are very few in number (Lehninger, 1975). In case of 'M' enzymes, the binding of an allosteric modulator to the allosteric site of the enzyme causes a conformational change of only the catalytic site of the enzyme, which results in a change of velocity of the enzyme action, but the substrate affinity of the enzyme remains unaltered.

NSOU ● CC-ZO- 08 ____ 99 2. 'K' enzymes: The mechanism of allosteric modulation of 'K' enzymes is complex. A model, called as 'Sequential model' and proposed by D. E. Koshland in 1973, best explains the mechanism: Allosteric 'K' enzymes have multiple substrate-binding sites. In absence of any allosteric modulator, those sites remain in a 'partially accessible' conformation where the substrate molecules cannot bind firmly. As a +ve allosteric modulator binds to the allosteric site of the enzyme, a sequential or gradual change of conformation occurs in the enzyme so that its 'partially accessible' substrate-binding sites become 'fully accessible' one after another. As a result, the binding of the first substrate molecule to one substrate-binding site is followed by the binding of another substrate molecule to another substrate-binding site and so on. Apparently, the binding of the first substrate molecule to the enzyme seems to stimulate the binding of the subsequently substrate molecules to the enzyme; the phenomenon is called +ve cooperativity. The substrate-saturation curve of the enzyme becomes sigmoid and shifts to the left of the original hyperbolic curve. Again, when a –ve allosteric modulator binds to the allosteric site of the enzyme, a sequential change of conformation occurs in the enzyme so that its 'partially-accessible' substrate-binding sites become 'too less accessible' one after another. As a result, the binding of the first substrate molecule to one substrate-binding site is followed by negligible binding of the subsequent substrate molecules at other substrate-binding sites; the phenomenon is called –ve cooperativity. The substrate-saturation curve of the enzyme remains sigmoid, but the slope is so lowered that the curve shifts to the right of the original hyperbolic curve. 3.12.6 Non-competitive inhibition vs. allosteric inhibition: (a) A non-competitive inhibitor generally binds to the cofactor associated with the apoenzyme, but an allosteric inhibitor binds to a specific allosteric site on the apoenzyme itself [exception : a non-competitive inhibitor like Hg ++ or Ag + ion binds to SH on the apoenzyme of glyceraldehyde-3-phosphate dehydrogenase]. (b) A non-competitive inhibitor is an external agent applied from outside the body of living organisms, but an allosteric inhibitor is a cellular substance or metabolite. (c) A non-competitive inhibitor does not change the K m value of the enzyme. An allosteric inhibitor causes an increase of the K m value of the enzyme. (d) An enzyme undergoing non-competitive inhibition has a single substrate- binding site, but an enzyme undergoing allosteric inhibition has multiple substrate binding sites.

100 ____ NSOU ● CC-ZO- 08 (e) No cooperativity is found when the substrate binds to an enzyme undergoing non-competitive inhibition, but a –ve cooperativity is found when substrate molecules bind to an enzyme undergoing allosteric modulation. (f) The substrate-saturation curve is hyperbolic for the first type of enzyme, but becomes sigmoid for the second or allosteric type of enzyme, when an inhibitor effect goes on. 3.13 Covalent regulation of enzyme action Two types of covalent regulation are found : 3.13.1 Irreversible covalent activation : Some enzymes are secreted in an inactive precursor form or 'zymogen' form. These are then converted into an active form by an enzyme-catalysed hydrolytic process, which is a type of cleavage of covalent bond, e.g. Trypsinogen is a zymgogen secreted from pancreatic acinar cells. When it passes into the intestine, an intestinal enzyme called enterokinase cleaves a hexapeptide from its N-terminal and produces the active proteolytic enzyme trypsin. Again, pepsinogen is a zymogen secreted by stomach cells. It is converted into an active form called pepsin in the stomach by the action of already-formed pepsin at a low pH, which removes 42 amino acids as a few short peptides from the N-terminal end of pepsinogen. 3.13.2 Reversible covalent modification : Some enzymes may be reversibly activated or inactivated by change of covalent bond (e.g. addition or removal of phosphate or adenyl groups) by some enzymatic process, e.g. Phosphorylase phosphatase removes four phosphate groups from the active glycogen phosphorylase 'a' and produces two molecules of inactive glycogen phosporylase 'b'; phosphorylase kinase uses four ATP molecules to phosphorylate two molecules of glycogen phosporylase 'b' to produce one molecule of active glycogen phosphorylase 'a'. 3.14 Questions (with hints to answers) 1. What are enzymes? How do they differ from inorganic catalysts? [see Section 3.1]. 2. Classify enzymes and explain the functioning of each class with example [see Section3.2.1]. 3. Explain the terms: Enzyme code number; turnover number of enzymes; international unit of enzymes [see Section 3.2.2].

NSOU ● CC-ZO- 08 ____ 101 4. What are coenzymes? How do they act? [see Section 3.3.1]. 4. What are cofactors? How do they act? [see Section 3.3.2]. 5. Explain 'lock-and-key model' and 'induced-fit model' of enzyme-substrate binding. State the merit and demerit of each model [see Sections 3.4.1 and 3.4.2 I]. 6. Write a short note on isozymes [see Section 3.5.1]. 7. What are ribozymes? Cite examples from both pro- and eukaryotes [see Section 3.5.2]. 8. What do you mean by abzymes? [see Section 3.5.3]. 9. Explain the transition-state theory of enzyme action [[see Section 3.6.4]. 10. What is enzyme kinetics? How will you derive Michaelis-Menten equation? [see Section 3.7.1]. 11. What is K m of an enzyme? Prove that K m = [S], when v = V max /2 [see Section 3.7.2]. 12. Explain Lineweaver-Burk plot and its significance [see Section 3.8]. 13. Explain the principles of single-displacement and double-displacement enzyme actions[see Section 3.9]. 14. Explain the effect of substrate concentration on enzyme action [see Section 3.10.3]. 15. Explain the effect of temperature on enzyme action [see Section 3.10.5]. 16. Give an account of competitive inhibition [see Section 3.11.1]. 17. Give an account of non-competitive inhibition [see Section 3.11.2]. 18. What isallosteric modulation of enzymes? Define and exemplify positive and negative allosteric modulations.Distinguish between 'K'and 'M' types of allosteric enzymes. Explain the molecular mechanism of allosteric modulation [see Sections 3.12.1, 3.12.3, 3.12.4 and 3.12.5]. 19. Write notes on irreversible and reversible covalent modifications of enzymes [see Sections 3.13.1 and 3.13.2]. 3.15 References 1. Biochemistry – A. H. Lehninger (1975), Worth Publishers, New York. 2. Outlines of Biochemistry – Conn and Stumpf (1972), John Wiley, New York. 3. Principles of Biochemistry – Nelson and Cox (2005), Freeman & Co., New York. 4. Textbook of Biochemistry – West and Todd (1966), Macmillan, New York.

102 ____ NSOU ● CC-ZO- 08 Unit-4 Overview of Metabolism Structure 4.0. Objectives 4.1. Introduction 4.2. Anabolism vs. catabolism 4.3. Stages of catabolism 4.4. Compartmentalisation of metabolic pathways 4.4.1 Meaning and significance of compartmentalization 4.4.2 Examples of compartmentalization of metabolic pathways 4.5. Shuttle systems and membrane transporters 4.5.1 Definitions 4.5.2 Glycerophosphate shuttle 4.5.3 Malate-aspartate shuttle 4.6. ATP as 'energy currency' of cells 4.7. Use of reducing equivalents and cofactors 4.7.1 Use of reducing equivalents 4.7.2 Use of cofactors 4.8. Intermediary metabolism and regulatory mechanisms 4.8.1 Intermediary metabolism 4.8.2 Regulatory mechanisms 4.9. Questions 4.10. References 4.0 Objectives Upon going through this Unit IV, learners will be able to : ● Compare between anabolism and catabolism. ● Understand the stages of catabolism. 102

NSOU ● CC-ZO- 08 ____ 103 ● Understand the meaning and significance of compartmentalization of metabolic pathways. ● Cite various examples of compartmentalization of metabolic pathways. ● Understand the functioning of glycerophosphate shuttle. ● Understand the functioning ofmalate-aspartate shuttle. ● Understand why ATP is considered to be the 'energy currency' of cells. ● Know about the use of reducing equivalents in cells. ● Know about the use of cofactors in enzyme function. ● Grow knowledge of intermediary metabolism in cells. ● Grow knowledge of mechanisms regulating metabolic pathways in living beings. 4.1 Introduction Metabolism denotes all the biochemical processes that allow an organism to live, grow, reproduce, heal and adapt to its environment. Metabolism has two components: anabolism and catabolism. Anabolism refers to the process which builds molecules the body needs; it usually requires energy for completion. Catabolism refers to the process that breaks down complex molecules into smaller molecules; it usually releases energy for the organism to use. In this unit, various aspects of metabolism will be discussed. 4.2 Anabolism vs. catabolism 1. Anabolism refers to biochemical processes which build large and complex molecules needed by the body from simple molecules. Catabolism refers to biochemical processes which break down large molecules of the body into simple molecules. 2. Anabolic processes generally require energy for their completion. Catabolic processes generally release energy for utilization by the organism. 3. Anabolic processes are controlled by hormones like growth hormone, insulin, testosterone and estrogen. Catabolicprocesses are controlled by hormones like adrenaline, cortisol and glucagon. 4. Examples of anabolism include biosynthesis of polypeptides from many molecules of amino acids and glycogenesis or biosynthesis of glycogen from many molecules of glucose. Examples of catabolism include glycolysis or breakdown of a glucose molecule into two pyruvic acid molecules and glycogenolysis or breakdown of glycogen into many glucose molecules.

104 ____ NSOU ● CC-ZO- 08 4.3 Stages of catabolism Catabolism can be divided into 3 main stages. The three stages are as explained as follows : Stage 1–Stage of Digestion: The large organic molecules like polysaccharides, proteins andfats are digested into their smaller components (monomer units) outside cells. This stage acts mainly on starch, cellulose or proteins or fats that cannot be directly absorbed by the cells. After digestion, starch and cellulose are broken down into glucose; proteins are broken down into different amino acids and fats are broken down into fatty acids and glycerol. Stage 2 – Release of energy: Once the macromolecules are broken down into monomer units, the latter molecules are taken up by cells. Within the cells, those monomer units are converted into yet smaller molecules through different chemical pathways, along with the production of some amounts of NADH and FADH 2 molecules. Stage 3 – Energy Stored: Finally, NADH and FADH 2 molecules enter into the mitochondria of cells. Inside the mitochondria, electrons from NADH and FADH 2 are transported through the 'electron transport chain' (ETC). The transported electrons are combined with H + ions (protons) and molecular oxygen to produce water while the energy liberated from the transport of electrons is used to produce high-energy ATP molecules from ADP and P i (inorganic phosphate). ATP acts as the 'energy currency' of cells and provides energy required for various physiological functions carried out by living cells. 4.4 Compartmentalisation of metabolic pathways 4.4.1 Meaning and significance of compartmentalization : Different metabolic reactions occurring in cells take place in different spaces or compartments, which are separated from other compartments by means of semi permeablemembranes. Such compartments help to separate the microenvironments (pH, ionic environment etc.) and optimise the course of different metabolic reactions. Different enzymes act under different optimal conditions; therefore, compartmentalization provides proper optimal conditions for the activities of the enzymes required for different metabolic reactions. Moreover, compartmentalization allows proper distribution of the machinery required for different metabolic reactions and thereby prevents chaos in running different metabolic reactions, for instance, the electron transport chain being located on the mitochondrial inner membrane

NSOU ● CC-ZO- 08 ____ 105 facilitates a systematic flow of electrons and production of ATP by means of oxidative phosphorylation. 4.4.2 Examples of compartmentalization of metabolic pathways : Different cellular compartments for the occurrence of different metabolic reactions are as follows: (a) Cytosol (cytoplasm without organelles) : 1)Metabolism of carbohydrates: glycolysis, part of gluconeogenesis, glycogenolysis, glycogenesis, pentose phosphate pathway. 2) Metabolism of fatty acids: fatty acid synthesis. 3) Metabolism of amino acids: synthesis of nonessential amino acids, some of the transamination reactions. 4) Other pathways: parts of heme and urea synthesis, metabolism of purines and pyrimidines. (b) Mitochondria : 1) Metabolism of carbohydrates : part of gluconeogenesis (conversion of pyruvate to oxaloacetic acid). 2) Metabolism of fatty acids : beta-oxidation of fatty acids, synthesis and degradation of ketone bodies. 3) Metabolism of amino acids : oxidative deamination, some of the transamination reactions. 4) Other pathways : Krebs' cycle, electron transport chain and oxidative phosphorylation, parts of heme and urea synthesis. (c) Rough endoplasmic reticulum : 1) Protein synthesis (translation of mRNA). 2) Posttranslational modifications of proteins. (d) Smooth endoplasmic reticulum : 1) Triacylglycerol and phospholipid synthesis. 2) Fatty acid elongation (to a maximal length of 24 carbon atoms). 3) Part of steroid synthesis. 4) Biotransformation of xenobiotics. (e) Golgi complex : 1) Glycosylation of proteins and lipids.

106 ____ NSOU ● CC-ZO- 08 Schematic diagram of compartmentalized cell interior (Taken from Wikimedia Commons — https://commons.wikimedia.org/ wiki/ File : Animal_cell_structure_en.svg) 2) Protein sorting and formation of secretory vesicles. (f) Lysosomes : 1) Hydrolysis of carbohydrates, proteins,lipids and nucleic acids. (g) Peroxisomes : 1) Degradation of long-chain fatty acids (< 20 carbon atoms). 4.5 Shuttle systems and membrane transporters 4.5.1 Definitions : 'Shuttle system'denotes cellular 'membrane transporter systems' whichtransfer the reducing equivalents (electron and H + ion) from NADH (which is produced during glycolysis in the cytosol or ground cytoplasm) into the mitochondria across the outer and inner mitochondrial membranes. The two main shuttle systems are (i) ?-glycero phosphates huttle and (ii) malate-aspartate shuttle. The presence of shuttle systems is extremely important for the accomplishment of mitochondrial electron transport and ATP production - the inner mitochondrial membrane is impermeable to

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NSOU ● CC-ZO- 08 ____ 107 NADH. Therefore, electrons and protons from NADH must enter into the inner mitochondrial chamber by the help of shuttle systems, or else electron transport and ATP production will stop. 4.5.2 Glycerophosphate shuttle : (i) This shuttle system consists of two enzymes, glycerol 3-phosphate dehydrogenase of cytoplasm and flavoprotein dehydrogenase of the inner mitochondrial membrane. The first enzyme transfers H + and electron to dihydroxyacetone phosphate which thus gets reduced into glycerol 3-phosphate. (ii) Glycerol 3-phosphate diffuses through the outer mitochondrial membrane and reaches the outer surface of the inner mitochondrial membrane where it gives out H + and electron to the FAD part of flavin dehydrogenase; the FAD part thus gets reduced into FADH 2 while glycerol 3-phosphate is re-oxidized into dihydroxyacetone phosphate. (iii) Then, FADH 2 donates H + and electron to CoQ of mitochondrial electron transport chain. 4.5.3 Malate-aspartate shuttle : (i) Cytoplasmic malate dehydrogenasetransfers H + and electron from NADH to oxaloacetate which thus gets reduced into malate. (ii) Then, malate á-ketoglutarate transporter of the inner mitochondrial membrane transports the malate from cytoplasm into the mitochondrion in exchange of mitochondrial á-ketoglutarate. (iii) Thereafter, mitochondrial malate dehydrogenase transfers H + and electron from the malate to NAD + ; malate is thus re-oxidized into oxaloacetate and NAD + gets reduced into NADH. (iv) Finally, NADH transfers H + and electron from itself to the FMN part of NADH dehydrogenase of mitochondrial electron transport chain. 4.6 ATP as 'energy currency' of cells ATP or Adenosine triphosphate is a high-energy purine nucleotide found in all living cells. ATPpossesses two high-energy phosphate bonds in their molecules: the 3rdor g and the 2nd orbphosphate bonds of ATPare high-energy bonds while the 1st or aphosphate bond connected directly to the ribose sugar is a low-energy phosphate bond.The high-energy bonds of ATPor Adenosine triphosphateare hydrolyzed to provide energy for driving a large number of cellular processes.Hydrolysis of 1 mole of ATP into ADP releases 30 kilo joules or 7 kilo caloriesof energy.ATP is, therefore, called as the 'energy currency' of living cells. A few roles of ATP are cited below : (i) Active transport of Na + and K + :The enzyme Na + -K + -ATPase of plasma membrane catalyzes the hydrolysis of one ATP to ADP and Pi in one hand,

108 ____ NSOU ● CC-ZO- 08 and the carrier-mediated active transports of three Na + ions outwardand two K + ions inward across the plasma membrane against their respective concentration gradients. This role of ATP is essential for maintaining the polarized state of the membrane, higher extracellular concentration of Na + and higher intracellular concentration of K + . (ii) Phosphorylation of substrates: In many metabolic pathways, substrates or intermediates are phosphorylated into low-energy phosphate compounds such as glucose 6-phosphate, fructose 1,6-bisphosphate and glycerol 3-phosphate by respective phosphotransferase enzymes utilizing the high-energy phosphate bond of ATP. (iii) Cellular protein synthesis:The energy released from cleavage of ATP isutilized by amino acyl-tRNAsynthetase enzyme for the formation of amino acyl-tRNA, which represents the first step of biosynthesis of proteins in cells. (iv) Other physiological functions:The cleavage ofATP also provides the energy necessary for contraction of muscles, movement of cilia and flagella, exocytosis and endocytosis. 4.7 Use of reducing equivalents and cofactors : 4.7.1 Use of reducing equivalents : A reducing equivalent serves as the electron donor in a redox reaction (= oxidation-reduction reactionbetween two reactants)and becomes oxidized (loses electrons) when it donates an electron to an electron acceptor. A reducing equivalent can donate an electron in multiple forms: a lone electron, hydrogen atom, a hydride, or bond formation with an oxygen atom. Each form of reducing equivalent is characterized by the donation of at least one electron: (i) Lone electrons : In redox reactions involving metal ions, lone electrons can be transferred from the electron donor to the electron acceptor. That is, no other atoms or protons are transferred along with the electron in the redox reaction. The following reaction between iron and copper is a typical example: Fe Cu Fe Cu 2 2 3 + + + + + —→ —+ Redox reaction with iron and copper ions Iron ion serves as the reducing equivalent since it donates an electron to the copper ion.The iron and copper ion each begin the reaction with a double Iron (electron donor) Copper (electron acceptor)

NSOU ● CC-ZO- 08 ____ 109 positive charge (2+). At the end of the reaction, the charge on copper decreases to a single positive charge (1+) while the charge on iron increased to a triple positive charge (3+). The alteration of charges is due to the transfer of a single electron from the iron atom to the copper atom. As a result, iron is oxidized because it loses one of its electrons resulting in a greater positive charge. (ii) Hydrogen atom : A neutral hydrogen atom consists of one electron and one proton. Hydrogen's electronegativity is less than that of the atoms that hydrogen is commonly bound to, such as oxygen, nitrogen, carbon, or fluorine. When a hydrogen atom forms a covalent bond with a more electronegative atom, the latter will have a greater affinity for the electrons and pull the electrons away from hydrogen. When a highly electronegative atom binds to hydrogen atom, it is reduced because it gains the electrons involved in the covalent bond. Conversely, when an atom loses a hydrogen atom, it is oxidized because it loses electrons. For example, in the reaction involving Flavin Adenine Dinucleotide (FAD) and succinate, FAD is reduced to FADH 2 because it accepts two hydrogen atoms from succinate. Succinate serves as the reducing equivalent because it donates electrons to FAD in the form of hydrogen atoms and is itself oxidized. (iii) Hydride : A hydride is a hydrogen anion that carries two electrons and one proton. The chemical species that accepts a hydride ion will be reduced because it gains the electrons from the hydride ion. The reduced form of Nicotinamide Adenine Dinucleotide (NADH) is a reducing equivalent that donates a hydride ion to an electron acceptor in complex I of the mitochondrial electron transport chain. (iv) Bond formation with oxygen atom : A chemical species with a lower electronegativity than oxygen can serve as a reducing equivalent when it covalently binds to an oxygen atom. Oxygen is highly electronegative and will have a greater affinity for electrons in a covalent bond, resulting in the reduction of the oxygen atom. When an atom of lower electronegativity forms a bond with oxygen, it is oxidized because the electrons are pulled closer to oxygen and away from that atom. For instance, during the formation of carboxylic acid from the oxidation of an aldehyde, a carbon is oxidized through the formation of a covalent bond with oxygen : 110 ____ NSOU ● CC-ZO- 08 Formation of carboxylic acid from oxidation of aldehyde (v) Reducing equivalents in the mitochondrial electron transport chain : NADH and FADH 2 serve as reducing equivalents and donate electronsto the components of the mitochondrial electron transport chain.During aerobic oxidation, NADH and FADH 2 are produced in cells. NADH and FADH 2 enter into the mitochondria wherein electrons from these substances are transported through the 'electron transport chain' (ETC). The transported electrons are combined with H + ions (protons) and molecular oxygen to produce water while the energy liberated from the transport of electrons is used to produce ATP from ADP and P i (inorganic phosphate) by the help of ATP synthetase. The overall process of ATP production is called 'oxidative phosphorylation', because the substrates (viz. NADH and FADH 2) give out electrons for transport through the ETC and thus, get oxidized while ADP gets phosphorylated or added with phosphate for formation of ATP. 4.7.2 Use of cofactors : Sometimes, a metal ion instead of a coenzyme (non-protein organic compound) remains attached with the holoenzyme. Such a metal ion is called a cofactor. Enzymes to which the metal ions remain loosely bound are called metal-activated enzymes and enzymes to which the metal ions remain tightly bound are called metalloenzymes. Metal- activated enzymes contain alkali metals like Na + and K + or alkaline earth metals like Ca ++ and Mg ++ , but metalloenzymes contain transitional metals like Cu ++ , Cu + , Zn ++ etc. Metal ions help in the action of enzymes in different ways : (i) Metal ions may provide the proper three-dimensional conformation to the active site of an enzyme for binding to a substrate, e.g. pyruvate kinase requires Mg ++ ions while it transfers the phosphate group from phosphoenolpyruvate to ADP for production of ATP. (ii) A metal may help in substrate-binding by binding to the enzyme in one hand and to the substrate on the other, e.g. Enolase requires the help of Mg ++ ions when it binds to 2-phosphoglycerate to produce phosphoenolpyruvate.

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NSOU ● CC-ZO- 08 ____ 111 (iii) A metal ion may act as a donor or acceptor of electron to and from a substrate during an enzyme-catalyzed reaction, e.g. Cu ++ ions of plasma ceruloplasmin (an enzyme) can oxidize Fe ++ ions entering the plasma into Fe +++ ions. 4.8 Intermediary metabolism and regulatory mechanisms 4.8.1 Intermediary metabolism: Intermediary metabolism refers to such metabolic reactions that form link between two different metabolic pathways. Some examples are cited below: (i) Intermediary metabolism involving carbohydrate : Ordinarily glucose is catabolized in cells producing pyruvate (in aerobic condition) or lactate (in anaerobic condition). However, a part of glucose is converted to glycogen for stor-age, particularly, in liver and skeletal muscle. Again, the pentose phos-phate pathways arising from interme-diates of glycolysis is a source of re-ducing equivalents (2H) for biosyn-thesis of fatty acids and cholesteroland it is also a source of ribose which is important for nucleic acid biosynthesis. Moreover, glyceraldehydes-3-phosphate of glycolytic pathway is a precursor of glycerol of fat. Pyruvate of glycolytic pathway and different intermediates of Krebs' TCA cycle form various amino acids. (ii) Intermediary metabolism involving fat : Oxidation of fatty acids results in the formation of variable numbers of acetyl-CoA molecules which combine with oxaloacetate and enter into TCA cycle for complete oxidation and production of energy. (iii) Intermediary metabolism involving protein : Metabolism of different amino acids may yield pyruvate, acetyl-CoA or different intermediates of TCA cycle. For instance, serine converts into pyruvate by non-oxidative deamination; Ketogenic amino acids like leucine and tyrosine, after catabolism of their carbon-skeleton, produce acetoacetate which, in turn, converts into acetyl-CoA; Valine, isoleucine, methionine and threonine can change to succinyl-CoA due to metabolism of their carbon-skeleton. All such products may then undergo the final oxidation through TCA cycle along with production of energy. Again, metabolism of either the carbon-skeleton or the nitrogenous part of many amino acids produces gluconeogenic intermediates which are finally converted into glucose in the animal body.
112 ____ NSOU ● CC-ZO- 08 4.8.2 Regulatory mechanisms: The body of living beings possesses distinct regulatory mechanisms that regulate the rate of different metabolic pathways. A few examples are being cited here: (a) Regulation of glycolysis : (1) The rate-limiting step of glycolysis is production of fructose 1,6-diphosphate from fructose-6-phosphate by the catalytic action of phosphofructokinase. It has been found that physiological concentrations of ATP in cells tend to allosterically inhibit the activity of phosphofructokinase while physiological concentrations of AMP try to resist the inhibitory allosteric activity of ATP. So, a rise in ATP/AMP ratio in cells decreases while a rise in AMP/ATP ratio in cells increases the activity of phosphofructokinase and the rate of glycolysis. A 20% fall in ATP concentration raises the rate of glycolysis about tenfold. (2) Glycogen phosphorylase, which initiates glycolysis in muscles by converting glycogen into glucose-1-phosphate, exists in 2 forms : (a) inactive phosphorylase B, which has no phosphates on their serine residues and (b) active phosphorylase A, which has phosphorylated serine residues. Phosphorylase B is changed to the active phosphorylase a by phosphorylase kinase in presence of ATP. (3) Adrenaline enhances muscle glycolysis in 2 ways : (a) In skeletal and cardiac muscles, adrenaline activates adenylatecyclase which converts ATP into PPi and cAMP. The cAMP activates a protein kinase called cAMP-dependent protein kinase, which then uses ATP to phosphorylate and change phosphorylase kinase B into an active phosphorylase kinase A. Phosphorylase kinase a uses ATP to phosphorylate and change glycogen phosphorylase B into an active glycogen phosphorylase A, which initiates glycolysis. (b) In smooth muscles, adrenaline increases cytosolic Ca ++ concentration. Ca ++ ions bind to calmodulin subunits of phosphorylase kinase b, which thus gets activated and changes into an active phosphorylase kinase a without any need of phosphorylation. The kinase A phosphorylates glycogen phosphorylase B to generate an active glycogen phosphorylase A, which initiates glycolysis.

NSOU ● CC-ZO- 08 ____ 113 (4) Insulin secretion from the islets of Langerhans of pancreas increases when blood-glucose level rises. Insulin promotes glycolysis in 2 ways : (a) Insulin enhances biosynthesis of phosphofructokinase and pyruvate kinase, which enhances the rate of glycolysis. (b) Insulin also induces biosynthesis of hexokinase in kidney, brain and erythrocytes. Hexokinase catalyzes the first step of glycolysis. (5) In skeletal muscles, AMP concentration rises during heavy exercise. AMP then allosterically activates glycogen phosphorylase B, which can then catalyze conversion of glycogen into glucose-1-phosphate in spite of its so-called inactive form. (6) A rise in concentration of molecular O 2 depresses glycolysis in all aerobic cells. This is called Pasteur Effect. Aerobic metabolism through TCA cycle produces large amounts of ATP and citrate, which allosterically inhibit phosphofructokinase and reduces the rate of glycolysis. (ii) Regulation of TCA cycle : Three enzymes, viz., citrate synthase, isocitrate dehydrogenase and á- ketoglutarate dehydrogenase are the rate limiting enzymes of TCA cycle : (a) Citrate synthase is activated by the rise of concentrations of its substrates like acetyl-CoA and oxaloacetate. On the other hand, the enzyme is competitively inhibited by its product citrate. Moreover, the enzyme is inhibited by ATP and NADH. (b) Isocytrate dehydrogenase is activated by the rise of concentration of its substrate isocitrate. It is allosterically activated by ADP. Moreover, it is activated by the rise of intracellular concentration of Ca ++ ions. On the other hand, the enzyme is inhibited by ATP and NADH. (c) ?-ketoglutarate dehydrogenase is activated by Ca ++ ions, ADP and AMP. On the other hand, the enzyme is inhibited by ATP and NADH. 4.9 Questions (with hints to answers) 1. Define metabolism. Comapare anabolism and catabolism (see Sections 4.1 and 4.2). 2. Explain the stages of catabolism (see Section 4.3). 3. Give an account of the meaning and significance of compartmentalization of metabolic pathways (see Section 4.4.1).
114 ____ NSOU ● CC-ZO- 08 4. Cite any four examples of compartmentalization of metabolic pathways (see Section 4.4.2). 5. What are shuttle systems and membrane transporters? Describe the functioning ofglycerophosphate shuttle and malate-aspartate shuttle(see Sections 4.5.1, 4.5.2 and 4.5.3). 6. Why is ATP considered to be the 'energy currency' of cells? (see Section 4.6). 7. What are reducing equivalents? Explain their different forms (see Section 4.7.1). 8. What are cofactors ? State their functional significance (see Section 4.7.2). 9. Define and exemplify intermediary metabolism (see Section 4.8.1). 10. Give a brief account of regulation of glycolysis (see Section 4.8.2). 4.10 References 1. Biochemistry – A. H. Lehninger (1975), Worth Publishers, New York. 2. Biochemistry – Debajyoti Das (2005), Academic Publishers, Kolkata. 3. Outlines of Biochemistry – Conn and Stumpf (1972), John Wiley, New York. 4. Principles of Biochemistry – Nelson and Cox (2005), Freeman & Co., New York. 5. Textbook of Biochemistry – West and Todd (1966), Macmillan, New York.
NSOU ● CC-ZO- 08 ____ 115 Unit-5 Carbohydrate Metabolism Structure 5.0. Objectives 5.1. Introduction 5.2. Glycolysis and its regulation 5.2.1 Process of glycolysis 5.2.2 Regulation of glycolysis 5.3. Citric acid cycle 5.3.1 Description of TCA cycle 5.3.2 Anabolic role of the cycle 5.3.3 Regulation of TCA cycle 5.3.4 Integration of carbohydrate, fat and protein metabolism 5.4. Pentose phosphate pathway 5.4.1 Detailed account of the pathway 5.4.2 Significance of pentose phosphate pathway 5.5. Gluconeogenesis 5.5.1 Gluconeogenesis from glycerol 5.5.2 Gluconeogenesis from lactate 5.5.3 Gluconeogenesis from propionate 5.5.4 Gluconeogenesis from amino acids 5.6. Glycogenolysis 5.7. Glycogenesis 5.8. Questions 5.9. References 5.0 Objectives After studying the topics included in this chapter, you will be able to : ? Define carbohydrate metabolism. ? Have knowledge of glycolysis and its regulation. ? Develop gross knowledge of TCA cycle. ? Have knowledge of integration of carbohydrate, fat and protein metabolism through TCA cycle. ? Have knowledge of regulation of TCA cycle in aerobic cells. 115

116 ____ NSOU ● CC-ZO- 08 ? Have thorough knowledge of pentose phosphate pathway and its significance. ? Develop thorough knowledge of gluconeogenesis from a wide variety of substrates. ? Develop thorough concept of glycogenolysis with special reference to rate limiting steps. ? Have thorough knowledge of Glycogenesis. 5.1 Introduction Carbohydrates consumed with food are hydrolyzed into monosaccharides in the small intestine and the monosaccharides are absorbed from the intestinal mucosa. The principal monosaccharide obtained from different carbohydrates is glucose. Another monosaccharide, fructose obtained from digestion of certain dietary carbohydrates is largely converted into glucose in the liver. Glucose is transported to different tissues of the body by means of blood circulation. Glucose undergoes chemical transformations in different tissues for either producing energy or for production of storage carbohydrate (glycogen) and various useful substances (glycoprotein, glycolipid and nucleic acid etc.) in the body. All kinds of chemical transformations of glucose in the body are called as carbohydrate metabolism. The synthesis of glycogen from glucose in liver and muscles is called glycogenesis. On the other hand, the breakdown of glycogen in liver into glucose is called glycogenolysis. Glucose is utilized for energy production in all tissues of the body. When muscles work for very brief periods (less than 2 minutes), glucose is anaerobically converted into lactic acid with the production of only two molecules of ATP per molecule of glucose ; the process is called as anaerobic glycolysis. On the other hand, in all tissues of the body as well as in muscles working for a considerable period, glucose undergoes glycolysis in presence of oxygen and converts into pyruvic acid which enters into Krebs' TCA cycle for complete oxidation ; aerobic glycolysis followed by TCA cycle produces as many as 38 molecules of ATP per molecule of glucose. Those ATP molecules are used for various activities of different kinds of cells. 5.2 Glycolysis and its regulation 5.2.1 Process of glycolysis : The anaerobic degradation of the 6-carbon sugar, glucose in the cytosol of living cells into two 3-carbon pyruvic acid or lactic acid alongwith production some amount of ATP molecules is called as glycolysis. The series of reactions in glycolysis is called Embden-Meyerho f-Parnas pathway or EMP pathway after the name of the discoverers. Starting-points and end-points of EMP pathway : In liver, cardiac and skeletal muscles, glycolysis starts from glycogen as such, but in kidney, brain and NSOU ● CC-ZO- 08 ____ 117 RBCs, it starts from glucose, as these tissues store little glycogen. In strictly anaerobic condition, glycolysis ends in formation of lactic acid, but in aerobic cells, glycolysis ends in formation of pyruvic acid which then enters into TCA cycle for complete oxidation. Embden-Meyerhof-Parnas pathway of glycolysis : (1) Formation of glucose-6-phosphate :In liver, cardiac and skeletal muscles, glycogen reacts with inorganic phosphate under the catalytic action of glycogen phosphorylase. Glucose-1-phosphate is produced and it converts into glucose-6-phosphate by the catalytic action of phosphoglucomutase. In brain, kidneys and RBCs, glucose is phosphorylated in presence of ATP with the help of hexokinase and glucose-6-phosphate is produced. (2) Formation of fructose-6-phosphate : Then, glucose-6-phosphate is isomerised into fructose-6-phosphate by the catalytic action of phosphoglucose isomerase. (3) Formation fructose-1, 6-diphosphate : Fructose-6-phosphate is then phosphorylated to fructose-1, 6-diphosphate in presence of ATP by the help of phosphofructokinase (PFK). Muscle PFK is a distinct isozyme, compared to that found in liver and RBCs and kidneys. (4) Formation of glycerol dehyde-3-phosphate :Fructose-1, 6-diphosphate is then cleaved by the enzyme aldolase into two triose phosphates, glycerol dehyde-3-phosphate and dihydroxyacetone phosphate. Each has 3 carbons while a hexose has 6 carbons. Aldolase occurs as 3 isozymes in mammalian body ; aldolase A occurs in the muscles, aldolase B in liver and kidneys while aldolase C occurs in brain. (5) Interconversion of dihydroxyacetone phosphate :Soon, dihydroxyacetone phosphate interconverts into glycerol dehyde-3-phosphate by the enzyme triose phosphate isomerase. Thus, in the long run, 2 glyceraldehyde-3- phosphates are produced from one fructose-1, 6-diphosphate. (6) Formation of 1, 3-diphosphoglyceric acid :Each glycerol dehyde-3- phosphate is oxidized and phosphorylated in presence of NAD + , H 2 O and inorganic phosphate by the help of glyceraldehydes-3-phosphate dehydrogenase. The products are 1, 3-diphosphoglyceric acid, NADH and H + ion. (7) Formation of 3-phosphoglyceric acid : An enzyme, phosphoglycerate kinase transfers the phosphate group of 1 st carbon of diphosphoglyceric acid to an ADP. Thus, 3-phosphoglyceric acid and an ATP are produced. (8) Formation of 2-phosphoglyceric acid : 3-phosphoglyceric acid is then isomerised into 2-phosphoglyceric acid by the enzyme phospho- glyceromutase. (9) Formation of phosphoenolpyruvic acid :2-phosphoglyceric acid is then dehydrated into phosphoenolpyruvic acid by the action of enolase.

118 ____ NSOU ● CC-ZO- 08 (10) Formation of pyruvic acid : Then, pyruvic kinase transfers the phosphate group from phosphoenolpyruvic acid to an ADP. Thus, enolpyruvic acid and an ATP are produced. Enolpyruvic acid spontaneously changes into keto- pyruvic acid. Thus, from one initial glucose molecule, 2 pyruvic acid molecules, each with 3 carbons, are formed. (11) Formation of lactic acid : Under strictly anaerobic conditions, each pyruvic acid is reduced in presence of NADH and H + by the help of lactate dehydrogenase. In consequence, lactic acid and NAD + are produced. Comments : (1) The enzyme hexokinase, phosphor fructokinase, phosphoglycerate kinase and enolase require Mg ++ ions for their activities. (2) Pancreatic insulin stimulates glycolysis by inducing the synthesis of hexokinase, phosphofructokinase and pyruvate kinase. (3) Adrenal medullary adrenalin promotes glycolysis by activating muscle glycogen phosphorylase. (4) Glycolysis and lactate formation are depressed in presence of high amount of oxygen ; this is called as Pateur effect. (5) Genetic deficiency of glycogen phosphorylase in muscles lead to type V glycogenosis and that of phosphofructokinase in muscles lead to type VII glycogenosis ; both are characterized by reduced glycolysis and high glycogen in muscles. Production of high-energy phosphate bonds or ATP in glycolysis : Reaction Enzyme ATP produced In In presence of absence of O 2 O 2 1. 1, 3-diphosphoglyceric acid? Phosphoglycerate 1×2 = 2 1×2 = 2 3- phosphoglyceric acid kinase 2. Phosphoenol pyruvic acid? Pyruvate kinase 1×2 = 2 1×2 = 2 enolpyruvic acid 3. NADH ? NAD + Mitochondrial 3×2 = 6 0 respiratory-chain enzymes Total = 10 Total = 4 Utilisation of ATP: (1) Glucose ? Glucose-6- phosphate = = 1 = 1 (2) Fructose-6-phosphate?Fructose-1, 6-diphosphate = = 1 = 1 Net Gain of ATP : = 8 = 2

NSOU ● CC-ZO- 08 ____ 119 Process of glycolysis (contd. to next page)

120 ____ NSOU ● CC-ZO- 08 Process of glycolysis (contd. from previous page)

NSOU ● CC-ZO- 08 ____ 121 5.2.2 Regulation of glycolysis: (1) The rate-limiting step of glycolysis is production of fructose 1,6-diphosphate from fructose-6-phosphate by the catalytic action of phosphofructokinase. It has been found that physiological concentrations of ATP in cells tend to allosterically inhibit the activity of phosphofructokinase while physiological concentrations of AMP try to resist the inhibitory allosteric activity of ATP. So, a rise in ATP/AMP ratio in cells decreases while a rise in AMP/ATP ratio in cells increases the activity of phosphofructokinase and the rate of glycolysis. A 20% fall in ATP concentration raises the rate of glycolysis about tenfold. (2) Glycogen phosphorylase, which initiates glycolysis in muscles by converting glycogen into glucose-1-phosphate, exists in 2 forms : (a) inactive phosphorylase b, which has no phosphates on their serine residues and (b) active phosphorylase a, which has phosphorylated serine residues. Phosphorylase b is changed to the active phosphorylase a by phosphorylase kinase in presence of ATP. The enzyme phosphorylase kinase itself occurs in an inactive form called as phosphorylase kinase b and an active form called as phosphorylase kinase a. The inactive kinase b changes into the active kinase a when serine residues of the former get phosphorylated by cAMP-dependent protein kinase. The active phosphorylase kinase a then phosphorylates glycogen phosphorylase b, producing the active glycogen phosphorylase a. This enhances the rate of glycolysis in muscles [Fig. 7(iv)]. On the other hand, an enzyme, protein phosphatase-I can cleave phosphate groups from phosphoserine and can thus change glycogen phosphorylase a into the inactive glycogen phosphorylase b and can also change phosphorylase kinase a into the inactive phosphorylase kinase b. (3) Adrenaline enhances muscle glycolysis in 2 ways : (a) In skeletal and cardiac muscles, adrenaline activates adenylate cyclase which converts ATP into PPi and cAMP. The cAMP activates a protein kinase called cAMP-dependent protein kinase, which then uses ATP to phosphorylate and change phosphorylase kinase b into an active phosphorylase kinase a. Phosphorylase kinase a uses ATP to phosphorylate and change glycogen phosphorylase b into an active glycogen phosphorylase a, which initiates glycolysis. (b) In smooth muscles, adrenaline increases cytosolic Ca ++ concentration. Ca ++ ions bind to calmodulin subunits of phosphorylase kinase b, which thus gets activated and changes into an active phosphorylase kinase a without any need of phosphorylation. The kinase a phosphorylates glycogen phosphorylase b to generate an active glycogen phosphorylase a, which initiates glycolysis.

122 ____ NSOU ● CC-ZO- 08 Regulation of muscle glycogen phosphorylase (4) Insulin secretion from the islets of Langerhans of pancreas increases when blood-glucose level rises. Insulin promotes glycolysis in 2 ways : (a) Insulin enhances biosynthesis of phosphofructokinase and pyruvate kinase, which enhances the rate of glycolysis. (b) Insulin also induces biosynthesis of hexokinase in kidney, brain and erythrocytes. Hexokinase catalyzes the first step of glycolysis. (5) In skeletal muscles, AMP concentration rises during heavy exercise. AMP then allosterically activates glycogen phosphorylase b, which can then catalyze conversion of glycogen into glucose-1-phosphate in spite of its so-called inactive form. (6) A rise in concentration of molecular O 2 depresses glycolysis in all aerobic cells. This is called Pasteur Effect. Aerobic metabolism through TCA cycle produces large amounts of ATP and citrate, which allosterically inhibit phosphofructokinase and reduces the rate of glycolysis. Aerobic metabolism also uses up ADP and Pi for ATP production; depletion of ADP and Pi lowers the activity of phosphoglycerate kinase and pyruvate kinase. (7) Certain chemicals may inhibit glycolysis by inhibiting the activity of some particular enzymes, e.g. Fluoride inhibits the activity of enolase while iodoacetate inhibits the activity of glyceraldehyde-3-phosphate dehydrogenase. 5.3 Citric Acid Cycle : 5.3.1 Description of TCA Cycle : Pyruvic acid produced in the cytosol of cells from glycolytic breakdown of glucose undergoes a final oxidation through the TCA cycle or Tricarboxytic acid cycle inside the mitochondria. TCA cycle is a cyclic series of reactions, occurring in NSOU ● CC-ZO- 08 ____ 123 presence of oxygen, inside the mitochondrial matrix of living, aerobic cells. The cycle was originally described by Sir Hans Krebs in 1937 and hence, it is also called as Krebs' cycle or Krebs' TCA cycle. The cycle is described below [Fig.7(i)] : (i) Pyruvic acid passes from cytosol to mitochondrial matrix where it undergoes oxidative decarboxylation in presence of NAD + and also reacts with coenzyme A (CoA.SH) with the help of a multienzyme complex, called pyruvate dehydrogenase system, resulting in the formation of acetyl-CoA, CO 2 , NADH and H + . (ii) Now, acetyl-CoA enters into TCA cycle. It combines with oxaloacetate of the cycle and water to form citrate by the help of citrate synthase enzyme. (iii) Citrate is then isomerised into isocitrate by the help of aconitase. (iv) Isocitrate gets dehydrogenated and decarboxylated in presence of NAD + with the help of isocitrate dehydrogenase to yield a-ketoglutarate, CO 2 , NADH and H + . (v) a-ketoglutarate then undergoes dehydrogenation and decarboxylation in presence of NAD + and CoA.SH by the help of a-ketoglutarate dehydrogenase system. Succinyl-CoA, CO 2 , NADH and H + are produced. (vi) Succinyl-CoA is then hydrolyzed in presence of GDP, P i and water by the help of succinate thiokinase. Succinate, CoA.SH and GTP are produced. (vii) Succinate is then dehydrogenated in presence of FAD by the help of succinate dehydrogenase. Fumarate and FADH 2 are produced. (viii) Fumarate then combines with water by the help of fumarase and malate is produced. (ix) Finally, malate is dehydrogenated in presence of NAD + by the help of malate dehydrogenase. Oxaloacetate, NADH and H + are produced. Oxaloacetate is recycled for further continuation of TCA cycle. Energy output : The complete oxidation of each molecule of pyruvic acid is accompanied by production of 15 molecules of high-energy phosphates (ATP). Of these 15 molecules, 3 are formed when the pyruvate gives rise to acetyl CoA and the other 12 are produced when acetyl CoA is oxidized through the Krebs cycle. Now, 2 molecules of pyruvic acid are produced in glycolytic breakdown of 1 molecule of glucose. So, 30 (or 15×2) molecules of high-energy phosphate (ATP) are produced during the complete oxidation of those 2 pyruvates. Further, 8 molecules of high-energy phosphates (ATP) are produced during glycolytic breakdown of glucose (production of 2 pyruvates from a glucose molecule). So, the net gain of high-energy phosphates during the complete oxidation of a glucose molecule (starting from glycolysis upto the end of Krebs' cycle) is 8+30 = 38 molecules of high-energy phosphates or ATP.
124 ____ NSOU ● CC-ZO- 08 5.3.2 Anabolic role of the cycle : Different intermediates produced in TCA cycle are used in many synthetic reactions of various cells. These synthetic reactions indicate an anabolic role of TCA cycle : Krebs' Tricarboxylic Acid Cycle

NSOU ● CC-ZO- 08 ____ 125 (a) Fatty acid biosynthesis :In hepatocytes, adipocytes and lactating mammary gland cells, acetyl-CoA is utilized in de novo synthesis of fatty acids in the cytosol. Mainly palmitic acid is synthesized from acetyl-CoA. (b) Cholesterol synthesis :Acetyl-CoA is also used for extra-mitochondrial synthesis of cholesterol. (c) Biosynthesis of heme :Succinyl-CoA is used in erythroid cells and hepatocytes for the biosynthesis of heme. A mitochondrial enzyme called ALA-synthase condenses succinyl-CoA with glycine to produce á-amino-â- ketoadipic acid which is soon decarboxylated into ?-aminolevulinic acid (ALA). Finally, ALA is used for synthesis of heme. (d)Gluconeogenesis :Malate and oxaloacetate may be utilized for gluconeogenesis. (e)Amino acid biosynthesis : á-ketoglutarate and oxaloacetate are transaminated by specific transaminase enzymes into glutamic acid and aspartic acid, respectively. 5.3.3 Regulation of TCA cycle : Three enzymes, viz., citrate synthase, isocitrate dehydrogenase and á- ketoglutarate dehydrogenase are the rate limiting enzymes of TCA cycle : (a) Citrate synthase is activated by the rise of concentrations of its substrates like acetyl-CoA and oxaloacetate. On the other hand, the enzyme is competitively inhibited by its product citrate. Moreover, the enzyme is inhibited by ATP and NADH. (b) Isocytrate dehydrogenase is activated by the rise of concentration of its substrate isocitrate. It is allosterically activated by ADP. Moreover, it is activated by the rise of intracellular concentration of Ca ++ ions. On the other hand, the enzyme is inhibited by ATP and NADH. (c) ?-ketoglutarate dehydrogenase is activated by Ca ++ ions, ADP and AMP. On the other hand, the enzyme is inhibited by ATP and NADH. 5.3.4 integration of carbohydrate, protein and lipid metabolism through tca cycle : TCA cycle or 'Tricarboxylic acid cycle' is a cyclic series of reactions, occurring in presence of oxygen inside the mitochondrial matrix of living cells. The cycle was originally described by Sir Hans Krebs in 1937 to account for the oxidation of pyruvic acid into CO 2 and water.

126 ____ NSOU ● CC-ZO- 08 In fact, TCA cycle serves as a common pathway for the final oxidation of all food-stuffs like carbohydrates, proteins and fats. Pyruvic acid produced from glycolytic degradation of glucose, acetyl CoA produced from oxidation of fatty acids and various products of catabolism of different amino acids are finally oxidized through TCA cycle. Thus, TCA cycle is a 'metabolic pool' through which the metabolism of all kinds of food-stuffs is integrated [Fig. 7(ii)]. Link between carbohydrate metabolism and TCA cycle : The final oxidation of pyruvic acid produced in the cytosol from glycolytic degradation of glucose occurs through TCA cycle, resulting in yield of CO 2 and water (E. E. Conn and P. K. Stumpf, Outlines of Biochemistry, 3 rd edition, 1972, John Wiley, New jersey] : The steps are as follows : (i) Pyruvic acid passes from cytosol to mitochondrial matrix and undergoes oxidative decarboxylation in presence of NAD + and also reacts with coenzyme A with the help of a multienzyme complex, called pyruvate dehydrogenase system, resulting in the formation of acetyl-CoA, CO 2 , NADH and H + . (ii) Acetyl-CoA enters into TCA cycle. It combines with oxaloacetate of the cycle and water to form citrate by the help of citrate synthase. (iii) Citrate is isomerised into isocitrate by the help of aconitase. (iv) Isocitrate gets dehydrogenated and decarboxylated in presence of NAD + with the help of isocitrate dehydrogenase to yield a-ketoglutarate, CO 2 , NADH and H + . (v) ?-ketoglutarate undergoes dehydrogenation and decarboxylation in presence of NAD + and CoA.SH by the help of ?-ketoglutarate dehydrogenase system. Succinyl-CoA, CO 2 , NADH and H + are produced. (vi) Succinyl-CoA is hydrolyzed in presence of GDP, P i and water by the help of succinate thiokinase. Succinate, CoA.SH and GTP are produced. (vii) Succinate is dehydrogenated in presence of FAD by the help of succinate dehydrogenase. Fumarate and FADH 2 are produced.

NSOU ● CC-ZO- 08 ____ 127 Integration of carbohydrate, protein and lipid metabolism through TCA cycle (viii) Fumarate combines with water by the help of fumarase and malate is produced. (ix) Finally, malate is dehydrogenated in presence of NAD + by the help of malate dehydrogenase. Oxaloacetate, NADH and H + are produced. Oxaloacetate is recycled for further continuation of TCA cycle.

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128 ____ NSOU ● CC-ZO- 08 Link between fat metabolism and TCA cycle : Oxidation of fatty acids results in the formation of variable numbers of acetyl-CoA molecules which combine with oxaloacetate and enter into TCA cycle for complete oxidation as shown below : Link between protein metabolism and TCA cycle : Metabolism of different amino acids may yield pyruvate, acetyl-CoA or different intermediates of TCA cycle. All such products may then undergo the final oxidation through TCA cycle : (1) Formation of pyruvate from amino acids : Cystine breaks into two cysteines which then give rise to pyruvates by both transamination and oxidative deamination. Serine converts into pyruvate by non-oxidative deamination. Tryptophan and glycine may convert into alanine and serine, respectively and the latter two amino acids then convert into pyruvate by non-oxidative deamination. Finally, pyruvate is oxidized through TCA cycle [Fig. 7(iii)]. Formation of pyruvate from amino acids (2) Formation of acetyl-CoA from amino acids : Ketogenic amino acids like leucine and tyrosine, after catabolism of their carbon-skeleton, produce acetoacetate which, in turn, converts into acetyl-CoA. Phenylalanine can change to tyrosine which later produces acetyl-CoA. Finally, acetyl-CoA is oxidized through TCA cycle.

NSOU ● CC-ZO- 08 ____ 129 (3) Formation of ?????-ketoglutarate from amino acids : Glutamic acid changes to ?-ketoglutarate by transamination. Again, histidine, arginine, proline and ornithine may give rise to glutamic acid by catabolism of their carbon-skeleton and thereafter, glutamic acid produces ?-ketoglutarate which finally, enters into TCA cycle for oxidation. (4) Formation of succinyl-CoA from amino acids : Valine, isoleucine, methionine and threonine can change to succinyl-CoA due to metabolism of their carbon-skeleton. Then, succinyl-CoA is oxidized through TCA cycle inside the mitochondria. (5) Formation of fumarate from amino acids : Metabolism of the carbon- skeleton of tyrosine can produce fumarate; phenylanine may change to tyrosine which in turn can produce fumarate. Asparatic acid may give rise to fumarate during urea synthesis and purine synthesis. Fumarate is then oxidized through TCA cycle. (6) Formation of oxaloacetate from amino acids : Transamination of aspartic acid produces oxaloacetate which then may enter into TCA cycle for continuation of the cycle. Comments : (i) Thus, TCA cycle serves as a 'common final pathway' through which the final oxidation of all kinds of foodstuffs, viz., carbohydrates, proteins and fats, takes place. (ii) The number of high-energy phosphate produced depends on which substrate gets oxidized through TCA cycle. When pyruvate is oxidized, 15 high-energy phosphates are produced per pyruvate. If an acetyl-CoA is oxidized, 12 high- energy phosphates are produced. Again, 9, 6 and 3 high engery phosphates are produced from oxidation of ?-ketoglutarate, succinyl-CoA and fumarate, respectively, through TCA cycle. (iii) Besides, TCA cycle not only acts as a catabolic pathway. Different anabolic pathways may start from the intermediates of TCA cycle. For instance, citrate may be used for synthesis of fatty acids and steroids; ?-ketoglutarate and oxaloacetate may be used for synthesis of different amino acids; again, ?- ketoglutarate, succinyl-CoA, fumarate and oxaloacetate may be used for gluconeogenesis. 5.4 Pentose Phosphate Pathway The principal route of carbohydrate metabolism in most animal tissues involves glycolytic pathway coupled with oxidation in the TCA cycle. However, the 'Pentose

130 ____ NSOU ● CC-ZO- 08 phosphate pathway' or 'Hexose monophosphate shunt' or 'Warburg-Dickens-Lipman pathway' or 'Phosphogluconate pathway' provides an alternative route of carbohydrate metabolism in certain tissues. Occurrence : Pentose phosphate pathway occurs in the adrenal cortex, testis, liver, adipose tissue, lactating mammary gland, leucocytes and to some extent, in the RBCs. The reactions occur in the cytosol of cells. 5.4.1 Detailed account of the pathway : (A) Oxidative phase : Formation of pentose phosphates from glucose-6- phosphate : Step I : At first, glucose-6-phosphate is oxidized by dehydrogenation to 6-phosphogluconolactone by glucose-6-phosphate dehydrogenase in presence of Mg ++ ions and NADP + . After the reaction, NADP + is reduced to NADPH. Step II : Now, 6-phosphogluconolactone is hydrolysed into 6-phosphogluconic acid by the action of gluconolactonase in presence of Mg ++ ions and water. Step III : Then, 6-phosphogluconic acid is oxidized by dehydrogenation and also decarboxylated to form a pentose phosphate called D-ribulose-5-phosphate by the help of 6-phosphogluconate dehydrogenase in presence of Mg ++ ions and NADP + . After the reaction, CO 2 and NADPH are also produced. Step IV : (a) In one hand, D-ribulose-5-phosphate is isomerised to D-ribose-5- phosphate by the enzyme phosphoriboisomerase. (b) On the other hand, D-ribulose-5-phosphate is isomerised into D-xylulose-5-phosphate by the enzyme phosphoketopentoepimerase. Comment : In this way, starting from 3 molecules of glucose-6-phosphate are initially produced 3 molecules of D-ribulose-5-phosphate and 3 molecules of CO 2 . Then, one D-ribulose-5-phosphate converts into D-ribose-5-phosphate while the rest two convert into two D-xylulose-5-phosphates.

NSOU ● CC-ZO- 08 ____ 131 Oxidative phase of pentose phosphate pathway : Formation of pentose phosphate (B) Non-oxidative phase : Conversion of pentose phosphates into hexose phosphates: Step I : (a) In presence of Mg ++ ions and TPP (thiamine pyrophosphate), a transketolase enzyme transfers the ketol group (CO-CH 2 OH) from D-xylulose-5- phosphate to the 1st carbon of D-ribose-5-phosphate. As a result, D-sedoheptulose-
132 ____ NSOU ● CC-ZO- 08 7-phosphate (with 7 carbons) and D-glyceraldehyde-3-phosphate (with 3 carbons) are produced. (b) D-sedoheptulose -7-phosphate and D-glyceraldehyde-3-phosphate immediately react with each other under the catalysis of transaldolase to form D-fructose-6-phosphate (with 6 carbons) and D-erythrose-4-phosphate (with 4 carbons). Step II :Now, the remaining D-xylulose-5-phosphate reacts with D-erythrose-4- phsphate under the catalysis of transketolase in presence of Mg ++ ions and TPP. The ketol group (CO-CH 2 OH) of the former is transferred to the 1st carbon of the latter. As a result, a D-fructose-6-phosphate and a D-glyceraldehyde-3-phosphate are formed. Non-oxidative phase of pentose phosphate pathway : Conversion of pentose phosphates into hexose phosphates
NSOU ● CC-ZO- 08 ____ 133 Net products : Thus, originally starting from 3 molecules of glucose-6- phosphate, the following are obtained : (i) 2 molecules of D-fructose-6-phosphate, (ii) 1 molecule of D-glyceraldehyde-3-phosphate, (iii) 3 molecules of CO 2 and (iv) 6 molecules of NADPH. The first two [(i) and (ii)] are produced in the non-oxidative phase and the last two [(iii) and (iv)] in the oxidative phase of the pentose phosphate pathway. Comment : Of the above products, fructose-6-phosphate may be isomerised into glucose-6-phosphate by phosphoglucose isomerase and glucose-6-phosphate may be then recycled for further continuation of the pentose phosphate pathway. 5.4.2 Significance of pentose phosphate pathway : (i) This pathway provides an alternative route of carbohydrate metabolism, which is independent of glycolysis and TCA cycle. (ii) This pathway helps in production of pentose phosphates and their inter- conversion with hexose phosphates. (iii) Ribose-5-phosphate produced by this pathway may be used for synthesis of nucleic acids. (iv) NADPH obtained from the pathway may be used as a reducing agent during fatty acid and cholesterol biosynthesis. (v) NADPH is used in RBCs for reduction of 'oxidized glutathione' into 'reduced glutathione' by the enzyme glutathione reductase. Reduced glutathione is then used by glutathione peroxidase for removal of H 2 O 2 , which tends to oxidize haemoglobin into methemoglobin and reduce the life- span of RBCs. (vi) NADPH obtained from this pathway may be oxidized into NADP in mitochondria by electon-transport chain. During the oxidation of each NADPH, 3 ATP molecules are produced. When one glucose-6-phosphate enters into pentose phosphate pathway, only one of its carbons is oxidized and 2 NADPH are produced. A glucose-6-phosphate shall enter into the pathway six times for oxidation of all its six carbons and this will produce 12 NADPH. Mitochondrial oxidation of 12 NADPH will be accompanied by production of 12 × 3 = 36 ATP molecules, which is comparable to that obtained from glycolysis-TCA cycle. However, NADPH is rarely oxidized in the mitochondria.
134 ____ NSOU ● CC-ZO- 08 5.5 Gluconeogenesis The formation of carbohydrates in animal body from non-carbohydrates like glycerol, lactate, pyruvate and amino acids is called gluconeogenesis. During gluconeogenesis, some of the steps of glycolysis or TCA cycle may simply be reversed by the same enzymes catalyzing forward reactions or by separate enzymes. 5.5.1 Gluconeogenesis from glycerol : Occurrence : Gluconeogenesis from glycerol is accomplished through a chain of reactions in the cellular cytosol in liver and kidneys. Process : (i) Glycerol is phosphorylated in presence of ATP to L-a-glycerophosphate with the help of glycerokinase. (ii) L-a-glycerophosphate is then oxidized in presence of NAD + to either dihydroxyacetone phosphate or glyceraldehyde-3-phosphate with the help of a-glycerophosphate dehydrogenase. (iii) Dihydroxyacetone phosphate and glyceraldehydes-3-phosphate combine with the help of aldolase B to form fructose-1, 6-diphosphate. (iv) Fructose-1, 6-diphosphate is then hydrolysed by Fructose-1, 6-diphosphatase to yield fructose-6-phosphate and inorganic phosphate. (v)Fructose-6-phosphate is isomerised into glucose-6-phosphate by phosphoglucose isomerase. (vi) Glucose-6-phosphate then changes into either glucose by glucose-6- phosphatase (not hexokinase) or glycogen by the process of glycogenesis. Comments : (i) Adrenal glucocorticoids and adrenaline, and pancreatic glucagon stimulate gluconeogenesis from glycerol by inducing the synthesis of fructose-1, 6- diphosphatase. (ii) Pancreatic insulin depresses the process by acting as a repressor of fructose- 1, 6-diphosphatase.
NSOU ● CC-ZO- 08 ____ 135 Gluconeogenesis from glycerol 5.5.2 Gluconeogenesis from lactate : Occurrence : Gluconeogenesis occurs from lactate in the liver and kidney; some of the reactions occur within cytosol but some others take place inside the mitochondria. Process : (i) Lactic acid produced in glycolysis is oxidized back to pyruvic acid in presence of NAD + with the help of lactate dehydrogenase in cytosol.

136 ____ NSOU ● CC-ZO- 08 (ii) Pyruvic acid is then converted to phosphoenol pyruvic acid in a complex way; pyruvate kinase that changes phosphoenol pyruvic acid into pyruvic acid during glycolysis cannot catalyse the reverse reaction : (a) Pyruvic acid enters the mitochondria where ATP-dependent pyruvate carboxylase condenses pyruvic acid with CO 2 to form oxaloacetic acid. (b) Oxaloacetic acid is reduced by mitochondrial malate dehydrogenase in presence of NADH and H + . Malic acid and NAD + are produced. (c) Malic acid is transported to cytosol by dicarboxylate transporter of mitochondrial membrane. It is now oxidized back to oxaloacetic acid in presence of NAD + by malate dehydrogenase of cytosol. (d) Thereafter, oxaloacetic acid is both decarboxylated and phosphorylated in presence of GTP by phosphoenolpyruvate carboxykinase (PEP carboxykinase) of cytosol to yield phosphoenolpyruvic acid, GDP and CO 2 . (iii) Phosphoenolpyruvic acid is next changed to fructose-1, 6-diphosphate by reversal of glycolysis steps with the same enzymes that catalyse the forward reactions. (iv) Fructose-1, 6-diphosphate is hydrolysed by fructose-1, 6-diphosphatase to yield fructose-6-phoshate which subsequently changes into either (i) glucose- 6-phosphate by phosphoglucose isomerase ; glucose-6-phosphate is changed to glucose by glucose-6-phosphatase, or (ii) glycogen through the process of glycogenesis. Comments : (1) Adrenal glucocorticoids promote gluconeogenesis from lactate by inducing synthesis of PEP carboxykinase. (2) Pancreatic insulin suppresses the process by suppressing synthesis of PEP carboxykinase. Gluconeogenesis from lactate

NSOU ● CC-ZO- 08 ____ 137 5.5.3 Gluconeogenesis from propionate : Occurrence : In ruminant mammals, dietary cellulose is converted into lower fatty acids like acetic, propionic and butyric acids due to fermentation caused by microflora in rumen and reticulum of the stomach. These fatty acids, especially propionic acid, after absorption from intestine, convert into glucose by gluconeogenesis in liver and kidneys. The reactions occur partly within the mitochondria and partly in the cytosol of cells. Process : (1) Inside the mitochondria, propionic acid is converted into propionyl-CoA in presence of ATP and Mg ++ ions by the help of acetate thiokinase. (2) Propionyl-CoA is carboxylated in presence of CO 2 , ATP, Mg ++ ions and biotin by the help of propionyl-CoA carboxylase ; biotin acts as the coenzyme for this enzyme. The product is D-methylmalonyl-CoA. (3) D-methylmalonyl-CoA is now changed by mitochondrial methylmabnyl-CoA recemase to its L-isomer, L-methylmalonyl-CoA. (4) L-methylmalonyl-CoA is converted to succinyl-CoA by the help of methylmalonyl-CoA isomerase containing cobamide as its coenzyme. (5) Succinyl-CoA is then converted to malate through TCA cycle inside the mitochondria. (6) Malate is then transferred to the cytosol where it changes into either glucose or glycogen as it happens in case of gluconeogenesis from lactic acid. Comment : Deficiency of methylmalonyl-CoA isomerase owing to gene mutation may lead to the disease methylmalonic aciduria characterized by rise in urinary methylmalonate, acidosis and fall in blood pH. Gluconeogenesis from propionate

138 ____ NSOU ● CC-ZO- 08 5.5.4 Gluconeogenesis from amino acids : Metabolism of either the carbon-skeleton or the nitrogenous part of many amino acids produces gluconeogenic intermediates which are finally converted into glucose in the animal body. Normally, a small amount of glucose is produced from amino acids but during starvation, amino acids serve as the main source of glucose. Occurrence : The process occurs mainly in liver and to some extent, in the kidneys. Process : (1) Cysteine and alanine give rise to pyruvate through either transamination or deamination; serine produces pyruvate through deamination. Again, tryptophan and glycine may change to alanine and serine, respectively and the latter two amino acids in turn produce pyruvate. Normally, alanine is the largest source of glucose among amino acids. Inside the mitochondria, pyruvate changes to oxaloacetate by the action of pyruvate carboxylase. Some amount of oxaloacetate is produced from aspartic acid through transamination. Oxaloacetate is then changed to malate through TCA cycle. (2) Glutamic acid can produce a-ketoglutarate by transamination. Again, histidine, arginine, proline and ornithine give rise to glutamic acid due to metabolism of their carbon-skeleton and thereafter, glutamic acid produce a- ketoglutarate by deamination, which in turn changes to malate through TCA cycle in mitochondria. (3) Valine, isoleucine, methionine and threonine can change to succinyl-CoA due to metabolism of their carbon-skeleton. Then, succinyl-CoA changes to malate through TCA cycle in mitochondria. (4) The metabolism of the carbon-skeleton of tyrosine and aspartic acid produces fumarate; phenylalanine may change to tyrosine which in turn changes to fumarate. Fumarate is then changed to malate through TCA cycle in mitochondria. (5) Finally, malate passess out to the cytosol and gradually convert into either glucose or glycogen.

NSOU ● CC-ZO- 08 ____ 139 Gluconeogenesis from amino acids Comments : (i) In normal condition, gluconeogenesis occurs mainly from lactate or pyruvate. During starvation, gluconeogenesis occurs mainly from amino acids (alanine is the largest source of glucose among amino acids). (ii) In both normal and starving conditions, the rate of gluconeogenesis is about ten times higher in the liver than in kidneys. 5.6 Glycogenolysis The breakdown of the animal storage polysaccharide, glycogen into glucose is called as 'glycogenolysis'. An account follows : Occurrence : Glycogenolysis occurs mainly in the liver and to some extent, in the kidneys. Although glycogenesis occurs in muscles, no glycogenolysis occurs in muscles, since muscles lack glucose-6-phosphatase enzyme which is essential for glycogenolysis. Brain too does not have this enzyme. Structure of glycogen : Glycogen has a highly branched molecular structure. 10 to 15 ?-D-glucose units are joined by 1,4-glycosidic bonds to form short straight- chains. Many such chains are joined with one another by 1,6-glycosidic bonds while the glucose residues in the chains remain connected by 1,4-glycosidic bonds. Events in glycogenolysis : Phase I : Liberation of glucose-1-phosphates and traces of glucose : (i) A reaction between glycogen and inorganic phosphate is catalysed by glycogen phosphorylase. Initially, the enzyme occurs as inactive phosphorylase b. Pancreatic glucagon and adrenal medullary adrenalin raises
140 ____ NSOU ● CC-ZO- 08 the level of cyclic-AMP in hepatic cells. The increased cAMP activates dephosphophosphorylase kinase which in turn adds two phosphates from two ATPs to phosphorylase b and converts it into active phosphorylase a. Phosphorylase a phosphorolytically splits the 1, 4-glycosidic bonds between the glucose residues in a branched chain of glycogen, one at a time, starting from the free end of the chain. As a result, glucose-1-phosphates are liberated, one at a time. The enzyme acts until only 4 glucose residues remain attached to the branch-point and is again gets inactivated by phosphophosphorylase phosphatase. (ii)Now, a second enzyme, oligo (?-1,4 ? ?-1,4)-glucan transferase hydrolytically splits the 3rd 1,4-glycosidic bond from the free end of the shortened branch and transfers the cut out trisaccharide to some other branch of the glycogen molecule. Thus, only one glucose residue remains attached by 1,6-glycosidic bond to the branch-point. (iii) Then, a third enzyme, the debranching enzyme or amylo-1,6-glucosidase hydrolytically splits the 1,6-glycosidic bond at the branch-point a free glucose is liberated. Phase-II : Formation of glucose-6-phosphates : Glucose-1-phosphate produced by the action of glycogen phosphorylase a is isomerised into glucose-6-phosphate by phosphoglucomutase in presence of Mg ++ ions. Phase-III : Liberation of free glucose : Finally, glucose-6-phosphate is hydrolysed into free glucose and inorganic phosphate. The reaction is catalysed by glucose-6-phosphatase in presence of Mg ++ ions. Rate limiting steps in glycogenolysis : The conversion of glycogen into glucose-1-phosphate by glycogen phosphorylase is the rate limiting step in glycogenolysis. The activity of glycogen phosphorylase is increased by adrenaline and glucagon. Glycogen phosphorylase can exist in two forms : An inactive form called glycogen phosphorylase b and an active form called glycogen phosphorylase a. The inactive form of the enzyme is converted into the active form by adrenalin and glucagon in the following way : Adrenaline and glucagon activate adenylate cyclase of cell membrane, which converts ATP into PPi and cAMP. The increased cAMP activates dephosphophosphorylase kinase which in turn adds two phosphates from two ATPs to phosphorylase b and converts it into active phosphorylase a, which initiates glycogenolysis.
NSOU ● CC-ZO- 08 ____ 141 Moreover, adrenaline increases the release of Ca ++ ions from endoplasmic reticulum into the cytosol of hepatocytes. The binding of Ca ++ ions with a cytoplasmic protein calmodulin causes activation of calmodulin-sensitive phosphorylase kinase which in turn phosphorylates the inactive glycogen phosphorylase b and to convert it into an active glycogen phosphorylase a, which initiates glycogenolysis. Significance : Glycogenolysis represents an essential part of carbohydrate metabolism in the animal body. The liberated glucose passes to blood for transport to different tissues for its oxidation and production of energy. Conclusion : (i) Hormones like pancreatic glucagon and adrenal medullary adrenaline promote glycogenolysis by activating glycogen phosphorylase. (ii) Hormones like glucocorticoids of adrenal cortex and thyroxine of thyroid also promote glycogenolysis by stimulating glucose-6-phosphatase activity. (iii) Gene mutations may lead to inborn failure of glycogenolysis, leading to high hepatic glycogen concentration and hypoglycemia. The condition is called as 'glycogenosis'. Deficiency of glycogen phosphorylase is known as type VI glycogenosis ; deficiency of debranching enzyme is called as type III or partial glycogenosis ; deficiency of glucose-6-phosphatase is known as type I glycogenosis. Reactions in Glycogenolysis

142 ____ NSOU ● CC-ZO- 08 5.7 Glycogenesis The synthesis of glycogen, which is the storage polysaccharide of animals, from hexose sugars is called glycogenesis. Glycogenesis occurs mainly from glucose. Occurrence : Glycogenesis occurs mainly in liver and muscles. Some amount of glycogenesis also takes place in spleen, testis and intestine, but no glycogenesis occurs in brain and kidney. Process : (i) Formation of glucose-6-phosphate : At first, glucose gets phosphorylated at its C 6 in presence of ATP and Mg ++ ions by the help of either hexokinase or glucokinase. Glucokinase predominates over hexokinase in liver while hexokinase predominates over glucokinase in muscles and extrahepatic tissues. Interestingly, glucokinase can catalyze glycogenesis when blood sugar level is above 100 mg/100 ml but hexokinase can do so, even when the blood sugar level is much lower. It so happens, because glucokinase has a much higher K m (5 mM of glucose) than that of hexokinase (50 μm of glucose), which means that glucokinase has a much lower affinity for glucose, compared to hexokinase. (ii) Formation of glucose-1-phosphate : Then, phosphoglucomutase acts on glucose-6-phosphate in presence of Mg ++ ions. At first, glucose-6-phosphate accepts a phosphate from a phosphoserine residue at the active site of the enzyme itself, resulting in formation of glucose-1, 6-biphosphate and dephosphorylated enzyme. Then, the 2 products react further with each other so that the phosphate from C 6 of glucose-1, 6-biphosphate is returned to the enzyme. Consequently, glucose-1-phosphate and the original enzyme are produced. (iii) Formation of UDP-glucose : Then, glucose-1-phosphate reacts with UTP or uridine triphosphate under the catalytic action of UDP-glucose pyrophosphorylase. Two terminal phosphates of UTP are released as PPi or inorganic pyrophosphate while glucose-1-phosphate occupies their place to form UDP-glucose or uridine diphospho-glucose. A pyrophosphatase enzyme soon hydrolyzes the PPi into 2 inorganic phosphates (Pi). (iv) Elongation and branching of glycogen chain : This step is complex : (a) At first, a primer protein called glycogenin and having some enzymatic power of itself catalyzes the binding of a glucose residue of a UDP-glucose to a tyrosine residue of itself. The C 1 of glucose binds to the OH group of the tyrosine.

NSOU ● CC-ZO- 08 ____ 143 (b) Then, glycogenin catalyzes the binding of 7 more glucose residues from 7 more UDP-glucose molecules. Each time, the C 1 of a glucose residue binds to the C 4 of a glycogenin-bound glucose. In this way, a total of 8 glucose residues get linked to glycogenin. (c) Then, the catalytic activity of glycogenin stops and glycogen synthase begins to add 12-14 more glucose residues (from UDP-glucose molecues) to the glycogenin-bound oligosaccharide. Each time, a 1,4-glycosidic linkage is formed, i.e. the C 1 of a new glucose residue is linked with the C 4 of the terminal glucose of the glycogenin-bound oligosaccharide. (d) Thereafter, a branching enzyme (Amylo-1,4 ? 1,6-transglycosylase) cuts out an oligosaccharide (6-8 glucose unit-long) from the terminus of a glycogenin-bound glucose chain and joins the cut-out oligosaccharide to any other point of the chain by means of a 1,6-glycosidic linkage. In this way, repeated actions of glycogen synthase and branching enzyme produce a highly branched glycogen molecule. Significance : (i) Glycogenesis allows storage of excess carbohydrates of the body in the liver in the form glycogen which may be broken into glucose whenever the body needs a large amount of energy. (ii) Glycogenesis prevents any undesirable rise of blood glucose level. Regulation : (i) Reversible phosphorylation and dephosphorylation modulates the activity glycogen synthase. The active enzyme called 'glycogen synthesis a' exists in dephosphorylated from. It is changed into an inactive 'glycogen synthase b' due to phosphorylation of its 7 serine residues in presence of ATP by the help of cAMP-dependent protein kinase, Ca ++ -calmodulin-dependent protein kinase and glycogen synthase kinase. On the other hand, protein phosphatase- I removes the phosphates from phosphoserines and converts the inactive 'glycogen synthase b' into the active 'glycogen synthease a'. (ii) Adrenaline activates cAMP-dependent as well as Ca ++ -calmodulin-dependent protein kinase, which in turn phosphorylates the active 'glycogen synthase b'. This retards glycogenesis. (iii) Insulin stimulates the biosynthesis of glucokinase and glycogen synthase. This in turn promotes glycogenesis in liver.

144 ____ NSOU ● CC-ZO- 08 Glycogenesis 5.8 Questions (with hints to answers) A. Short-answer type questions : 1. How many ATP molecules are produced from anaerobic and aerobic oxidations of one molecule of glucose ? (see Section 5.3.1). 2. Name the rate limiting enzyme and rate limiting step of glycolysis. (see Section 5.2.2).

NSOU ● CC-ZO- 08 ____ 145 3. Name the inactive and active forms of glycogen phosphorylase. (see Section 5.7). 4. Name the rate limiting enzymes of TCA cycle. (see Section 5.3.3). 5. Name two indermediate products of TCA cycle that are used in gluconeogenesis. (see Section 5.5.2). 6. Name two amino acids used in gluconeogenesis. (see Section 5.5.4). 7. Name the substrate used for gluconeogenesis during starvation. (see Section 5.5.4). 8. Name the substrates used for gluconeogenesis in ruminating mammals. (see Section 5.5.3). 9. What is the significance of pentose phosphate pathway in red blood cells ? (see Section 5.4.2). 10. What is the difference between glycogenolysis and glycogenesis ? (see Section 5.6). 11. What is the function of glycogen synthase? (see Section 5.7). 12. What is glycogenin ? (see Section 5.7). 13. State the function of phosphoglucomutase. (see Section 5.6). 14. State the function of branching enzyme ? (see Section 5.7). 15. What is the function of debranching enzyme ? (see Section 5.7). 16. Name two hormones that promote glycogenolysis. (see Section 5.6). 17. Why does glycogenolysis not occur in muscles ? (see Section 5.6). 18. Name the rate limiting enzyme of glycogenolysis. (see Section 5.6). 19. What do you mean by glycogenosis ? (see Section 5.6). 20. What is type I glycogenosis ? (see Section 5.6). B. Long-answer type questions : 1. Precisely describe the reactions occurring in EMP pathway. (see Section 5.2.1). 2. Give a concise account of Krebs' TCA cycle. (see Section 5.3.1). 3. Give an account of the anabolic role of Krebs' TCA cycle. (see Section 5.3.2). 4. How will link between protein metabolism and Krebs' TCA cycle? (see Section 5.3.4). 5. Give an account of regulation of glycolysis. (see Section 5.2.2). 6. Write a note on regulation of the rate limiting enzymes of Krebs' TCA cycle. (see Section 5.3.3).

146 ____ NSOU ● CC-ZO- 08 7. Describe gluconeogenesis from glycerol. (see Section 5.5.1). 8. Give an account of gluconeogenesis from lactate. (see Section 5.5.2). 9. List the end-products of pentose phosphate pathway. (see Section 5.4). 10. Give an account of glycogenesis. (see Section 5.7). 11. Give an account of glycogenolysis. (see Section 5.6). 12. Give an account of regulation of the rate limiting enzyme of glycogenolysis. (see Section 5.6). 5.9 References 1. Biochemistry – A. H. Lehninger (1975), Worth Publishers, New York. 2. Biochemistry – Debajyoti Das (2005), Academic Publishers, Kolkata. 3. Outlines of Biochemistry – E. E. Conn and P. K. Stumpf (1972), John Wiley, New York. 4. Principles of Biochemistry – D. L. Nelson and M. M. Cox (2005), Freeman & Co., New York. 5. Textbook of Biochemistry – E. S. West and W. R. Todd (1966), Macmillan, New York.

NSOU ● CC-ZO- 08 ____ 147 Unit-6 Lipid Metabolism Structure 6.0. Objectives 6.1. Introduction 6.2. ?????-oxidation and omega-oxidation of saturated fatty acids with even and odd number of carbon atoms 6.2.1 Some essential terms 6.2.2 Site of ?????-oxidation of fatty acids 6.2.3 ?????-oxidation of saturated fatty acids (even and odd-carbon) 6.2.4 ATP production in â-oxidation of saturated fatty acids 6.2.4.1 Even-carbon fatty acids 6.2.4.2 Odd-carbon fatty acids 6.2.5 Omega-oxidation of fatty acids 6.3. Biosynthesis of palmitic acid 6.3.1 'Fatty acid synthetase' system 6.3.2 Carbon-sources for palmitic acid biosynthesis 6.3.3 Overall reaction of palmitic acid biosynthesis 6.3.4 Sequence of reactions in palmitic acid biosynthesis 6.4. Ketogenesis 6.5. Questions 6.6. References 6.0 Objectives After studying the topics included in this chapter, you will be able to : ● Define lipid metabolism ; ● Gain thorough knowledge of ?-oxidation of saturated fatty acids ; ● Grow clear concept of ATP production in ?-oxidation of saturated fatty acids (both even-carbon and odd-carbon fatty acids) ; ● Gain knowledge of omega-oxidation of saturated fatty acids ; ● Have clear concept of 'fatty acid synthetase system' ; ● Have a detailed idea on biosynthesis of palmitic acid ; ● Gain knowledge on ketogenesis in animal body. 147

148 ____ NSOU ● CC-ZO- 08 6.1 Introduction Lipid metabolism refers to all kinds of chemical transformations of lipids and their components in the body of living beings. Such chemical transformations in the animal body include the de novo biosynthesis of fatty acids, chain elongation of fatty acids, biosynthesis of fat and different conjugated lipids, breakdown of stored fat, biosynthesis of different steroid hormones (e.g. androgens, oestrogens and adrenal hormones) as well as metabolism of fatty acids obtained from digestion of dietary fats in the alimentary canal and breakdown of fats stored in adipose tissues of the body. It may be added in this connection that the metabolism of fatty acids is accompanied by a significant yield of energy in the form of ATP molecules. 6.2. ?????-oxidation and omega-oxidation of saturated fatty acids with even and odd number of carbon atoms 6.2.1 Some essential terms : ? = C 2 starting from COOH group. ? = C 3 starting from COOH group. ? = Double-bond. Cis, trans = H atoms attached to same side (cis)/ opposite sides (trans) of two carbon atoms on two sides of a double- bond. Acyl = Adjective of saturated fatty acid. Enoyl = Adjective of unsaturated fatty acid. L(+) = OH lies on top of a carbon atom. L(–) = OH lies at bottom of a carbon atom. Saturated fatty acid = CH 3 (CH 2) n COOH 6.2.2 Site of ?????-oxidation of fatty acids : Most of the saturated fatty acids and all unsaturated fatty acids are metabolized by the process of â-oxidation inside the mitochondria of cells of the liver, kidney, adipose tissue and muscles. The basic mechanism of â-oxidation can be easily explained with reference to the saturated fatty acids ; the pathway was first described by F. Knoop in 1905. In case of unsaturated fatty acids, â-oxidation involves some additional and special steps to change the double-bonds in their molecules so that the process can reach its completion. 6.2.3 ?????-oxidation of saturated fatty acids (even and odd carbon): ?-oxidation of saturated fatty acids involves the following steps: 1. The fatty is first combined with coenzyme A (CoA.SH) at the outer NSOU ● CC-ZO- 08 ____ 149 mitochondrial membrane-surface by the catalytic action of acyl-CoA synthetase, resulting in the formation of acyl-CoA. This is called as activation of fatty acids. The overall process of activation is simple, but it actually occurs in the following sequence: (i) (Acyl adenylate)(Pyrophosphate) Acyl CoASynthetase Fatty acid + ATP Acyl AMP PPi ???????????????????????? (ii) Acyl Acyl AMP + CoA.SH Acyl CoASynthetase CoA —→ ——————+ AMP (iii) PPi O Pyrophosphates + H 2 Pi(Inorganic phosphate) 2 —→ —————Fattyacid + CoA.SH + ATP + H 2 O Acyl CoA AMP Pi → + + 2 Moreover, there are 3 kinds of acyl-CoA synthetase which activate different fatty acids, depending on the chain-length of the latter, viz. (a) Acetyl-CoA synthetase activates C 2 or C 3 fatty acids like acetic acid (CH 3 COOH) and propionic acid (CH 3 CH 2 COOH) ; (b) Medium-chain acyl-CoA synthetase activates C 4 to C 12 fatty acids like valeric (C 5) acid [CH 3 (CH 2) 3 COOH] ; (c) Long-chain acyl-CoA synthetase activates fatty acids with more than 12 carbons, such as, palmitic (C 16) acid [CH 3 (CH 2) 14 COOH and Stearic (C 18) acid [CH 3 (CH 2) 16 COOH]. 2. Acyl-CoA is then passed to the mitochondrial matrix by the help of a mobile carrier substance called as carnitine. Inside the matrix, acyl-CoA is oxidized due to dehydrogenation [= loss of H 2] under the catalytic action of acyl-CoA dehydrogenase. Acyl-CoA is converted into ? 2 -trans-enoyl-CoA while FAD which is a prosthetic group of the enzyme, acts as an acceptor of H 2 and gets reduced into FADH 2 . 3. Then ? 2 -trans-enoyl-CoA combines with water under the catalytic action of ? 2 -enoyl-CoA hydrase. As a result, L(+)-?-hydroxyacyl-CoA is formed. 4. Then, L(+)-?-hydroxyacyl-CoA is oxidized due to dehydrogenation at its â- carbon by the catalytic action of L(+)-?-hydroxy-acyl-CoA dehydrogenese. As a result, L(+)-?-hydroxyacyl-CoA is converted into ?-ketoacyl-CoA while NAD + , which is a prosthetic group of the enzyme, acts as an acceptor of H 2 and gets reduced to yield NADH and H + . 5. Then, in presence of another CoA.SH, thiolase cleaves ?-ketoacyl-CoA in between its ? and ?-carbons (= 2 nd and 3 rd carbons). Consequently, one molecule of acetyl-CoA (C 2) and a new acyl-CoA, which is shorter than the original acyl-CoA by two carbons, are produced.
150 ____ NSOU ● CC-ZO- 08 6. Thereafter, the steps (2) to (5) are repeated with the new acyl-CoA. Finally, in case of an even-carbon fatty acid, n/2 number of acetyl-CoA is produced, if the total number of carbon atoms in the original fatty acid is 'n'. On the other hand, in case of an odd-carbon fatty acid, one molecule of propionyl-CoA (C 3) and several molecules of acetyl-CoA (C 2) are produced. ?????-oxidation of saturated fatty acid 6.2.4 ATP production in ?????-oxidation of saturated fatty acids : 6.2.4.1 Even-carbon fatty acids : (i) Each cycle of ?-oxidation produces one acetyl-CoA (C 2) and the total number of acetyl-CoA produced from the complete ?-oxidation of an even-carbon D/Barun-2022/Netaji Subhas Open University/HZO-CC-08/Final Makup/Title Final/150/3rd Proof/27.06.22

NSOU ● CC-ZO- 08 ____ 151 fatty acid is n 2 (n = number of carbons in the acid). Each acetyl-CoA enters Krebs cycle for oxidation along with production of 12 ATPs, So, n 2 – ⎛ ⎝ ⎜ ⎞ ⎠ ⎟ 1 ATPs will be obtained in this way. (ii) Now, the last acetyl-CoA is not obtained from â-oxidation, but represents the acetyl-CoA left-out at the end of ?-oxidation. Hence, n 2 – ⎛ ⎝ ⎜ ⎞ ⎠ ⎟ 1 cycles are necessary for the complete ?-oxidation of an even-carbon fatty acid. During each of these cycles, a FADH 2 and a NADH get oxidized by the mitochondrial electron transport system along with the production of 2 and 3 ATPs, respectively. So, n 2 1 5 – ⎛ ⎝ ⎜ ⎞ ⎠ ⎟ × ⎡ ⎣ ⎢ ⎤ ⎦ ⎥ ATPs obtained in this way. (iii) Now, 2 high-energy phosphates are spent during the initial activation of the original fatty acid. (iv) So, the net gain of ATP molecules from â-oxidation of an even-carbon fatty acid = × ⎛ ⎝ ⎜ ⎞ ⎠ ⎟ + – ⎛ ⎝ ⎜ ⎞ ⎠ ⎟ × – ⎡ ⎣ ⎢ ⎤ ⎦ ⎥ n n 2 12 2 1 5 2 molecules of ATP. eg. In case of palmitic acid [CH 3 (CH 2) 14 COOH] with C 16 , the net gain of ATP will be ; = × ⎛ ⎝ ⎜ ⎞ ⎠ ⎟ + – ⎛ ⎝ ⎜ ⎞ ⎠ ⎟ × – ⎡ ⎣ ⎢ ⎤ ⎦ ⎥ = + – 16 2 12 16 2 1 5 2 96 35 2 ( ) = 129 ATPs. Comment: However, according to modern concept (D. Nelson and M. Cox, Principles of Biochemistry, 4 th edition, 2005, Freeman and Company, New York), the net gain of ATP from â-oxidation of an even-carbon fatty acid will be n n 2 10 2 1 4 2 × ⎛ ⎝ ⎜ ⎞ ⎠ ⎟ + – ⎛ ⎝ ⎜ ⎞ ⎠ ⎟ × – ⎡ ⎣ ⎢ ⎤ ⎦ ⎥ . The number of ATPs obtained from oxidation of acetyl- CoA, FADH 2 and NADH are 10, 1.5 and 2.5, respectively, eg. Palmitic acid : (8×10+7×4 – 2) = 106 ATPs. 6.2.4.2 Odd-carbon fatty acids: (i) Each cycle of ?-oxidation produces an acetyl-CoA (C 2) and the last acyl-CoA is left out as a propionyl-CoA (C 3). So, one will get one propionyl-CoA and n– ⎛ ⎝ ⎜ ⎞ ⎠ ⎟ 3 2 acetyl-CoA from ?-oxidation of an odd-carbon fatty acid (n = number of carbons in the acid). The propionyl-CoA changes into 152 ____ NSOU ● CC-ZO- 08 succinyl-CoA which enters Krebs cycle for oxidation along with production of 6 ATPs while each acetyl-CoA enters Krebs cycle for oxidation along with production of 12 ATPs. So, 6 3 2 12 + – ⎛ ⎝ ⎜ ⎞ ⎠ ⎟ × ⎡ ⎣ ⎢ ⎤ ⎦ ⎥ n ATPs will be obtained in this way. (ii) Now, the propionyl-CoA is not obtained from ?-oxidation, but represents the acyl-CoA left-out at the end of ?-oxidation. So, n– ⎛ ⎝ ⎜ ⎞ ⎠ ⎟ 3 2 cycles are necessary for the complete ?-oxidation of an odd-carbon fatty acid. During each of these cycles, a FADH 2 and and NADH are oxidized by the mitochondrial electron transport system along with the production of 2 and 3 ATPs, respectively. So, n– ⎛ ⎝ ⎜ ⎞ ⎠ ⎟ × ⎡ ⎣ ⎢ ⎤ ⎦ ⎥ 3 2 5 ATPs are obtained in this way. (iii) Now, 2 high-energy phosphates are spent during the initial activation of the original fatty acid. (iv) So, the net gain of ATP molecules from ?-oxidation of an odd-carbon fatty acid 6 3 2 12 3 2 5 2 + – ⎛ ⎝ ⎜ ⎞ ⎠ ⎟ × + – ⎛ ⎝ ⎜ ⎞ ⎠ ⎟ × – ⎡ ⎣ ⎢ ⎤ ⎦ ⎥ n n molecules of ATP. In case of valeric acid [CH 3 (CH 2) 3 COOH] with C 5 , the net gain of ATP = 6 5 3 2 12 5 3 2 5 2 + – ⎛ ⎝ ⎜ ⎞ ⎠ ⎟ × + – ⎛ ⎝ ⎜ ⎞ ⎠ ⎟ × – ⎡ ⎣ ⎢ ⎤ ⎦ ⎥ = 21 ATPs. Comment :According to modern concept (Nelson and Cox, 2005), the net gain of ATP from ?-oxidation of an odd-carbon fatty acid will be 5 3 2 10 3 2 4 2 + – ⎛ ⎝ ⎜ ⎞ ⎠ ⎟ × + – ⎛ ⎝ ⎜ ⎞ ⎠ ⎟ × – ⎡ ⎣ ⎢ ⎤ ⎦ ⎥ n n . The number of ATPs obtained from oxidation of succinyl-CoA, acetyl-CoA, FADH 2 and NADH are 5, 10, 1.5 and 2.5, respectively, eg. Valeric acid : 5 5 3 2 10 5 3 2 4 2 + – ⎛ ⎝ ⎜ ⎞ ⎠ ⎟ × + – ⎛ ⎝ ⎜ ⎞ ⎠ ⎟ × – ⎡ ⎣ ⎢ ⎤ ⎦ ⎥ 6.2.5 Omega-oxidation of fatty acids : Omega-oxidation (ù-oxidation) is a process of fatty acid metabolismin some species of animals. It is an alternative pathwayto beta oxidationthat, instead of involving the â-carbon (3rd carbon from the COOH-end of the fatty acid), involves the oxidation of the ù-carbon (the carbon most distant from the COOH-end of the fatty acid). Omega-oxidation occurs in smooth ER of liver and kidney cells and

NSOU ● CC-ZO- 08 ____ 153 involves only some medium-chain fatty acids (C 6 to C 12) fatty acids, e.g. Lauric acid. At first, a mxed-function oxidase converts the fatty acid into an omega-hydroxy fatty acid in which the methyl group at the last carbon of the fatty acid is converted by the enzyme into hydroxyl-methyl group. The enzyme utilizes NADPH and molecular O 2 for its function. At the end of its function, NADPH changes into NADP while O 2 changes into H 2 O. Thereafter, an alcohol dehydrogenase and an aldehyde dehydrogenase acts one after another on the omega-hydroxy fatty acid and the latter converts into a alpha,omega-dicarboxylic fatty acid (????-dicarboxylic fatty acid). Finally, the alpha,omega-dicarboxylic fatty acid undergoes â-oxidation in the mitochondria. 6.3 Biosynthesis of palmitic acid A multienzyme system called 'fatty acid synthetase' system catalyzes the de novo synthesis of palmitic acid (a common, saturated fatty acid of animal body) from acetyl-CoA and malonyl-CoA in the cytosol of the cells of liver, brain, lung, renal cortex, adipose tissue and lactating mammary gland of mammals. An account follows. 6.3.1 'Fatty acid synthetase' system : This cytoplasmic multienzyme system is an ellipsoid dimer of two identical polypeptide monomers (chains), associated with each other in a head-to-tail fashion. Six enzymes and an acyl-carrier protein (ACP) are covalently linked in each monomer in the following order : (1) ?-ketoacyl synthase, (2) Transacylase, (3) Enoyl reductase, (4) â-hydroxyacyl dehydratase, (5) ?-ketoacyl reductase, (6) ACP and (7) Thioesterase. Composition of 'fatty acid synthetase' system

154 ____ NSOU ● CC-ZO- 08 The first member of this complex, viz., ?-ketoacyl synthase carries a cysteine residue, while the 6 th member of ACP carries a phosphopantetheine residue. Thus, the Cys–SH of one monomer lies close to the Pan–SH of the other monomer. The individual monomers are inactive when isolated from each other. But, in the dimer form, the two monomers jointly synthesize two palmitates at the two ends of the dimer. The production of each palmitate involves coordinated action of the first two members of one monomer and the last five members of the other. 6.3.2 Carbon-sources for palmitic acid biosynthesis: The carbon-sources are acetyl-CoA and malonyl-CoA. Acetyl-CoA arises within the mitochondria either by oxidative decarboxylation of pyruvate or by ?-oxidation of fatty acids. It is then transferred in other chemical forms through the mitochondrial membranes to the cytosol. Acetyl–CoA is regenerated in the cytosol. Pathway of malonyl CoA synthesis Within the cytosol, a large amount of acetyl–CoA is carboxylated
to form malonyl-CoA with the help of acetyl-CoA carboxylase,
biotin, HCO 3 – and ATP. At first, a biotin-enzyme complex is formed; it is converted into an intermediary compound, carboxybiotin-enzyme which causes carboxylation of acetyl-CoA into malonyl-CoA : 6.3.3 Overall reaction of palmitic acid biosynthesis : Usually, fatty acid synthetase system produces palmitic acid (C 16) as the end- product. It is actually produced by means of 7 cycles of reactions. In the 1 st cycle, a C 2 unit is added from a malonyl group to an acetyl group (C 2), resulting in formation of a C 4 acetoacetyl group. Each subsequent cycle adds a new C 2 unit from a fresh malonyl group and finally, palmitoyl group is produced. The overall reaction is thus, as follows : 3 2 14 Acetyl CoA 7malonyl CoA 14NADPH 14H CH (CH) COOH
NSOU ● CC-ZO- 08 ____ 155 6.3.4 Sequence of reactions in palmitic acid biosynthesis : The synthesis of palmitic acid by the help of 'fatty acid synthetase' system involves the following steps : (i) Formation of acetyl-malonyl-enzyme : Transcylase of the multienzyme complex transfers the acetyl group from an acetyl–CoA to the Cys–SH of one monomer and the malonyl group from a malonyl–CoA to the adjacent Pan– SH of the other monomer. Thus, an acetyl-malonyl-enzyme complex is formed. (ii) Condensation reaction : Under the catalytic action of ?-ketoacyl synthase, the acetyl group linked to Cys–SH is transferred to the 2 nd carbon of the malonyl group linked to Pan–SH, with the release of the free carboxyl group of the malonyl residue as CO 2 . The malonyl group is thus, changed into an acetoacetyl group. (iii) First reduction step : The acetoacetyl group is now reduced into ?-hydroxybutyryl group by ?-ketoacyl reductase, in presence of NADPH and H + ion. (iv) Dehydration step : ?-hydroxyacyl dehydratase now removes water from the ?-hydroxybutyryl group which thus, changes into ? 2 -trans-enoyl group. (v) Second reduction step : The ? 2 -trans-enoyl group is now reduced into butyryl group by enoyl reductase, in presence of NADPH and H + ion. This completes the first cycle of reactions. (vi) 2nd to 7th cycles of reactions : Now, transacylase transfers the butyryl group from Pan–SH of ACP to the adjacent Cys–SH of the other monomer and also transfers the malonyl group from a second malonyl–CoA to the free Pan–SH of ACP. Now, the steps (2) to (5) or 'Condensation reaction' to 'Second reduction step' are repeated. At the end of the each cycle, a new acyl group which is longer than the previous one by 2 carbon atoms is formed. Finally, at the end of 7 cycles, palmitoyl group is formed. The palmitoyl group is released as free palmitic acid (CH 3 (CH 2) 14 COOH) by the hydrolytic action of thioesterase of the multienzyme complex. Comments : (i) In the liver and most of the other tissues, all the 7 cycles are completed and the end-product is palmitic acid (16 carbon).
156 ____ NSOU ● CC-ZO- 08 Biosynthesis of palmitic acid by 'fatty acid synthetase' system (ii) In mammary gland, some 10 to 14-carbon fatty acids are synthesized. In such cases, all the 7 cycles of reactions are not completed. (iii) Sometimes, fatty acids with an odd number of carbons are formed. In such cases, propionyl–CoA (3 carbon) is utilized in the first step, instead of an acetyl–CoA (2 carbon).

NSOU ● CC-ZO- 08 ____ 157 6.4 Ketogenesis Three substances, viz., acetoacetate, acetone and ?-hydroxybutyrate are knowns as ketone bodies and their production in the body is called ketogenesis. Ketone bodies are produced from acetyl-CoA in the mitochondria of liver cells. Further, ketogenesis occurs in response to an unavailability of blood glucose, such as (i) during starvation, (ii) prolonged intake of high-fat but low-carbohydrate diet and (iii) in case of diabetes mellitus, a disease in which glucose accumulates in blood but cannot enter into cells for undergoing oxidation. Ketogenesis occurs as follows: (1) Acetyl-CoA molecules formed from ?-oxidation of different types of fatty acids are condensed in pairs by thiolase enzyme, resulting in formation of acetoacetate (acetoacetyl-CoA). (2) Small amounts of acetoacetate are spontaneously decarboxylated into acetone or decarboxylated into acetone by the help of the enzyme acetoacetate decarboxylase. Acetone is eliminated by way of the lungs. (3) Large amounts of acetoacetate are reduced into â-hydroxybutyrate by the hepatic mitochondrial enzyme D-â-hydroxy-butyrate dehydrogenase which uses NADH as a hydrogen donor during its reducing action. Therefore, â-hydroxybutyrate is the predominant ketone body to be found in blood during starvation and diabetes. ?-Hydroxybutyrate and acetoacetate can pass through cell membranes easily, and are therefore a source of energy for the brain, which cannot directly metabolize fatty acids. The brain derives 60-70% of its required energy from these two ketone bodies when blood glucose levels are low. However, when the incidence of ketogenesis in the body becomes considerably high, the excess or unused ?-hydroxybutyrate from the blood is excreted through the urine; this is called as ketonuria. Moreover, in severe diabetic patients, the incidence of ketogenesis in the body may become excessively high, resulting in ketoacidosis in which the pH of blood becomes lower than normal due to accumulation of ?-Hydroxybutyrate and acetoacetate (both are acidic in nature), nausea, vomiting, abdominal pain, deep breathing and weakness. 6.5 Questions (with hints to answers) A. Short-answer type questions : 1. What do the terms 'acyl' and 'enoyl' mean ? (See Section 6.2.1). 2. Who discovered the pathway of ?-oxidation of fatty acid ? (See Section 6.2.2).
158 ____ NSOU ● CC-ZO- 08 3. Name three kinds of acyl-CoA synthetase ? (See Section 6.2.3). 4. Name a C 16 fatty acid and a C 18 fatty acid. (See Section 6.2.3). 5. What is the function of thiolase ? (See Section 6.2.3). 6. How many ATP molecules are produced from ?-oxidation of palmitic acid ? (See Section 6.2.4). 7. Name the enzyme system for de novo fatty acid synthesis. (See Section 6.3.1). 8. Name the components of each polypeptide chain of fatty acid synthetase. (See Section 6.3.1). 9. What is ACP ? (See Section 6.3.1). 10. Name the carbon sources of de novo fatty acid synthesis. (See Section 6.3.2). 11. Name the three ketone bodies. (See Section 6.4). 12. What is ketoacidosis ? (See Section 6.4). B. Long-answer type questions : 1. Discuss the mitochondrial pathway of ?-oxidation of saturated fatty acids. (See Section 6.2.3). 2. Describe the organization of fatty acid synthetase. (See Section 6.3.1). 3. Discuss the sequence of steps in palmiticacid biosynthesis. (See Section 6.3.4). 4. Write a note on activation of fatty acids. (See Section 6.2.3). 5. Give an account of ATP production from ?-oxidation of palmitic acid. (See Section 6.2.4). 6. Give an account of ketogenesis. (See Section 6.4). 6.6 References 1. Biochemistry – A. H. Lehninger (1975), Worth Publishers, New York. 2. Biochemistry – Debajyoti Das (2005), Academic Publishers, Kolkata. 3. Principles of Biochemistry – D. L. Nelson and M. M. Cox (2005), Freeman & Co., New York. 4. Textbook of Biochemistry – E. S. West and W. R. Todd (1966), Macmillan, New York.
NSOU ● CC-ZO- 08 ____ 159 Unit-7 Protein Metabolism Structure 7.0. Objectives 7.1. Introduction : 7.2. Catabolism of amino acids : 7.2.1 Transamination 7.2.2 Deamination 7.3. Formation of urea : 7.3.1 Ammonotelism, ureotelism and uricotelism 7.3.2 Description of urea cycle 7.4. Fate of C-skeleton of glucogenic and ketogenic amino acids 7.5. Questions 7.6 References 7.0 Objectives After studying the topics included in this chapter, you will be able to : ? Define and explain the term protein metabolism ; ? Have a detailed idea on transamination ; ? Have a detailed idea on deamination ; ? Explain the terms ammonotelism, ureotelism and uricotelism ; ? Have a detailed idea on biosynthesis of urea ; ? Have an idea on the fate of C-skeleton of different types of amino acids. 7.1 Introduction Various proteins consumed with diet are hydrolyzed into different amino acids in the stomach and intestine by the help of protease enzymes secreted from stomach, pancreas and small intestine. Those amino acids are absorbed through the intestinal mucosa into blood and transported to various organs and tissues of the body. However, amino acids cannot be stored for a long time in any tissue or organ of the body. Therefore, all amino acids entering into different tissues are chemically converted into either various substances that are useful for the body or nitrogenous wastes that are eliminated from the body through urine. The chemical transformation 159

160 ____ NSOU ● CC-ZO- 08 of amino acids in tissues is called as amino acid metabolism or grossly, as protein metabolism. Most of the amino acids entering into different tissues are utilized for biosynthesis of new proteins including various enzymes in cells by the help of tRNA, mRNA and ribosome. Some of the amino acids entering into some particular tissues or organs are utilized for the biosynthesis of specific useful substances, e.g. thyroxine hormone is produced in the thyroid gland ; catecholamine hormones are produced in the adrenal gland ; melatonin hormone is produced in the pineal gland ; histamine (a vasodilator) is produced in basophil cells of blood and mast cells of connective tissue. Some amino acids like cysteine and alanine as well as the products of metabolism of certain amino acids are utilized for gluconeogenesis in the liver. Some products of amino acid metabolism enter into Krebs' TCA cycle for further oxidation along with production of energy. Finally, the unused amino acids from various tissues are passed to the liver for undergoing chemical transformation into nitrogenous wastes like ammonia, urea and uric acid which are harmful for the body and consequently, eliminated from the animal body through the gills (in teleost fishes) or the kidneys (in elasmobranch fishes, amphibians, reptiles, birds and mammals). 7.2 Catabolism of amino acids Catabolism of various amino acids is accomplished mainly through transamination and deamination, as described below : 7.2.1 Transamination : Transamination is an important method of nitrogen catabolism of amino acids. Basic principle : Transamination is a reversible process in which the á-amino group of an amino acid is transferred to a keto acid so that the latter changes to a new amino acid while the original amino acid converts into a new keto acid. Thus, transamination involves deamination and amination side by side, but without the liberation of any free ammonia [Fig. 6(x)] : Net result of transamination

NSOU ● CC-ZO- 08 ____ 161 Occurrence : Transamination takes places mainly in the liver and to some extent, in other tissues like the kidney, brain, heart and testis. Concerned enzymes: Transamination is catalyzed by transaminases or aminotransferases : (i) These enzymes act on the L-amino acids but not on the D- isomers, (ii) They require pyridoxial phosphate as the cofactor, (iii) They occur in both mitochondria and cytosol as separate isozymes and (iv) There are many transaminases ; each acts on a particular pair of amino acid and keto acid. Participant amino acids and keto acids : (i) Almost all naturally occurring amino acids undergo transamination. Exceptions include the basic amino acid lysine, the hydroxy amino acids like serine and threonine, and also, the heterocyclic amino acids like proline and hydroxyproline. (ii) Keto acids like pyruvic acid, oxaloacetic acid and á-ketoglutaric acid are commonly involved in transamination. However, glyoxylic acid may also act as an amino-acceptor in transamination. Examples of transamination : Some examples of transamination of amino acids using different amino-acceptors and catalysed by different transaminases are shown below : (i) Using pyruvate as amino-acceptor : Transamination using pyruvate as amino-acceptor (ii) Using oxaloacetate as amino-acceptor : Transamination using oxaloacetate as amino-acceptor

162 ____ NSOU ● CC-ZO- 08 (iii) Using glyoxylate as amino-acceptor : Transamination using glyoxylate as amino-acceptor (iv) Using ?????-ketoglutarate as amino-acceptor : Transamination using ?????-ketoglutarate as amino-acceptor Significance of transamination : Transamination is an important method of nitrogen catabolism of amino acids. It helps in the synthesis of new amino acids from keto acids. It also serves to produce pyruvic acid and oxaloacetic acid, which in turn are used for gluconeogenesis in the liver. Serum levels of glutamic-oxaloacetate transaminase and glutamic-pyruvate transaminase are found to be significantly increased in certain diseases like myocardial infarction of heart, hepatitis and toxic hepatic jaundice. 7.2.2 Deamination : Deamination is an important method of nitrogen catabolism of amino acids. In this process, the ?-amino group (NH 2 group attached to the central C-atom) of an amino acid is converted into ammonia while the amino acid itself converts into its corresponding keto acid. Deamination may be of three kinds : (A) Oxidative deamination : Here, the presence of oxygen is essential for deamination to occur : (i) By the help of L-amino acid oxidase : L-amino acids are oxidatively deaminated by L-amino acid oxidase present in mitochondria, ER (endoplasmic reticulum) and peroxisomes of mammalian kidneys. The enzyme cannot act on glycine

NSOU ● CC-ZO- 08 ____ 163 (which exists in the body only as L-isomer) and the L-isomers of sulphur-containing, hydroxy, dicarboxylic and basic amino acids. The enzyme contains FMN as the prosthetic group. During deamination, the enzyme at first catalyzes dehydrogenation of the amino acid which gets oxidized to an imino acid while FMN of the enzyme gets reduced to FMN.H 2 by accepting hydrogen. Then, the imino acid spontaneously reacts with water to give the keto acid and ammonia while FMN.H 2 is reoxidized by molecular O 2 to produce H 2 O 2 : Deamination by L-amino acid oxidase (ii) By D-amino acid oxidase : D-amino acids are oxidatively deaminated by D- amino acid oxidase present in peroxisomes of mammalian liver and kidney. The enzyme cannot act on the D-isomers of glutamic acid, asparagine, dicarboxylic and basic amino acids. The enzyme contains FAD as prosthetic group. Its mode of action is comparable to that of L-amino acid oxidase: Deamination by D-amino acid oxidase (iii) By Glycine oxidase : Glycine is oxidatively deaminated by a hepatic enzyme, glycine oxidase instead of either L-or D-amino acid oxidase. Like D-amino acid oxidase, glycine oxidase possesses FAD as the prosthetic group: Deamination by glycine oxidase (B) Non-oxidative deamination :In this type of deamination, molecular oxygen (O 2)
164 ____ NSOU ● CC-ZO- 08 is not directly required for deamination to occur. It occurs mainly in liver and by the help of different enzymes : (i) By amino acid dehydratase :Amino acid de-hydratases catalyze dehydration, followed by deamination, of hydroxy amino acids like serine and threonine : Deamination of L-serine (ii) By amino acid lyase :L-histidine and L-aspartic acid are non-oxidatively deaminated by C-N amino acid lyases: Deamination of L-aspartic acid (iii) By amino acid desulphydrase :The sulphur-containing amino acid cysteine is non-oxidatively deaminated by amino acid desulphydrase in presence of water : Deamination of L-cysteine (4) By trans-sulfurase : Trans-sulfurase catalyzes partial deamination of the sulphur-containing amino acid cystine (formed by joining of 2 cysteines) in presence of water, to
NSOU ● CC-ZO- 08 ____ 165 yield pyruvic acid, ammonia and thiocysteine which still retains both the sulphur atoms of cystine: Deamination of cystine (5) By amino acid amide hydrolase :L-Asparagine may be hydrolytically deaminated by asparagine amide hydrolase in presence of water : Deamination of L-asparagine (C) Transdeamination : It is a cyclical process in which (a) at first, transamination catalyzed by transaminase of mitochondria and cytosol of hepatic cells causes transfer of the ?-amino group of a L-amino acid to ?-ketoglutaric acid, resulting in the formation of glutamic acid, and (b) thereafter, oxidative deamination of glutamic acid is catalysed by mitochondrial glutamate dehydrogenase which utilizes NAD + as hydrogen-acceptor, in presence of water, resulting in reproduction of ?-ketoglutatic acid which may be recycled for transamination of another amino acid : Transdeamination cycle Significance of deamination: The surplus amino acids of the animal body are catabolized by means of deamination, resulting in the formation of the nitrogenous
166 ____ NSOU ● CC-ZO- 08 waste ammonia. Ammonia may be transformed into urea or uric acid in higher vertebrates. All these nitrogenous wastes are finally excreted through urine. Besides, pyruvic acid produced from deamination of different amino acids may be used for gluconeogenesis in the liver. 7.3 Urea Cycle 7.3.1 Ammonotelism, ureotelism and uricotelism : Dietary proteins are broken down into amino acids by the activity of proteolytic enzymes in stomach and small intestine. These amino acids are absorbed into blood through the intestinal mucosa. A large part of the absorbed amino acids is utilized for building proteins in cells. The unutilized amino acids are passed from blood to the liver. However, amino acids cannot be stored indefinitely in liver and instead, these are catabolized in the liver, resulting in the formation of nitrogenous excretory substances (Ammonia is produced first and it may be transformed into urea or uric acid in different animals). Finally, the nitrogenous wastes are eliminated from the animal body through the gills (in teleost fishes) or the kidneys (in elasmobranch fishes, amphibians, reptiles, birds and mammals). Depending on the nature of the end-product of catabolism of amino acids, animals have been classified into three groups, viz., ammonotelic, ureotelic and uricotelic animals. In teleost fishes, the predominant end-product of amino acid catabolism is ammonia. Hence,

NSOU ● CC-ZO- 08 ____ 167 teleosts are called ammonotelic animals. In elasmobranch fishes, amphibians and mammals, the predominant end-product of amino acid catabolism is urea. Hence, these groups of animals are called ureotelic animals. On the other hand, in reptiles and birds, the predominant end-product of amino acid catabolism is uric acid. Hence, reptiles and birds are called uricotelic animals. 7.3.2 Description of urea cycle : Urea is the end-product of amino acid catabolism in elasmobranch fishes, amphibians and mammals. Chemically, urea is known as 'carbamide' or 'diamide of carbonic acid'. Deamination of amino acids produces large amounts of NH 3 which is toxic for the animal body. Different animals have acquired different mechanisms to eliminate this NH 3 . Teleost fishes are ammonotelic and directly excrete NH 3 through the gills ; reptiles and birds convert NH 3 into uric acid for excretion through the kidneys and they are, thus, uricotelic ; mammals, amphibians and elasmobranch fishes convert NH 3 into urea for renal excretion and they are called as ureotelic. In ureotelic animals, urea synthesis occurs through a cyclical pathway [Fig. 6(xv)] called as 'urea cycle' or 'arginine-urea pathway' or 'Krebs-Henseleit ornithine cycle', after the name of the discoverers. Urea is formed mainly in the liver and to a very small extent, in the kidneys and brain. Details of urea cycle : (i) Formation of carbamoyl phosphate : NH 3 , CO 2 and one phosphate of an ATP are condensed by the mitochondrial enzyme, carbamoyl phosphate synthetase I, in presence of Mg ++ ions and N-acetylglutamate. The result is the formation of carbamoyl phosphate. Another ATP is broken down into ADP and inorganic phosphate during this process and the liberated energy is utilized for the reaction. (ii) Formation of citrulline : Now, the carbamoyl group of carbamoyl phosphate is transferred to the amino acid, L-ornithine by the mitochondrial enzyme L-ornithine transcarbamoylase. The product of the reaction is L-citrulline. (iii) Formation of arginosuccinic acid : From the mitochondria, L-citrulline passes into the cytosol where the enzyme arginosuccinate synthetase causes condensation of L-citrulline with L-aspartic acid, in presence of Mg ++ ions and ATP so that L- arginosuccinic acid and water are produced ; the ATP breaks into AMP and pyrophosphate to provide energy for the reaction.

168 ____ NSOU ● CC-ZO- 08 (iv) Formation of arginine :Another cytosol-enzyme arginosuccinase then cleaves L- arginosuccinic acid into L-arginine and fumaric acid. (v) Formation of urea : Finally, the cytosol-enzyme arginase irreversibly cleaves L- arginine into L-ornithine and urea, in presence of water. Thus, L-ornithine is regenerated and it is recycled for further continuation of the urea cycle. Comments : Liver is the major site of urea synthesis, as it possesses all the enzymes necessary for the urea cycle. The mitochondrial enzymes, carbamoyl phosphate synthetase I and ornithine transcarbamoylase are absent in kidneys and brain. Hence, citrulline can't be formed in these organs and only a little urea can be formed from citrulline reaching these organs from the liver via blood. In man, hereditary deficiency of carbamoyl synthetase I may lead to hyperammonemia showing high blood ammonia levels, nausea, tremor, blurring of vision and mental retardation. Again, hereditary deficiency of arginase may lead to argininemia characterized by accumulation of arginine in blood, nausea, lethargy and mental retardation. Urea cycle 7.4 Fate of C-skeleton of glucogenic and ketogenic amino acids We now turn to the fates of the carbon skeletons of amino acids after the removal of the ?-amino group. The fate is to transform the carbon skeletons into (1) metabolic intermediates that can be converted into glucose or (2) metabolic intermediates that NSOU ● CC-ZO- 08 ____ 169 can be oxidized by the Krebs' citric acid cycle.

The carbon skeletons of the 20 fundamental amino acids are funneled into only seven metabolic intermediates : Acetyl-CoA, Acetoacetyl-CoA, Pyruvate, Á-Ketoglutarate, Succinyl-CoA, Fumarate

and Oxaloacetate. Amino acids that are degraded to acetyl-CoA or acetoacetyl-CoA are termed ketogenic amino acids because they can give rise to ketone bodies. Amino acids that are degraded to pyruvate, á-ketoglutarate, succinyl-CoA, fumarate, or oxaloacetate are termed glucogenic amino acids. The net synthesis of glucose from these amino acids is feasible, because pyruvate, á-ketoglutarate, succinyl-CoA, fumarate, or oxaloacetate can be converted into phosphoenolpyruvate and then into glucose. It may be mentioned here that mammals lack a pathway for biosynthesis of glucose from acetyl-CoA or acetoacetyl- CoA

170 ____ NSOU ● CC-ZO- 08 Of the 20 fundsmental amino acids, only leucine and lysine are solely ketogenic. Isoleucine, phenylalanine, tryptophan and tyrosine are both ketogenic and glucogenic - their carbon skeletons change partly to acetyl-CoA or acetoacetyl CoA, and partly to the precursors of glucose. The other 14 amino acids are solely glucogenic in nature. 7.5 Questions (with hints to answers) A. Short-answer type questions : 1. State the function of transaminase. (See Section 6.2.1). 2. How does transamination help in gluconeogenesis? (See Section 6.2.1). 3. Name at least two keto acids that participate in transamination. (See Section 6.2.1). 4. Name the prosthetic groups of L-amino acid oxidase and D-amino acid oxidase, respectively. (See Section 6.2.2). 5. Name the keto acids produced from deamination of glycine, serine, aspartic acid and cysteine, respectively. (See Section 6.2.2) 6. What is the source of ammonia liberated from deamination ? (See Section 6.2.2) 7. Cite one example each of ammonotelic, ureotelic and uricotelic animals. 8. Give the chemical structure of urea. 9. Why is urea not produced in the kidney ? B. Long-answer type questions : 1. Cite any two examples of transamination. (See Section 6.2.1). 2. Give an account of deamination of glycine. (See Section 6.2.2) 3. Distinguish between the prosthetic group and modes of action of L-amino acid oxidase and D-amino acid oxidase. (See Section 6.2.2) 4. Cite any three examples of non-oxidative deamination. (See Section 6.2.2) 5. Write a note on transdeamination. (See Section 6.2.2) 6. Give an account of urea cycle. (See Section 6.3.2) 7. Discuss the fate of C-skeleton of glucogenic and ketogenic amino acids. (See Section 6.4) 7.6 References

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PREFACE In a bid to standardise higher education in the country, the University Grants Commission (UGC) has introduced Choice Based Credit System (CBCS) based on five types of courses viz. core, discipline specific, generic elective, ability and skill enhancement for graduate students of all programmes at Honours level. This brings in the semester pattern, which finds efficacy in sync with credit system, credit transfer, comprehensive continuous assessments and a graded pattern of evaluation. The objective is to offer learners ample flexibility to choose from a wide gamut of courses, as also to provide them lateral mobility between various educational institutions in the country where they can carry acquired credits. I am happy to note that the University has been accredited by NAAC with grade 'A'. UGC (Open and Distance Learning Programmes and Online Learning Programmes) Regulations, 2020 have mandated compliance with CBCS for U.G. programmes for all the HEIs in this mode. Welcoming this paradigm shift in higher education, Netaji Subhas Open University (NSOU) has resolved to adopt CBCS from the academic session 2021-22 at the Under Graduate Degree Programme level. The present syllabus, framed in the spirit of syllabi recommended by UGC, lays due stress on all aspects envisaged in the curricular framework of the apex body on higher education. It will be imparted to learners over the six semesters of the Programme. Self Learning Materials (SLMs) are the mainstay of Student Support Services (SSS) of an Open University. From a logistic point of view, NSOU has embarked upon CBCS presently with SLMs in English / Bengali. Eventually, the English version SLMs will be translated into Bengali too, for the benefit of learners. As always, all of our teaching faculties contributed in this process. In addition to this we have also requisitioned the services of best academics in each domain in preparation of the new SLMs. I am sure they will be of commendable academic support. We look forward to proactive feedback from all stakeholders who will participate in the teaching-learning based on these study materials. It has been a very challenging task well executed, and I congratulate all concerned in the preparation of these SLMs. I wish the venture a grand success. Professor (Dr.) Subha Sankar Sarkar Vice-Chancellor
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Netaji Subhas UG : Zoology Open University (HZO) Course : Principles of Ecology Code : CC-ZO-09 Unit-1 ????? Introduction to ecology 7-12 Unit-2 ????? Population 13-42 Unit-3 ????? Community 43-54 Unit-4 ????? Ecosystem 55-71 Unit-5 ????? Wild life conservation 72-79 Unit-6 ????? Ecological, faunal and floral characteristics 80-86 Unit-7 ????? Zoogeography 87-96
NSOU CC-ZO-09 7 Unit 1 Introduction to Ecology Structure 1.0 Objectives 1.1 Introduction 1.2 Levels of ecological organisation 1.3 Laws of limiting factors 1.3.1 Law of minimum/Liebigs law 1.3.2 Blackman's law of limiting factor 1.3.3 Law of tolarance/Shelford's law 1.4 Study of physical factors 1.5 Summary 1.6 Questions 1.7 Suggested reading 1.0 Objectives After studying this unit, the learners will be able to do the following— To have a general idea on ecology. To learn about different levels of ecological organisation. To know about different limiting factors of an environment. To know the laws proposed to explain the effect of different factors on organism. To understand about the physical factors of an environment. 1.1 Introduction The scientific study of the interactions between organisms (biotic factors) and their environments (abiotic factors) is called ecology. Every organism is intricately linked to its surroundings and thus can't live in isolation, such as, an organism exchanges gases with the atmosphere. It acquires energy from autotrophs which in turn synthesizes organic food by assimilation of carbon dioxide from atmosphere in the presence of chlorophyll and sunlight. The waste products of an organism's metabolism are returned 7
NSOU CC-ZO-09 8 to the surrounding environment where they are recycled. It absorbs and radiates heat from and to the surrounding environment. It also competes with other organisms for limited resources (food and shelter). Most interestingly, organisms are either eat (predator) or being eaten (prey) by other organisms within an environment. The environment in which organisms survive can be divided into two basic categories: (1) Abiotic factors: It includes non-living chemical and physical factors of the environment, such as— light, temperature, pH, gravity, pressure, minerals, air etc. (2) Biotic factors: It includes living factors such as—bacteria, protozoans, plants, fungi, animals etc. 1.2 Levels of ecological organization The science of ecology is a broad and interdisciplinary aspect which can be subdivided into different levels of ecological organizations for simplicity in study and research. The levels of ecological organization are as follows: a) Organism: The organisms form
the basic unit of study in ecology. At each level, the biological unit has
its own specific structure and function. At this level, the physiology, behaviour, distribution and adptations that enable individual organisms to survive in their environment are studied. b) Population: The group of organisms belonging to same species that
have the potential for interbreeding and produce fertile offspring are called
population. At this level, population growth, density, interaction of animals are studied. c) Community: The ecological organization that
results from interdependence and interactions amongst population of different species in a habitat is
called biotic community.
This is an assemblage of populations of plants, animals, bacteria and fungi that live in an area and interact with each other. Each biotic community has a

distinct structure and species composition. d) Ecosystem: The ecosystems are parts of the
nature where living organisms interact amongst themselves and with their physical environment. An ecosystem is composed of a biotic community, integrated with its physical environment through the exchange of energy and recycling of the nutrients.
The term “ecosystem” was coined by Arthur Tansley in 1935.
NSOU CC-ZO-09 9 e)
Biome: This is
a large regional unit characterized by a major flora and associated fauna found in a specific climatic zone.
The biome includes all associated developing and modified communities occurring within the same climatic region, e.g., forest biomes, grassland and savanna biomes, desert biome, etc. f) Biosphere: The entire inhabited part of the earth and its atmosphere including the living components is called biosphere.
It is the highest ecological organization that constitutes all the earth’s terrestrial biomes and aquatic ecosystems. The global environment (abiotic factors) consists of the following three main sub-divisions: a)
Hydrosphere: It includes all the water components. b) Lithosphere: It comprises the solid components of the earth’s crust.
c) Atmosphere: It is the gaseous envelope around the earth. 1.3 Laws of limiting factors The resources (nutrients, light, water, space etc.) necessary for the survival of an organism present in limited supply in the environment. Therefore, it affects the organism’s life drastically. The importance of a physical or biological factor can be identified through a response of increased or shunted growth, abundance or distribution of a population, when the factor is altered in its quantity and quality. A resource or environmental condition can be categorized as a limiting factor when it affects the growth of an organism or population within an ecosystem. Limiting factors are theorized under Liebig’s Law of the Minimum, which states that “growth is not controlled by the total amount of resources available, but by the scarcest resource”. There are three laws proposed to explain the effect of different factors on organism: 1.3.1 Law of minimum / Liebig's law According to this law, the growth is regulated by the limited factors i.e., resources in scarcity and not by the resources in abundance. This law was originated after studying and observing the crop and plant growth. The studies reveal that if we increase the supply of nutrients already present in enough amounts, it does not affect
NSOU CC-ZO-09 10 the growth of plants i.e., no further growth happens. But when we provide the nutrients which are present in scarcity or in limited supply, growth improvements are detectable. Hence, it is the limiting factor that affects the growth of plants. The principles of Liebig's law conclude as a concept, where "the availability of nutrient in scarcity is the limiting factor which is equally important for plant growth as the nutrient in abundance". This law is applicable on natural resource management. 1.3.2 Blackman's law of limiting factor Blackman was a plant physiologist and proposed the idea on limiting factor on plants photosynthesis system. He stated that a number of factors regulate the biological processes but the factors in different amount affect the process on the whole. For example, photosynthesis requires basic components like water, sunlight, chloroplast, temperature, carbon dioxide, chlorophyll present in certain required amount. Any of these factors, if present in scarcity will affect the rate of photosynthesis. 1.3.3 Law of tolerance / Shelford's law Till now we are concentrating on the minimal limiting factors affecting the growth or rate of biological process. But Shelford's law states that it's not only the factor present in limits/scarcity but also the excess/ abundance of that same factor can affect the growth and development of organism or rate of biological process. For instance all nutrients required for the growth and development of organism are equally important but any nutrient in abundance may limit other nutrients absorption, thus indirectly restricting or limiting the growth of organism. Thus, the law of tolerance by Shelford revealed that the growth and development of organism depends on the maximum and minimum limits of factors involved in the biological process. Therefore, every factor has its own maximum and minimal limits in every organism and the tolerance is the range between these two limits. 1.4 Study of physical factors The factor in the abiotic environment which influences the growth and development of organisms of biological communities is called physical factors. It includes: a) Sunlight: Solar energy powers nearly all ecosystems. Since sunlight is such an important resource, many life-forms spend energy competing for it. b) Water: Water is limited resource that life is very dependent upon. The amount of water on the ground, in the air, in the soil, and at different times of year influences the types of life-forms that are successful in

NSOU CC-ZO-09 11 different habitats. The ability to conserve water or get rid of excess water is some major adaptations has been observed in organisms. c) Temperature: Temperature is highly important because of its influential role on metabolism. Most organisms operate optimally at between 32° F and 122° F. Above and below those temperatures, most organisms do not function well, partially due to the denaturing of enzymes and destruction of tissues and cells. However, some species are well adapted to extreme temperatures, including many desert species of plants and animals as well as some reptile and amphibian species that can withstand being completely frozen for several months each year. The ability to maintain internal temperature is a big hurdle facing living organisms and likewise, there are many adaptations (physiological, anatomical, and behavioral) that enable organism to survive in different habitats on Earth. d) Wind: Wind has many effects upon organisms. Some groups that live on nutrient poor substrates depend on wind to blow in nutrients (i.e., bacteria, protozoans & some insects). Many plants depend on wind to disperse their pollen (sperm) and seeds. Wind storms create patchiness in forest by blowing down trees. Wind also influences the rate of water loss by plants. Wind also plays important role in evaporative cooling which directly affects the internal temperature control of animals (mostly mammals). Wind chill can be a factor for organisms in temperate and arctic regions where any form of shelter serves as an important micro-habitat. e) Rocks and Soil: The physical and chemical structure of rock and soil limit the distributions of plants and the animals that feed on plants. The chemical content of soil and rock impact the conditions of water sources (streams, rivers, and lakes). f) Disturbances: Disturbances (i.e., fires, hurricanes, tornadoes, volcanoes, drought, flood, grazing) can greatly impact biological communities and ecosystems. After a disturbance, the habitat begins to reemerge and is slowly re-structured. This process of disturbance and re-structuring is called succession and is a vital role in biological communities and ecosystems. 1.5 Summary The scientific stroy of the environment between biotic and abiotic factors is called ecology.

NSOU CC-ZO-09 12 The global environment consists of hydrosphere, lithosphere and atmosphere. There are three laws proposed to explain the effectes of different factors on organism. 1.6 Questions i) Define ecology and ecosystem. ii) Describe the major biotic and abiotic factors of an ecosystem. iii) What do you know about the levels of ecological organization? iv) Define population, community, biome and biosphere. v) What are the laws of limiting factors? vi) Describe the Liebig's law of minimum. vii) Describe the Blackman's law of limiting factors. viii) Why it is important to study the physical factors of an ecosystem? ix) Discuss about the role of different physical factors on organisms. x) Define photoperiod. How is it related to survival of organisms? 1.7 Suggested reading 1. Basu, R.N. (2004). A Compendium of Terms in Ecology and Environment. Naya Udyog. 2. Chapman, R.
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NSOU CC-ZO-09 13 Unit 2 Population Structure 2.0 Objectives 2.1 Introduction 2.2 Population attributes 2.2.1 Natality or birth rate 2.2.2 Mortality 2.2.3 Sex ratio or dispersal 2.2.4 Survivorship curves 2.2.5 Population density 2.2.6 Life tables 2.2.7 Population growth 2.2.8 Age structure 2.2.9 Patterns of distribution 2.2.10 Population regulation 2.2.11 Population interactions 2.2.12 Lotka-voltera equation for competition 2.3 Summary 2.4 Questions 2.5 Suggested reading 2.0 Objectives After studying this unit, the learners will be able to do the following— To know about population. To learn about various attributes of population. To understand about the characteristics of survivorship curves. 13

NSOU CC-ZO-09 14 To know tabout k-and r-selected species and their differences. To learn about different population growth forms. To know about density dependent and density independent factors. To learn about different tybes of population interactions. To know about lotka-voltera equation for competition. 2.1 Introduction Population is a group of individuals of a particular species, which are found in a particular geographical area at a particular time. The population that occupies a very small area is called local population. A group of such a closely related local population is called meta-population. Population ecology is an important area of ecology as it links ecology to the population genetics and evolution. Natural selection operates at the levels of population to bring about evolution. 2.2 Population attributes A population shows certain characteristic features/attributes which are discussed below. There is a line of difference between a population and an organism. A population has certain characteristics / attributes that an individual organism does not have. The different attributes of a population can be summarized as birth (natality) and death (mortality) rates, sex ratio, age distribution (demography), population density, survivorship curve, life table etc. These attributes could be statistically measured for a population but not for an organism. Let us discuss the different attributes of a population one by one. 2.2.1 Natality or birth rate Population increases by the addition of individuals in two ways, by birth and by immigration. On the other hand, individuals leave population by two ways, death and emigration. The birth of new individuals is referred to as natality. Natality is a broad term and it covers the production of new individuals of any organisms, whether they are born, hatched, germinate or arise by division. The theoretical maximum production of new individuals under ideal conditions (in absence of any environmental stress) is said to be maximum natality that remains constant for

NSOU CC-ZO-09 15 a given population. The increase in population under an actual or specific environmental field condition is called ecological or realized natality which is not a constant. It is variable depending on the size and age composition of the population and with the physical environmental conditions. Natality is expressed as rate, that is as numbers in a given time. For example, if there are 320 births in a population during a year, then the natality rate is 320 per year. The crude natality rate of population can be expressed as follows— Birth (natality) rate (b) = number of birth per unit time average population or, b = DNa NDt Where, b = natality rate per unit time D = entity that is changing N = initial number of individuals in the population Na = number of new individual added to the population by natality t = time Natality rate is of two types 1. Crude or absolute natality rate is obtained by dividing the number of new individuals produced in a specific unit of time. 2. Specific natality rate is obtained by dividing the number of new individuals per unit time by initial number of individuals in the population. It is also referred to as average rate of change per unit population. Example To illustrate the difference between crude and specific natality, let us consider a population of 1,000 fishes in a pond that has increased by reproduction to 3,500 in a year. The crude natality is (3,500 – 1,000) = 2,500 per year and the specific natality is 3,500 / 1,000 = 3.5 per year per individual. 2.2.2 Mortality Morality or death value of individuals is more or less the opposite of natality.

NSOU CC-ZO-09 16 The death rate is the number of individuals dying during a given time interval (deaths per unit time), or it can be expressed as a

specific rate in terms of units of the total population.

The loss of individuals under a given environmental condition is referred to as ecological or realised mortality. Similar to ecological natality, it is also not a constant, but may vary with the size and age composition of the population and environmental conditions. However,

the minimum loss under ideal or non-limiting conditions is a constant for a population

and is referred to as minimum mortality. The crude rate of death of a population can be calculated by the following equation: Death (d) rate (mortality) = number of deaths per unit time average population or, d = DNa NDt Where, d = mortality rate per unit time. D = entity that is changing. N = initial number of individuals in the population. Na = number of dead individuals excluded from the population by mortality. t = time. Scientists are interested not only why organisms die but also the reasons of their death at a given age. The opposite of mortality is survivals or longevity, which focuses on the age of death of individuals in a population. Often the survival rate is of great importance than the death rate. Longevity can be of two types— a) Potential longevity The maximum life span attained by an individual of a particular species is said to be potential longevity. It depends upon the physiological condition of plants and animals (also referred to as physiological longevity) and the organisms die simply due to old age. Potential longevity can also be described as the average longevity of

NSOU CC-ZO-09 17 individuals living under optimum conditions. In nature. few organisms live in optimum conditions. b) Realised longevity It is the actual life span of an organism. It is the average longevity of the individuals of any population living under real environmental conditions. In nature, most animals and plants die from disease or are eaten by predators, or succumb to natural hazards. Thus, this longevity is measured in the field and is also referred to as ecological longevity. Example European robin has an average life expectancy of 1 year in the wild, whereas in captivity it can live at least 11 years. 2.2.3 Sex ratios and dispersal The ratio of males to female organisms in a population is called sex ratio. Competitions often result in biased sex ratios. Female- biased sex ratios are formed due to competition among males for mates. On the other hand, sex ratios toward more males (male biased) take place when there is competition for resources, both among siblings and between offspring and parent. A stable sex ratio enables the population to reach optimum population growth. Births often result in dispersal of offspring to avoid over-crowding. Young males of mammals and a few birds disperse far away from their birth places than do females. This phenomenon is called natal dispersal. Daughters have a tendency to remain near their mother and thus compete with her and among themselves for resources necessary for reproduction. This tendency to remain near their birth place is called philopatry (home-loving). 2.2.4 Survivorship curves A graphical presentation of the proportion of individuals in a given species those are alive at different ages. Typically, the number of individuals of the population is plotted on the y-axis of the graph and the age of survivorship is plotted on the x-axis of the graph. Survivorship curves are hypothetically of three types: Types I, II and III, or better known as convex, diagonal and concave survivorship curves respectively (see figure 1).

NSOU CC-ZO-09 18 a) Convex or Type-I curve It indicates high survivorship or very low mortality among younger individuals up to a particular age, after which most of the population dies. This situation is characteristic of some human population, many species of large animals and Dali mountain sheep. Such a situation would happen if environmental factors were found to be unimportant and most of the organisms lived out their full physiological longevity. The abrupt drop in survivorship would depend on how variable the population was in genetic factors affecting length of life. b) Concave or Type-II curve It indicates high mortality rate during the young stages. This pattern is typical in the case of Oak trees, marine invertebrates (oysters), many fishes and some human population. Mortality is extremely high during the free-swimming larval stage or the acorn seedling stage. This results from such factors like inexperience in foraging and avoiding predators and lack of immunity to disease. Once an individual is well- established on a favourable substrate, life expectancy improves considerably. c) Diagonal or Type-III curve It indicates a constant probability of dying. It can be otherwise stated that a constant percentage of the population is lost in each
time period. Probably no population in the natural world has a constant age-specific survival rate throughout its whole life span. However, a slightly concave curve, approaching a diagonal straight line on a semilog plot (Type II), is characteristic of many birds, mice, rabbit and deer. In these cases, the mortality rate is high in young but low and more nearly constant in the adults (1 year or older).

The shape of survivorship curve is related to the following factors— 1) Shape related to the degree of parental care or other protection given to the young. For example, survivorship curve for honey bees, robins etc. who protect their young ones, are less concave than those occurring for grasshopper, sardines etc. who do not protect their young ones. I II III Total life span Fig. 1: Different survivorship curves number of individuals

NSOU CC-ZO-09 19 2) Shape related with the density of the population. For example, survivorship curves for two mule deer populations show a concave curve for denser population. This is due to deer living in the managed area where food supply is high, have a shorter life expectancy than deer living in unmanaged area. In the latter case, there is increased hunting pressure, intraspecific competition etc. Humans also have greatly increased their own ecological longevity because of greater medical knowledge and facility, increased nutrition and adequate and proper sanitation. Thus, the curve depicting the survival rate of human beings approaches the sharp angled type I minimum normality curve. 2.2.5 Population density The number of individuals (population size) of a species or population biomass per unit geographical area or volume at specific time is called population density. For example, we can express the population size as 500 rabbits per square mile or 500 rabbits in a square block or 500 rabbits per hectare. The population density can be expressed as follows— Population density (PD) = Number of individuals in a region (N) ———————————————— Number of unit area in the region (S) ; PD = N — S In a particular habitat, the density of individuals of a particular species depends upon the intrinsic quality of their habitat, and on the net movement of individuals into that habitat from other habitats. It is obvious that individuals are numerous where resources are most abundant. Study of population density provides us with the following informations: (i) The interaction of a population with its environment; and (ii) Changes in density reflect changing local conditions. The factors that regulate population size can be classified as extrinsic and intrinsic. The population own response to density is said to be intrinsic, while the interaction with the rest of the community is said to be the extrinsic factor. Intrinsic factors include intraspecific competition, immigration, emigration and physiological and behavioral changes affecting reproduction and survival. Extrinsic factors are interspecific competition, predation, parasitism and disease.

NSOU CC-ZO-09 20 Type of population density 1. Crude density: It is the number (or biomass) per unit of total geographical space. 2. Ecological density: Ecological

density is the number (or biomass) per unit of habitat space (area or volume available that can be colonised by the population). 3.

Relative abundance: It is used to denote changing (increasing or decreasing) population and is time relative. Example: the number of birds seen on a tree per hour. Population density can be estimated either by direct counting of individuals or biomass or through a method called mark-recapture method. This method involves capturing of a fraction of the population and marking with tags, paint, radio collars etc. and releasing them back into the population. Enough time is allowed for the marked individuals to recover and mingle with the rest of the population. The ratio of the marked to unmarked is noted and the estimate of the population size can be calculated by the following equation: X = nM/N i.e., N = nM/x Where, x is the number of marked individuals recaptured; n is the total number or size of the second sample; M is the number of individuals marked initially (first sampling), N is the total size of the population. 2.2.6 Life tables Population possesses a spatial as well as genetic structure. A third aspect is to do with the rates of births and deaths and the pattern of distribution of individuals among different age classes. Life table is a tabular accounting of the birth rates and probabilities of death for each age class in the population. It, thus, gives a statistical account of death and survival of a population by age. Pearl and Parker first introduced the life table into general biology, for a laboratory population of the fruit fly, Drosophila melanogaster. The individuals from birth (born at approximately the same time) to the end of the life cycle, form a group known as a cohort and their investigation is turned as cohort analysis. To understand the construction of a life table, you must have knowledge of the age structure of the population. It comprises of different age classes and the

NSOU CC-ZO-09 21 number of individuals in each age class residing at the same time. In a life table, age is designated by the symbol x. The first or youngest age class is x = 0. Ages are depicted in years (for some organism it may even be months, days or hours). The age specific variables are indicated by the subscript x. In L x survivorship (the number of individuals alive at the start) d x is mortality, q x is mortality rate (number dying divided by the number alive at the beginning of the time interval) and e x is the life expectation (the average time left to an individual at the beginning of the interval). Table shows the life table of Mckinley Murre population. At the start (age 0) 100 individuals were taken to be born at the beginning of the interval. Over one half (55) died during the first interval. The mortality was 55 / 100 × 100 = 55%. As in the first year 55 animals died, so 100 – 55 = 45 survived to begin the second year. During the second period (from age one to two), 30 died. Mortality rate in the second year was found to be slightly higher i.e., 30 / 45 × 100 = 67%. The life expectation at birth was, on an average, just over one year (1.15). The number aged one year has a life expectation of slightly less than one year (0.94). At age 0 life expectation is the same as mean natural longevity. Physiological longevity is another aspect of longevity which is the age reached by individuals dying of old age. Individuals living under conditions where death results due to predation, accident, poor nutrition and infection are not factors. Limitation of life table construction (1) It takes a long time to collect the data, and (2) It is difficult to apply to highly mobile animals. The r-and k-strategies MacArthur and Wilson suggested another way of classifying evolutionary strategies, when they applied the terms r-selected and k- selected to populations. The initials r and k are taken from the logistic equation, used for Survivorship Mortality Mortality Life Rate Expectation Age x l x d x q x e x 0 100 55 0.55 1.15 1 45 30 0.67 0.94 2 15 10 0.67 0.83 3 5 5 1.00 0.50 4 0 — — — Table-1 : Life table of Mekinley-Murre population
NSOU CC-ZO-09 22 describing the actual rate of growth of populations (R):R = dN/dt = rN (1-N/K) Where, r is maximum rate of intrinsic increase of the population. k is number of organisms that are able to live in the population, when it is in equilibrium; or, in other words, it is the carrying capacity of the population. N is number of organisms in the population at time t. As we can observe from the above logistic equation, r-selected populations are ones where maximum rate of increase (r) is important. In temperate and arctic regions, populations undergo periodic reduction (irrespective of their genotypes) due to catastrophic weather conditions. These crashes in population are followed by longer period of rapid population increase. A r-selected population has the ability to take advantage of these favorable situations through increased fecundity and earlier maturity. They have many offspring which under normal circumstances die before reaching maturity, but survives if circumstances change and are selected. Thus, r-selections are associated with the type-III of survivorship curve. A k-selected population is associated with a steady carrying capacity. For example, in 'constant' tropical environments, where populations fluctuate little, populations remain near the limit imposed by resources (k). Adaptations that improve competitive ability and efficiency of resource utilization are selected. Thus k-selected populations are less able to take advantage of particular opportunities to expand (than r-selected populations). They are generally more stable and less likely to suffer high mortality. k-selected organisms usually have few and well-cared young. Thus, they are associated with type-I and II of survivorship curves. Many ecologists have attempted to contrast genetic responses to r-selected and k-selected spectrums in laboratory populations. Francisco showed that when populations of Drosophila were maintained for long periods under crowded conditions, the numbers of adults per cage increased gradually. This was due to selection of traits that improved fecundity and survival at high densities. In another experiment, Drosophila populations were kept much below the carrying capacity by removing adults. The selective effects of low density with those of high mortality resulted. Similar experiments of bacteria
NSOU CC-ZO-09 23 and protozoans on laboratory populations have also given negative results. Key differences between k-and r-selected species Characters r-selection K-selection Population size Variable Constant Usually below the carrying Close to carrying capacity capacity Emigration common, reco- Recolonisation uncommon lonisation high Mortality Variable and unpredictable More constant and Not density-dependent predictable. Density- dependent Intraspecific and inter- Variable, often weak Usually strong specitic competition Survivorship curve (semilog plot) Selection favours Rapid development, early Slow development, delayed reproduction, small body reproduction, large body size. semelparity size, iteroparity Lifespan Usually shorter Longer, usually more than one year Leads to High productivity High efficiency 2.2.7 Population growth Living things undergo sexual maturity and have the ability to produce young ones of its own type. In other words, natural populations have the ability to grow. The capacity for populations to grow is enormous, particularly when they are introduced in new regions having suitable habitats. This rapid increase in numbers lead to the development of mathematical equations that predicts the growth of population and its regulation. The study of population growth is called demography. Reproduction provides an increase in population growth. But, in nature, populations do not explode. As the

NSOU CC-ZO-09 24 reproduction continues, but populations do not always grow. Darwin pointed that the sizes of populations are often regulated by environmental factors. Population growth is of two types : a) Exponential population growth (growth without regulation) A small population living in a very large and favorable habitat has a growth rate that depends on two factors - the size of the population and the capacity of the population to increase (referred to as biotic potential or intrinsic rate of natural increase). The important periodical production of offspring results in important differences in the way in which population grows. Young ones may be added to the population only at specific times of the year, i.e., during discrete reproductive periods. Such populations are said to have geometric growth where the increment of increase is proportional to the number of individuals in the population at the beginning of the breeding season. Geometric growth is the typical pattern of population growth (see the figure in left). There are some organisms which do not have distinct reproductive seasons, but instead add young at any time of the year. Such populations increase more or less continuously and are referred to as exponential growth. Exponential growth rate is the rate at which a population is growing at a particular time, expressed as a proportional increase per unit of time. In exponential growth, the curve of numbers versus time becomes steeper and steeper. Growth depends on the biotic potential which does not change, and on the size of the population which changes continually growing larger and larger. As a result, the growth rate of the population increases steadily from a slow rate (when the population is low) to a faster rate (when the population is high). Examples of exponential growth rate are many in laboratory studies, but in field conditions they are scarce as it requires hard work for accurate censuring. One such example is the ring-necked pheasant population introduced on Protection Island (off the coast of Washington). → ↑ → time → Number of Individuals

NSOU CC-ZO-09 25 The initial population of 8 birds reached to 1,898 in six breeding seasons. Another example is of a herd of tule elk introduced into Grizzly Island (northwest of San Francisco, California). This animal released in mid-1977, developed from 8 animals to a population of 150 by 1986. If birth rate equals death rate, the rate of population growth is zero and the population is in a stable condition. If the population grows at a fairly constant rate (say 1%, 5% or less than 1%), the population size will increase exponentially. However, if the population does not have a stable age distribution the growth rate is faster than predicted from the biotic potential. Subsequently, if growth persists at a constant rate a stable age distribution is quickly established. Equation of exponential growth The formula by which exponential growth occurs is dN/dt = rN where, dN/dt is the population growth rate and refers to the change in numbers (dN) per time interval (dt). Biotic potential, (r), is the increase in number of individuals per time period per head (or per individual) and combines birth rate and death rate. N is the number of individuals in the population.

In the above formula, growth rate is higher in a population with a high r compared with one with a low r. Conversely, the growth rate also depends on N, with a slow growth rate when N is small and rapid growth rate when N is large. The formula given above gives growth rate in a population growing exponentially. If, instead, the population size at various times during exponential population growth is to be noted then an equivalent expression is the integral equation N t = N o e rt . where, N t is the number of individuals in the population after t unit of time; N o is the number at time 0 (that is, at the beginning of the period being studied), r is the biotic potential and t is the time period being studied. The constant e is the base of the natural logarithm having a value of approximately 2.718. The term e r is the factor by which the population increases during each time unit and is written as the lower case Greek lambda (λ); that is when t = 1. Then Nt = N 0 e rt , or Nt = N 0 λ. Example Suppose a population of 10 duckweeds grows for 4 days and r is 0.20 per day. Then N 4 = 10 × e (0.20×4) = 10 × 2.22 = 22.2

NSOU CC-ZO-09 26 Thus, the population size at the end of 4 days is 22 or 23 duckweeds. (b) Logistic population growth (simple population regulation) As has been written earlier in exponential population growth when a population invades a new area where space and food are in plenty, the population undergoes exponential growth. However, the exponential population growth always seems ridiculous because the number of most organisms remain usually constant from year to year. Thus, the population growth curve shows an exponential, or approximately so, at the beginning having initially a slower growth rate which subsequently gets faster and faster. The population then becomes medium sized and the growth rate begins to slow down until it finally reaches zero, when birth balances death. This type of growth curve looks like a flat S and is called the sigmoid growth curve. The model depicting this type of growth is the logistic equation, introduced in ecology by Raymond Pearl and L. J. Reed in 1920. The logistic equation is defined as the mathematical expression for a particular sigmoid growth curve in which the percentage rate of increase/decreases in linear fashion as population size increases. The growth rate of the population is determined by biotic potential and the size of the population is modified by the environmental resistance (by all the factors that control crowding). These factors may include lowered production due to mothers' poor nutrition, high rate of death because of predators or parasites, increased emigration etc. Environmental resistance gradually increases as the size of the population gets closer to the carrying capacity (usually represented by K), which is the number of individuals in a population that the resources of a habitat can support. Thus, the S-shaped or sigmoid growth curve comprises of population that increases slowly at first, then more rapidly, but it subsequently slows down as → ↑ or

NSOU CC-ZO-09 27 environmental resistance increases until equilibrium is reached and maintained. This can be represented by a simple logistic equation dN/dt = rN × K – N/K. K is the maximum carrying capacity. The logistic growth curve, however, shows another basic pattern of growth, termed as the J- shaped growth curve. In the J-shaped growth curve, the density of the population increases rapidly in exponential manner. It frequently tends to overshoot the carrying capacity and then drops back rather sharply, as environmental resistance or other limiting factors become effective more or less suddenly. This curve can be presented by the simple model based on the experimental equation dN/dt = rN. The equation given above for the J-shaped growth form is same as that of the exponential equation except that a limit is imposed on N. The unrestricted growth is suddenly halted when the population runs out of resources like food or space; when frost or heat wave or any other environmental factor intervenes; or when the reproductive season suddenly terminates. When the population reaches the upper limit of N, it remains at this level for a while and then a sudden decline takes place. It thus produces a relaxation-oscillation (boom-and-bust) pattern in density. Such a pattern is the characteristic of many populations in nature, such as algal bloom, annual plants, zooplankton bloom, some insects and, perhaps, lemmings on the Tundra. The S-shaped or sigmoid pattern of growth shows a gradual increasing action of detrimental factors (environmental resistance or negative feedback) as the density of the population increases. However, in the J-shaped population growth, negative feedback is delayed until right at the end when it goes beyond the carrying capacity. The equation of the S-shaped curve differs from that of the J-shaped one, in the addition of one expression K - N/K or I - N/K, a measure of the portion of available limiting factors not used by the population. The S-shaped pattern of growth is followed by a great variety of populations represented by microorganisms, plants and animals, both in natural and laboratory populations. The S-shaped growth form includes two kinds of time lag: (1) the time needed for an organism to start increasing when conditions are favorable, and (2) the time required for organisms to react to unfavorable conditions by altering birth and death rates. The various phases seen in S-shaped curve are the lag, logistic growth, and point of inflection, environmental resistance and carrying capacity phases.

NSOU CC-ZO-09 28 The lag phase is the time lag necessary for a population to become acclimated to its environment. The point of inflection is the maximum rate of increase. The environmental resistance phase is the slowing of population growth due to limiting resources. The population ultimately reaches the carrying capacity condition when the rate of population increase is zero and the population density is maximum. Globally the humans have yet to reach the carrying capacity condition. 2.2.8 Age structure Another important attribute of population is age distribution or structure. Age structure of a population refers to the proportion of individuals of various ages. For most animals, the age of an individual is important in specifying its role in the population. Age distribution influences both natality and mortality. The reproductive status of a population is determined by the ratio of the various age groups. It also indicates what may be expected in the future. A rapidly growing or expanding population generally will contain large number of young individuals; stable population will show an even distribution of age classes, while a decline or collapsing population will have large number of old individuals. The population that is growing or declining at a constant rate, it is called stable age distribution. If the population is not changing and its growth or declining rate is zero, then it is called stationary age distribution. It can be calculated from the l x column of the life table. It tends to have large number of older individuals than younger ones. However, real populations usually have an age structure quite different than the above two because of various events in its recent past. It is evident that populations tend to go to a normal or stable age distribution. Once a stable age distribution is achieved, any unusual increase of natality or mortality will last for a short time and the population would spontaneously return to the stable condition. As rapidly increasing pioneer population gradually reaches mature and stable Percentge in age class
NSOU CC-ZO-09 29 condition having slow or zero growth, the percentage of younger age class individuals decreases. It has also been seen that the average age of individuals also increases in a stable population. The changing age structure, with an increasing percentage of old individuals, has some strong impacts on life style and economical and sociological consequences. A greater proportion of our resources will have to be used for helping the elderly and a small proportion used for education and other child welfare services. However, the economic burden may not be greater as the dependency ratio (the number of workers compared to the number of non-workers) will not be too different. Age structure also can be expressed in terms of three categories: pre-reproductive, reproductive and post-reproductive. In accordance to their lifespan, the relative duration of these ages varies greatly with different organisms. In case of humans, during recent times, the three age categories are relatively equal with a third of the human
life falling in each class. However, early humans had a much shorter post-reproductive period. Insects have extremely long pre-reproductive period, a very short reproductive period and no post-reproductive period.
For example, mayflies require from one to several years to develop during the larval stage and adults emerge to live for only a few days. In fish population that has a very high potential natality rate, a phenomenon called dominant age class has been observed. When in one year large survival of eggs and larval fish takes place, then in subsequent years reproduction is suppressed. 2.2.9 Patterns of distribution Distribution or dispersion of individuals within a population describes their spacing with respect to one another. In a population, individuals may be distributed according to four types of pattern— a) Random b) Regular c) Clumped, and d) Regular clumped. All the above four types of distribution are found in nature. a) Random distribution occurs in individuals that are distributed throughout a
NSOU CC-ZO-09 30 homogeneous area without regard to the presence of others. It takes place when the environment is uniform and there is no tendency to aggregate. Fig: Types of distribution of individuals (A : Random; B : Regular; C : Clumped; D : Regular Clumped) Examples Lone parasites or predators show a random distribution as they are often engaged in random searching behaviour for their host or prey. b) In regular or uniform or spaced distribution, each individual maintains a minimum distance between itself and its neighbour. It may occur when competition between individuals is severe or when there is strong hostility, which eventually promotes even spacing. Examples Trees present in forests that have reached sufficient height to form a forest canopy show a regular uniform distribution due to competition for sunlight. Other examples are monoculture crops, orchard or pine plantation, desert shrubs etc. A similar regular pattern of distribution is seen in territorial animals. (c) Clumped distribution takes place in individuals who maintain discrete groups. Clumping or aggregation, by far, is the most common pattern of distribution. It may occur due to— A C B D

NSOU CC-ZO-09 31 1) The social predisposition of individuals to form groups; 2) Clumped distribution of resources (the most common cause); or 3) Tendency of progeny to remain close to their parents. Examples Salamanders prefer to live in clumps under logs. Birds travel in large flocks. Trees form clumps of individuals through vegetative reproduction. d) In regular clumped distribution individuals are clumped and are spaced out evenly from other similar clumps. Examples Herds of animals or vegetative clones in plants show either random or are clumped in a regular pattern. In the absence of hostility and mutual attraction, individuals may distribute themselves at random. Thus, in a population, the position of an individual is not influenced by the positions of other individuals. A random distribution pattern implies that spacing is not related to a biological process. It is often used as a model to compare it with an observed distribution. To determine the type of spacing and the degree of clumping, several methods have been suggested of which two are mentioned: (i) To compare the actual frequency of occurrence of different sized groups obtained in a series of samples. If the occurrence of small sized and large sized groups is more frequent and the occurrence of mid-sized groups less frequent than expected, then the distribution is clumped. The reverse is seen in uniform distribution. (ii) The distance between individuals are measured and the square root of the distance is plotted against frequency. The shape of the resulting polygon indicates the pattern of distribution. A symmetrical polygon (bell-shaped) indicates random distribution, a slanted polygon to the right indicates a uniform distribution, and one slanted to the left indicates a clumped distribution. The pattern of dispersion for many species reflects the arrangement of habitat patches in the environment. For example, apple leaves are habitat patches for the mite. The pattern of dispersion for other species may be due to an interaction between the spatial arrangement of habitat patches and other ecological or behavioral processes. For example, kangaroo rats, in order to construct their burrows, require certain soil characteristics. It may be assumed that individual kangaroo rats would simply aggregate within suitable habitat patches when they can easily construct burrows.
NSOU CC-ZO-09 32 However, the aggregated dispersion in the population was not entirely due to habitat patchiness as banner tailed kangaroo rats have a tendency to leave the place of their birth. The movement of individuals may also influence the pattern of dispersion. For example, in case of plants, dispersal of seeds often depends on the action of other organisms. 2.2.10 Population regulation Individuals are subjected to a number of environmental hazards which affects its growth and proliferation. Populations are made up of individuals and the size of the population depends upon the reproductive fitness and lifespan of those individuals. Thus, population size is affected by factors such as nutrients, flood, drought, predators, diseases etc. The various limiting factors are— (a) Factors those are constant There are factors that are relatively constant and limits the population to a fairly constant size, as individuals has to compete for the resources. Plants, for example, compete for space and light, birds for nesting territories, heterotrophs for food etc. However, large changes in population are not produced. (b) Factors those are variable Although certain factors like seasonal drought or cold are variable however, they are predictable. Their presences are felt for some months or few days and may sometimes result in population crash. Evasive actions like migration or dropping of leaves (deciduous trees) may be taken to avoid such predictable factors. (c) Factors that are unpredictable (density independent and density dependent) Ecosystems are subjected to irregular or unpredictable extrinsic disturbances like weather, water currents, pollution etc. These physical factors often influence the population size. When there is low probability of physical stress such as storms or fire, populations tends to be biologically controlled and their density is self-regulatory. Factors favourable or limiting to a population are either: (i) Density-independent, that is, its effect on the population is independent of the population size, or

NSOU CC-ZO-09 33 (ii) Density-dependent, if its effect is a function of population density, climactic factors often acts in a density-independent manner, while biotic factors act in a density- dependent manner. The J-shaped growth curve occurs in case of density-independent population whose growth slows down or stops. On the other hand, sigmoid growth curve occurs in density-dependent population where self-crowding and other factors regulate the population growth. The primary differences between density- independent and density-dependent factors are: 1. Density-independent or extrinsic factors of the environment cause variations (sometimes drastic) in population density. This may cause shifting of carrying capacity levels (asymptotic). Density-dependent or intrinsic factors (such as competition) tend to maintain a stable population density. 2. In physically stressed ecosystem, density-independent environmental factors play a greater role. In favourable environment, density-dependent natality and mortality play an important role. 3. Density-independent factors involve interaction with the rest of the community. Density- dependent factors are the population's own response to density. 4. The main density-independent factors are predation, parasitism, disease and interspecific competition. Density-dependent factors include intra- specific competition, immigration, emigration and physical and behavioral changes that affects reproduction and survival. For many organisms, intraspecific competition is one of the most important density dependent factors. Like animals, plants exhibit density-dependent population regulation mechanisms. At very high density, plant populations undergo a process termed self-thinning. When in an area seeds are sown at a high density, the emerging young plants compete with one another. As the seedlings grow, competition among them becomes tougher and tougher. Many die leading to a gradual decline in the number of surviving plants. A similar condition occurs in over-populated caterpillars that tend to overshoot the carrying capacity conditions. Holling (1966), has emphasised the importance of behavioural characteristics, where a given insect parasite can effectively control the insect host at different densities.
NSOU CC-ZO-09 34 Population studies generally depend upon the type of ecosystem of which it is a part. Physically controlled and self-regulatory ecosystems are arbitrary. It presents an oversimplified model. However, it is a relevant approach, as human efforts have been directed towards replacing selfmaintained ecosystems with monocultures and stressed systems. At the same time, the cost of physical and chemical control has risen due to the resistance of pest to pesticides and the toxic chemical by-products in food, water and air, have become a potential threat to mankind. This has led to the increased implementation of integrative pest management (IPM). Evidences of the above are the generation of increased interest in a new frontier termed ecologically based pest management. This involves efforts to re-establish natural, density-dependent, ecosystem-level controls in agricultural and forest ecosystems. 2.2.11 Population interactions Biological interactions are the effects that the organisms in a community have on one another. In the natural world no organism exists in absolute isolation, and thus every organism must interact with the environment and other organisms. Population of two species may interact in ways that correspond to combination of neutral, positive and negative Three of these combinations (+, +) (–, –) (+, –) are subdivided resulting in nine important interactions and relationships that are broadly classified under two categories. Types of interactions (a) Negative interactions 1. Neutralism: Neutralism describes the relationship between two species that interact but do not affect each other. Neither of the population is affected by interaction with each other. Example: Rabbits, deer, frogs, live together in grassland with no interaction between them. 2. Direct interference: It is the type of interaction where both populations actively inhibit each other. It occurs directly between individuals via aggression etc. when the individuals interfere with foraging, survival, reproduction of others. Example: Between the ant Novomessor cockerelli and red harvester ants, where the former interferes with the ability of the latter to forage by plugging the entrances to their colonies with small rocks.
NSOU CC-ZO-09 35 3. Competition for resource:
Competition is an interaction between organisms or species in which both the species are harmed. Limited supply of at least one resource

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used by both can be a factor in this type of interaction. Competition among members of the same species is known as intraspecific competition while competition between individuals of different species is known as interspecific competition. It is an antagonistic interspecific interaction in which one species is inhibited while other species is neither benefitted nor harmed. It is also called antibiosis and the affected species is called amensaland the affecting species is called inhibitor. Example: Roots of certain plants produce allochemic substances which check the growth of other plants to conserve resources, such as, Convolvulus arvensis, a weed that inhibits the germination and growth of wheat. Competition always produces a winner and a loser. The winner is stronger in some or the other way, and hence, he wins. But when the competition is about life and death, you can say, it's the survival of the fittest and the smartest. The competitive exclusion principle is also known as Gause's law of competitive exclusion. It states that the two closely related species competing for the same resources cannot co-exist indefinitely and the competitively inferior one will be eliminated eventually. This is because, in a competition to survive, they try to consume as many resources as they can, not leaving anything for the opponent or competitor. The weaker species will either go extinct, or will adapt to some other resource and evolve, but it will be out of that competition sooner or later. Competition reduces the growth of other species. This means, in order to maintain the equilibrium, species that don't consume the same resources must coexist. 'Species' here will include all living things that depend on other living things for their food. Humans, animals (herbivores, carnivores), plants, microorganisms shows competition for resources. Example: Gray squirrels have replaced red squirrels in Britain. The population of red squirrels decreased substantially due to competitive exclusion, disappearance of hazelnuts, and diseases. Then, gray squirrels were introduced to Britain from 1876-1929, which easily adapted to the environment and slowly replaced the red squirrels. Experimental basis of Gause's principle: Gause formulated the law of competitive exclusion based on laboratory competition experiments using two species of Paramoecium, P. aurelia and P. caudatum. The conditions were to add fresh water every day and input a constant flow of food. Although P. caudatum initially dominated, P. aurelia recovered and subsequently drove P. caudatum extinct via exploitative
NSOU CC-ZO-09 36 resource competition. However, Gause was able to let the P. caudatum survive by alteration of the environmental parameters (food, water). Thus, Gause's law is valid only if the ecological factors are constant. Resource partitioning: It states that if two species compete for the same resource, they could avoid competition by choosing different times of feeding or different foraging patterns. In this relation, McArthur showed that five closely related species of warblers living on the same tree were able to avoid competition and co- exist due to behavioural differences in their foraging activities. Competitive release: It is a phenomenon, in which a species whose distribution is restricted to a small geographical area is found to expand its distributional range dramatically, when the competing species is experimentally removed. 4. Amensalism: It is a class of relationships between two organisms where one organism benefits from the other without affecting it. The commensal (the species that benefits from the association) may obtain nutrients, shelter, support, or locomotion from the host species, which is substantially unaffected. The commensal relation is often between a larger host and a smaller commensal; the host organism is unmodified, whereas the commensal species may show great structural adaptation consonant with its habits, as in the remoras that ride attached to sharks and other fishes. 5. Parasitism: Parasitism is a non-mutual symbiotic relationship between species, where one species, the parasite, benefits at the expense of the other, the host. Parasites can be micro parasites, which are typically smaller, such as protozoa, viruses, and bacteria. Examples of parasites include the plants mistletoe and cuscuta, and animals such as hookworms. Parasites typically do not kill their host, are generally much smaller than their host, and will often live in or on their host for an extended period. 6. Predation: It is a negative, direct food related interspecific interaction between two species of animals in which larger species called predator. Predator attacks, kills and feeds on the smaller species called prey. Predator population adversely affects the growth and survival of smaller prey population and therefore predation is considered as an antagonistic interaction. Example: Plant like Nepenthes (pitcher plant), Drosera (sundew), Dionoeae (Venus fly trap) etc. feed on insects to fulfill their nitrogen requirement. Some predators (such as frog) act as prey for others (snake) which in turn are prey to a higher carnivore (eagle).

NSOU CC-ZO-09 37 Significance of predation a) Local species diversity is directly related to the efficiency with which the predators prevent the monopolization of an environmental area by any species. b) Predation keeps the prey population under check, so as to maintain an ecological balance. Weak and less efficient members in the prey population are removed. c) Most important significance is in the practical utility of prey predator relationship on biological control of weeds and pests. Many insect pests are kept under check by introducing their predator into the area. Example: Opuntia which becomes a serious problem in Australia was brought under control by introducing its natural herbivore Cactoblastis (cochineal insects). (b) Positive interaction 7. Commensalism: The term commensal was coined by P. J. Van Beneden (1876). It is a simple type of positive association and probably represents the first step toward the development of mutual beneficial relations. Commensals live on or around individuals of some other species (host) and derive benefit from the association. Example: (i) Vulture, a scavenger, feeds upon the leftovers of a kill of large carnivores (tiger, lion etc.). (ii) The fish, remora, has a suction cup on the top of its head. With its help it attaches itself to a shark and travels with it. It eats the leftovers of the bigger fish's meals, (iii) A number of communal fish, clams, polychaete worms and crabs live by snatching surplus or rejected food or waste materials from the host. 8. Proto-cooperation: It is a positive inter specific interaction in which both the partners are mutually benefitted and increase the chance of their survival. However, the interaction is not obligatory for their survival as both can live without this interaction. Example: Crocodile bird (Pluvianus aegyptius) enters the mouth of the crocodile and feed on parasitic leeches. By this the bird gets food and the crocodile gets rid of blood sucking parasites. 9. Mutualism: It is a positive interspecific interaction in which members of two different species favour the growth and survival each other and their association is obligatory. Both the partners are benefitted by this interaction. Mutualism is also referred as symbiosis or symbiotic interaction and the partners are referred as symbionts. Example: Termites (white ants) are not capable of digesting wood, which they ingest as food. A multi flagellate protozoan Trichonympha campanula, which lives in the
NSOU CC-ZO-09 38 intestine of white ant secretes cellulase enzyme to digest the cellulose of wood. In return, the ant provides food and shelter to the protozoan. The following table will depict us about general nature of different types of interaction between two species (Species 1 and Species 2) Sl. No. Types of Interaction Species 1 Species 2 General nature of Interaction 1. Neutralism 0 0 Neither population is affected. 2. Mutual inhibition — — Direct inhibition of each species by the competition type other. 3. Competition resource — — Indirect inhibition when common resource use type is in short supply. 4. Amensalism — 0 One of the population inhibited, the other not affected. 5. Parasitism + — The parasite (smaller) gains at the expense of the host (larger). 6. Predation + — The predator is larger and gains at the expense of the prey which is smaller. 7. Commensalism + 0 The commensal (species 1) benefits while the host (species 2) is not affected. 8. Protocooperation + + Interaction favourable to both but not obligatory. 9. Mutualism + + Interaction favourable to both and is obligatory. 2.2.12 Lotka-Voltera equation for competition The Lotka-Volterra equations are so termed because interspecific associations were proposed as models by Lotka (1925) and Volterra (1926) in separate publications. It comprises of a pair of differential equations useful for modeling predator-prey, parasite-host, competition or other two species interactions. If one species is using some of the resources of the other, then the equations of growth for the two species are: For species 1 = For species 2 =
NSOU CC-ZO-09 39 Each population has a definite K or equilibrium level. The co-efficients α and β are competition factors indicating the effect of species 2 on 1 and the effect of species 1 on 2, respectively. N 1 and N 2 are the numbers of individuals of species 1 and 2, and r 1 and r 2 are the specific growth rate of species 1 and 2. The inhibitory effect of one new individual of species 2 on the growth of species 1 is α/K 1 and the inhibitory effect of another individual on itself is 1/K 1 . The growth of any one of the competing species will stop when its carrying capacity has been reached which is the combination of its own numbers plus that of the other species. Thus, species 1 stops growing when N 1 + αN 2 = K 1 Similarly, species 2 stops growing when N 2 + βN 1 = K 2 The two species system will be at equilibrium only when the stoppage of growth coincides for the two species simultaneously, that is, when dN 1 /dt = dN 2 /dt = 0 The above equation can be best understood by wing graphs of zero population growth (ZPG). The graph shows a straight line that consists of all the mixes of species 1 and species 2 that add up to K. When N 2 is o then N 1 is equal to K 1 . When N 1 is o then N 2 is equal to K 1 /α. The straight line represents all the combinations of numbers at which species 1 will stop growing. Ni will decrease if there is a mix of N 1 and N 2 as shown by the arrow at X. Similarly, N 1 will increase at a mix up at Y as shown by the arrow. Figure shows another graph for species 2 like that in species 1. When the lines for the two species are put Numbers of species 1 Numbers of species 2 Numbers of species 2 Numbers of species 2 Numbers of species 1 O O O

NSOU CC-ZO-09 40 together on the same graph it would be possible to determine how the densities of the two species will change from any point by drawing arrows for each species. We can see that any point (A) below line K 2 -K 2 /β, both species will be able to increase their numbers. When the mix of species forms a point (Z) between the two lines K 2 -K 2 /β and K 1 /α-K 1 , represented by the shaded area, species 1 will continue to increase but species 2 will decline. If species 2 remains the same but species 1 grows in number, the point B will slide horizontally towards C, thereby the numbers of species 2 will start to decline. In the area (X) above the line K 1 /α-K 1 both species 1 and 2 will decline. In this graph the invariable result will be the extinction of species 2. Similar sort of graphs are possible to show three other relationships-extinction of species 1, extinction of one species or the other and coexistence of the two species. The Lotka-Volterra predator-prey model The Lotka-Volterra predator-prey model is a simple but valuable one. This model presumes that the numbers of a predator (increase in birth rate) depends upon the prey population. For example, in a paddy field, if the mouse population is high, the foxes would eat a lot of mice and would have a lot of babies. If the mouse population falls to zero, the foxes will not breed. Conversely, the numbers of a prey would depend on the predator population, as it would act on the prey death rate. For example, most mouse babies would grow if the fox population is low. Even the old mice would live for a longer time. Therefore, prey are predator limited and predators are food-limited. The Lotka-Volterra predation model can be best represented in a graph (see figure at previous page) for the predator. The predator population shows neither growth nor decline (dN predator/dt = 0) at any point on line C. Any point to the left will result in decline of the predator population because of lack of food. A similar graph can be drawn for the prey population, when any point on the line D, the prey population will neither grow nor decline (dN prey/dt = 0). The probable happenings of the system are in accordance to the deep arrows forming a circle around E. At the quadrant marked by A, both the populations would increase and the system would move to the upper right quadrant. Here, the tendency NSOU ? CC-ZO-09 41 would be towards further increase of predator population while the prey population would decline. The system would then move towards the upper left quadrant where both populations would decline. The system would eventually return back to A. From this Lotka-Volterra model, if the numbers of predator and prey were plotted against time, a cyclic fluctuation could be observed of the two populations. A classic example of such a cycle can be illustrated by the Canadian lynx (Lynx canadensis) and the snowshoe hare (Lepus americanus) as shown in the Figure. High lynx numbers reduce the snowshoe hare population. This, in turn, causes a reduction in the number of lynx in subsequent years. This would allow the hare population to rise again and the cycle continues. 2.3 Summary ? Population is a group of individuals of a particular species, which are found in a particular geographical area at a particular time. ? The population shows different characteristics like natality, mortality, sex ratio, survivorship curve, population density, life tables, population growth. ? The lotka— voltera model presumes that the number of predator depends upon the prey population. 2.4 Questions i) What is population? ii) What are population attributes? iii) What is population density? Describe the types of population density. iv) What is natality and mortality? Mention its types. How the natality and mortality rates are calculated? v) What is life table? With the help of an example describe its significance. vi) What is survivorship curve? Describe type I, II and III survivorship curve. vii) What is demographic curve? Mention its types. viii) What are the different types of population dispersal? ix) Describe the exponential and logistic growth curves of a population with suitable equations.

NSOU CC-ZO-09 42 x) Discuss the Gause's principle of population exclusion. xi) Discuss the Lotka-Voterra equation for competition. 2.5 Suggested reading 1. Basu, R.N. (2004). A Compendium of Terms in Ecology and Environment. Naya Udyog. 2. Chapman, R.

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NSOU ? CC-ZO-09 43 Unit 3 ??Community Structure 3.0 Objectives 3.1 Introduction 3.2 Type of communities 3.3 Characteristics of communities 3.3.1 Species composition 3.3.2 Species of richness 3.3.3 Species diversity 3.3.4 Species abundance 3.3.5 Species dominance 3.3.6 Vertical stratification 3.3.7 Ecotone and edge effect 3.3.8 Habitat and ecological niche 3.4 Ecological succession 3.4.1 Types of ecological succession 3.4.2 Process of ecosystem succession 3.5 Summary 3.6 Questions 3.7 Suggested reading 3.0 Objectives After studying this unit, the learners will be able to do the following— ? ?To know about community. ? ?To learn about different types of communities. ? ?To know about keystone species. 43

NSOU CC-ZO-09 44 To know about keystone species. To know about ecotone and edge effect. To have an idea about ecological succession. To know about habitat and niche concept. 3.1 Introduction It is now a known fact that individuals of a species together constitute a population. Various places of earth are shared by many coexisting populations and such association is called a community. A generalized definition of community is any assemblage of populations of living organisms in a prescribed area or habitat. According to A. G. Tansley (1935), community plus its habitat constitutes an ecosystem. In the ecosystem, thus, community and habitat are bounded together by action and reaction. The biotic communities represents a higher order of biological organisation than populations, yet, since communities refers only to living organism, they are not as inclusive as ecosystem. 3.2 Types of communities Kendeigh (1974) divided the biotic community into two types - major and minor communities. Major communities are those that along with their habitats form near complete and self-sustaining units or ecosystems. However, the indispensable input of solar energy is not taken into account. Minor communities or societies, are not completely independent units as far as circulation of energy is concerned. They are, however, secondary aggregates within a major community. In this text, major communities are generally referred to as communities. . 3.3 Characteristics of communities Communities, like populations, are characterized by a number of unique properties which are referred to as community structure and community function. Community structure comprises of species richness (types of species and their relative abundances), physical characteristics of the vegetation and the trophic relationships among the interacting populations in the community. Community function comprises of rates of energy flow, community resilience to troubles and productivity. The structure and function of a community are the manifestation of a complex array of interactions, directly or indirectly tying all the numbers of a community together into an intricate

NSOU CC-ZO-09 45 web. The characteristic features of a community are described below. 3.3.1 Species composition A community is a heterogeneous assemblage of plants, animals and microbes. In ecosystem, virtually every organisms of a community, including the most insignificant microbes, plays some role or the other in determining its nature. The species in a community may be closely or distantly related but they are interdependent and are interacting with each other in several ways. 3.3.2 Species richness The number of variety of species represented in an ecological community, landscape or geographical region is called

species richness. It is simply a count of species, and it does not take into account the abundances of the species or their relative abundance distributions. Species

diversity takes into account both species richness and species evenness. Species richness is used to evaluate the relative conservation values of habitats or landscapes. However, species richness is blind to the identity of the species. An area with many endemic or rare species is generally considered to have higher conservation value than another area where species richness is similar, but all the species are common and widespread. 3.3.3 Species diversity Species diversity is defined as the number of species and abundance of each species that live in a particular location. Species diversity is of immense importance. Each species has a role in the ecosystem. For example, bees are primary pollinators for flowering plants. Imagine what would happen if bees went extinct? Fruits and vegetables could be next, and subsequently the animals that feed off them - this chain links all the way to humans. Various species provide us not only with food but also contribute to clean water, breathable air, fertile soils, climate stability, pollution, absorption, building materials for our homes, prevention of disease outbreaks, medicinal resources, and more. 3.3.4 Species abundance Species abundance is a component of biodiversity and refers to how common or rare a species is relative to other species in a defined location or community. Relative abundance is the percent composition of an organism of a particular kind

NSOU CC-ZO-09 46 relative to the total number of organisms in the area. 3.3.5 Species dominance All the species of a community are not equally important. There are a few overtopping or dominant species who, by their bulk and growth, modify the habitat. They also control the growth of other species of the community, thus forming a sort of nucleus in the community. Some communities have a single dominant species and are thus named after that species, such as sphagnum bog community, deciduous forest community etc. Other communities may have more than one dominant species, for example, oak-hickory forest community. a) Keystone species There are species upon whom several species depend and whose removal would lead to a collapse of the structure and ultimate disappearance of these other species. Such species are referred to as keystone species. The term keystone species was coined by Paine in 1966. These species may exert their keystone role in several ways. The beaver is one example whose ponds provide homes for many organisms from pond weeds to black ducks. Paine through his classic experiments showed that predators and herbivores can manipulate relationships among species at lower trophic levels and, thereby, control the structure of the community. Such predator species are called Keystone predators as their removal can tumble the community. Paine's work on the star fish, Pisaster ochraceus, is a classic example of keystone predator that feeds primarily on barnacles and mussles (Mytitus). After removal of this star fish from the experimental areas on the coast of Washington, Paine observed that the mussels spread very rapidly. They crowded other organisms out of the experimental plots, thereby reducing the diversity and complexity of local food webs. Similarly, removal of the herbivore sea urchin, Strongylocentrotus, allowed a small number of competitive macro algae to form healthy beds and crowding out limpets, chitons and other bottom-dwelling invertebrates. b) Bio-indicator An indicator species (bio-indicator) is
any species or group of species whose function, population, or status
signify the qualitative status of the environment. For example, copepods and other small water crustaceans that are present in many water
NSOU CC-ZO-09 47 bodies can be monitored for changes (biochemical, physiological, or behavioral) that may indicate a problem within their ecosystem. Bio-indicator species also indicates the presence of the pollutant and also attempt to provide additional information about the amount and intensity of the exposure. A classic example of indicator species is lichen whose population shows a reciprocal relationship with the SO 2 present in the atmosphere. 3.3.6 Vertical stratification Community structure can become stratified both vertically and horizontally during the process of succession as species become adapted to their habitat. Gradations in environmental factors such as light, temperature, or water are responsible for this fractionation. The vertical stratification that occurs within forests results from the varying degrees of light that the different strata receive; the taller the plant and the more foliage it produces, the more light it can intercept. Three or more vertical strata of plants: A herb layer, a shrub layer, a small tree layer, and a canopy tree layer, often are found in a forest. Animals are affected by this stratification of plant life. Although they can move from one layer to another quite easily, they often adhere closely to a specific layer for foraging, breeding, or other activities. 3.3.7 Ecotone and edge effect Communities generally have their boundaries well-defined. The intermediate zone lying between two adjacent communities are called ecotones.
The border between a forest and grassland, the bank of a stream running through a meadow,
an estuary (the junction where the river meets the sea), the transition between aquatic and terrestrial communities, between distinct soil types, are a few examples of ecotone. Even the transition between north-facing and south-facing slopes of mountains is ecotones where the transition between communities is abrupt and obvious. The ecotone may be as broad as 100 kms or as narrow as 1 km. Species are distributed at random in respect to one another giving an open structure. The environmental condition in an ecotone is variable, intermediate between the two adjacent communities. Boundaries between grassland and scrubland or between grassland and forest have sharp changes in surface temperature, soil moisture, light intensity and fire frequency. This results in replacement of many species. Grasses prevent the growth of shrub seedlings by reducing the moisture content of the surface layer of soil. Shrubs, on the other hand, depress the growth of grass seedlings

NSOU CC-ZO-09 48 by shedding them. The edge between prairies and forests in mid western United States is maintained by fire. Perennial grass resists fire damage to tree seedlings. Ecotone generally offers an abundance of food and shelter. It contains organisms from both the communities. As a rule, ecotone contains more species and often a denser population than the two concerned communities. This is called edge effect. There are certain species which are entirely restricted to the ecotone and are called edge species. However, it must be made clear at this point that the concept of ecotone is not restricted to the interaction among communities, nor to the transition in the number of species. Ecotone may be viewed as a surface forming common boundary between populations, or between ecosystems, as well as between communities. Eeotone transitions will include fluxes of materials as well as transition in number of species. To have a knowledge about ecotone a diagram of the species distribution across a transition zone of ecosystem between two communities have been presented in Figure below. Fig. Diagram of the species distribution across a transition zone or ecotone between two communities, labelled A and B (after Clapham, Jr., 1973).

NSOU CC-ZO-09 49 3.3.8 Habitat and ecological niche The word habitat is used to denote where an organism lives, or the place where one would go to find it. The word habitat is a Latin word which literally means 'it inhabits' or 'it dwells'. It was first used in the eighteenth century to describe the natural place of growth or occurrence of a species. For example, the lowland gorilla (Gorilla gorilla) has as its habitat lowland tropical secondary forest. Some species, like the tiger (Panthera tigris), have several habitats. It includes tropical rain forest, snow-covered coniferous and deciduous forests and mangrove swamps.

The habitat of some smaller organisms is highly specialized. Certain species of leaf miners live only in the upper photosynthetic layer of leaves, while other species live in the lower cell layer

in certain plant species. Thus, the habitat of the two species is different and such divisions of the environment are called microhabitats. Any one environment is divided up into many possibly thousands of microhabitats. The specific environmental variables in the microhabitat of a population are called micro- environment or microclimate. The term niche is used by ecologists to express the relationship of individuals or populations to all aspects of their environment. Niche, thus, is the ecological role of a species in the community. It represents the range of conditions and resource qualities within which an individual or species can survive and reproduce. Niche is multidimensional in nature. Difference between habitat and niche The words habitat and niche are often misunderstood. Therefore, a clear line difference between the two is required.

Habitat Niche A habitat is an area, where a species A niche is an

address where organisms lives and interact with the other factors. survive or shows its functional attributes in the provided environmental conditions. Habitat consists of numerous niches Niche does not contain such components. Desrets, oceans, forest, rivers, mountains, It is a part of habitat only, where shelter

etc. are examples

of habitat. for living being can be furnished. Habitat supports numerous species at a time. Niche supports a single species at a time. Habitat is a physical place. Niche is an activity performed by organisms. Habitat is not species specific. Niche is species specific.

NSOU CC-ZO-09 50 3.4 Ecological succession Ecological succession is the gradual and sequential replacement of one community by the other in an area over a period of time. According to E.P. Odum (1971), the ecological

succession is an orderly process of community change in a unit area. It

is the process of change in species composition in an ecosystem over time. In simpler terms, it is the process of Ecosystem Development in nature. The different types of ecological succession exist during different phases of an ecosystem, and depend on how developed that ecosystem is? In the concept of ecological succession, ecosystems advance until they reach a climax community. In the climax community, all of the resources are efficiently used and the total mass of vegetation maxes out. Many forests that have not been disturbed in many years are examples of a climax community. 3.4.1 Types of ecological succession a) Primary succession: When the planet first formed, there was no soil. Hot magma and cold water make hard rocks, as seen by newly formed islands. Primary ecological succession is the process of small organisms and erosion breaking down these rocks into soil. Soil is then the foundation for higher forms of plant life. These higher forms can produce food for animals, which can then populate the area as well. Eventually, a barren landscape of rocks will progress through primary ecological succession to become a climax community. After years and years, the soil layer increases in thickness and harbors many nutrients and beneficial bacteria that are required to support advanced plant life.

If this primary ecosystem is disturbed and wiped out, secondary succession can take place. b) Secondary succession: When a climex community is destroyed by a fire and the fire does not burn hot enough to destroy the soil and the organisms it harbors, secondary ecological succession takes place. Small plants will come back first. After they create a solid layer of vegetation, larger plants will be able to take root and become established. At first, small shrubs and trees will dominate. As the trees grow, they will begin to block the light from most of the ground, which will change the structure of the species below the canopy. Eventually the ecosystem will arrive at a climax community, which may or may not be the similar to the original community. It all depends on which species colonize the area, and which seeds are able to germinate and thrive. c) Cyclic succession: Cyclic ecological succession happens within established

NSOU CC-ZO-09 51 communities and is merely a changing of the structure of the ecosystem on a cyclical basis. Some plants thrive at certain times of the year, and lay dormant the rest. Other organism, like cicadas, lay dormant for many years and emerge all at once, drastically changing the ecosystem. . 3.4.2 Process of ecosystem succession The ecological succession is a complex process and it may take thousands of years. Frederic Clements in 1916 for the first time proposed the sequential phases of an ecological succession. The process of succession is completed through a series of sequential steps as given below: a)

Nudation: It is the development of a bare area (an area without any life form).

It is the first step in ecological succession. The causes of nudation are: (i) Topographic: Soil or topography related causes such as soil erosion, sand deposit, landslide and volcanic activity results in the formation of a bare area; (ii) Climatic: Destruction of the community due to glaciers, dry period and storm; (iii) Biotic: It includes forest destruction, agriculture and disease epidemics which results in the total destruction of the population in an area. b) Invasion: It is the successful establishment of a species in the bare area. It is the second step in ecological succession. A new species reaches the newly created bare area and they try to establish there. The process of invasion is completed in 3

steps: (i) Migration ((Dispersal): Seeds, spores, propagules of a species reach the bare area

due to migration. The migration can be achieved through air or water medium, (ii) Ecesis: It is the process of successful establishment of a species in the bare area. The seeds or spores that reached the new area due to migration will germinate, grow and reproduce. Only a few progenies will survive due to the harsh environmental condition prevailing in the area, (iii) Aggregation: Following the process

of ecesis, the individuals of a species increase their number and they stay close to each other.

This process is called aggregation. c) Competition and coaction: Aggregation results in the increase of the number of species within a limited space. This results in competition between individuals for food and space. The competition may be intra-specific (individuals within a species) or inter-specific (individuals between species).

Individuals of a species affect each other's life in various ways and this is called coaction.

Competition and coaction results the survival of fit individuals and the elimination of unfit individuals from the ecosystem. A species with wide reproductive capacity and ecological amplitude only will survive

NSOU CC-ZO-09 52 d) Reaction: Reaction is the most important stage in the ecological succession. It is

the modification of the environment through the influence of living organism present on it.

Reaction cause change in soil, water, light and temperature of the area. Due to these modifications, the present community becomes unsuitable for the existing environmental conditions. Such communities will be quickly replaced by another communities. The whole sequence of communities that replaces one another in the given area is called sere (

sera). e) Stabilization (Climax): It is the last

stage in ecological succession. The final or terminal

community becomes more or less stabilized for longer period of time. This community can maintain its equilibrium with the climate of the area.

This final community is

called the Climax Community (climax stage). The climax community is not immediately replaced by other communities. Climax community is determined by the climate of the region. Example of climax community: Forest, Grassland, Coral Reef etc. In the following diagram figure a diagramatic representation of the interactions between various aspects of the ecosystem as the mechanism for ecological succession has been presented. Fig. Diagrammatic representation of the interactions between various aspects of the ecosystem as the mechanism for ecological succession (after Clapham, Jr., 1973).

NSOU ? CC-ZO-09 53 Characteristics of a climax community The climax community in a succession shows the following characteristics: i) The vegetation of the climax community will have high ecological amplitude. ii) They possess high tolerance towards the environmental conditions. iii) They show rich diversity in species composition. iv) The species composition remains constant for many years. v) The community possesses a complex food chain system. vi) The ecosystem will be balanced and self-sustainable. vii) There will be equilibrium between gross primary productivity and respiration. viii) The energy used from the sunlight and energy released after decomposition will be balanced. ix) The uptake of nutrients from the soil and the release of nutrients back to the soil by decomposition will be in equilibrium. x) The individuals of the community lost by its death are replaced by the individuals of the same species. xi) The climax community is considered as the manifestation of the climate prevailed in the area. 3.5 Summary ? Communities are characterised by a number of unique properties which are referred to as community structure and community function. ? The characteristic features of communities are (i) Species composition; (ii) Species richness; (iii) species diversity; (iv) species abundance; (v) species dominance. ? There are species whose removal from any ecosystem lead to a collapse of the structure and ultimate disappearence of other structure and ultimate disappearence of other species is known as keystone species. ? They intermediate zone lying between two adjacent communities is known as ecotone. ? Ecological succession is the gradual and sequential replacement of one community by the other in an area over a period of time. NSOU CC-ZO-09 54 3.6 Questions i) What is community? Describe briefly the characteristic features of a community. ii) What is species richness and species diversity? iii) Define keystone species and bioindicator species. iv) Differentiate between habitat and niche. v) What is vertical stratification of a community? Give example. vi) What are the types of ecological succession? vii) Define sere, pioneer and climax community. viii) Describe the process of ecological succession. ix) What is hydrarch and xerarch succession? x) What are the characteristic features of a climax community? 3.7 Suggested readings 1. Basu, R.N. (2004). A Compendium of Terms in Ecology and Environment. Naya Udyog. 2. Chapman, R.

L. and Reiss, M. J. (2000). Ecology - Principles & Application. Cambridge University Press. 3. Dash, M.

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NSOU CC-ZO-09 55 Unit 4 Ecosystem Structure 4.0 Objectives 4.1 Introduction 4.2 Type of ecosystem 4.2.1 Aquatic ecosystem 4.2.2 Terrestrial ecosystem 4.2.3 Ocean ecosystem 4.2.4 Ecosystem according to the degree of human intervention 4.3 Detailed description of a typical ecosystem : Pond ecosystem 4.3.1 Abiotic components 4.3.2 Biotic components 4.3.3 Energy flow in pond ecosystem 4.4 Food chain 4.4.1 Types of food chain 4.5 Energy flow in an ecosystem 4.6 Food web 4.7 Ecological/Eltonian pyramid 4.8 Ecological efficiency 4.9 Biogeochemical cycle 4.9.1 Nitrogeo cycle 4.10 Summary 4.11 Model questions 4.12 Suggested reading 55

NSOU CC-ZO-09 56 4.0 Objectives After studying this unit, the learners will be able to do the following— To have an idea about ecosystem and its types. To know about food chain, food web and food pyramid. To learn about energy flow in ecosystem. To know about ecological efficiency. To know about biogeochemic cycle with the example of nitrogen cycle. 4.1 Introduction An ecosystem is a dynamic process that consists of community of living organisms in association with the abiotic components of their environment (air, water and mineral soil), interacting as a system. These biotic and abiotic components are linked together through nutrient cycles and energy flows. As ecosystems are defined by the network of interactions among organisms, and between organisms and their environment, they can be of any size but usually encompass specific, limited geographical location. For instance, in an ecosystem where there are both deer and lion, these two creatures are in a relationship where the lion eats the deer in order to survive. This relationship has a effect with the other creatures and plants that live in the same or similar areas. For instance, the more deer that lion eat, the more the plants may start to thrive because there are fewer deer to eat them. 4.2 Types of ecosystems There are different types of ecosystems according to the environment. These are the following: 4.2.1 Aquatic ecosystems These can then be broken up into smaller ecosystems. For instance: (i) Pond ecosystems: These are usually relatively small water bodies. It includes various types of plants, amphibians and insects. Sometimes they include fish, but as these cannot move around as easily as amphibians and insects, it is less likely, and most of the time fish are artificially introduced to these environments by humans.

NSOU CC-ZO-09 57 (ii) River ecosystems: As rivers always link to the sea, they are more likely to contain fish along side the usual plants, amphibians and insects. These sorts of ecosystems can also include birds, because birds often hunt in and around water for small fish or insects. (iii) Wetland: It is a zone of flat lands that has groundwater of shallow depth and that ascend to the surface in determined periods, forming lagoons and marshes, until where they come to live hundreds of species. There are five classes of wetlands: marine, estuarine, lake, rivarian and marshy. (iv) Mangrove: It is a grouping of semi-submerged trees that have been flooded with water, with high levels of salinity and therefore they develop and survive in coastal lands. The trees grow on long roots, which like stilts raise the trunks above the level of the waters. To reproduce, they quickly retain the seeds in the branches until they are about to develop. When the tide goes down they are able, within a few hours, to root and begin to grow before being again underwater. (v) Coral reef: It is one of the richest aquatic ecosystems of the planet, product of the great amount of species that inhabit in them (fish, snails, corals and algae). The reef structure consists of large colonies of corals, accumulations of sediments and calcareous sands. They are found mainly in tropical regions and there are two types of coral, i.e., hard and soft. According to different habitats of aquatic organism, aquatic ecosystems are various kinds and divided into the following: (i) Benthic: These are located at the bottom of aquatic ecosystems. In those that are not very deep, the main inhabitants are algae. In the deeper ones, the majority are consumers. (ii) Nectonic: These animals move freely, thanks to their means of locomotion can adapt to water currents. (iii) Planktonic: These living beings floated in the terrestrial or marine water and are dragged by the water currents. They do not move by their own movements. (iv) Neustonie: These live floating on the surface of the water. 4.2.2 Terrestrial ecosystems They are regions where organisms (animals, plants, etc.) live and develop in the soil

NSOU CC-ZO-09 58 and air that surround a certain terrestrial space. Terrestrial ecosystems are part of other larger ecosystems, called biomass or ecological regions. These zones are delimited by latitude, climate, temperature and the level of precipitations. Depending on the abiotic factors of each ecosystem, there are different types of terrestrial habitats: deserts, grasslands and forests. (i) Tropical forests: It is usually having extremely dense ecosystems because there are so many different types of animals and they all live in a very small area. They have a high biodiversity in plants and animals; is also one of the oldest ecosystems of the planet and they are below the 1200 meters of height; the temperature and light remain constant throughout the year. (ii) Temperate forest: Those who have a good number of trees like mosses and ferns are for them. Temperate forests exist in regions where the climate changes significantly from summer to winter. Summers and winters are clearly defined and trees lose their leaves during the winter months. (iii) Swamp: Situated just before the arctic regions, swamp is defined by evergreen conifers. The temperature is below zero degrees for almost half a year, the rest of the months, is full of migratory birds and insects. (iv) Tundra: It has an extremely cold climate. The ground remains frozen for much of the year. Its rainfall is very low, so it reduces the growth of living organisms. There are no large trees, only small plants (mosses, lichens and other tree species) remain present in this region. (v) Desert: Found in regions that receive annual rainfall of less than 25%. They occupy about 17% of all the land on our planet. Due to the high temperatures, low availability of water and intense sunlight, the fauna and flora are scarce and underdeveloped. (vi) Savanna: Tropical meadows are seasonally dry and have few individual trees. They support a large number of predators and herbivores. (vii) Grassland: The temperate of grassland are completely devoid of large shrubs and trees. Grasslands could be categorized as mixed grass, tall grass and grassy meadows. (viii) Mountain: Offers a dispersed and diverse matrix of habitats where a large number of animals and plants can be found. The harsh environmental conditions that
NSOU CC-ZO-09 59 normally prevail at higher altitudes, the alpine vegetation can only survive. The animals that live there have thick fur coats for preventing cold and hibernation in the winter months. (ix) Deserts: Quite the opposite of tundra in many ways, but still harsh, more animals live in the extreme heat. (x) Savannas: These differ from deserts because of the amount of rain that they get each year. Whereas deserts get only a tiny amount of precipitation every tea, savannas tend to be a bit wetter which is better for supporting more life. (xi) Forests: There are many different types of forests all over the world including deciduous forests and coniferous forests. These can support a lot of life and can have very complex ecosystems. (xii) Grasslands: Grasslands support a wide variety of life and can have very complex and involved ecosystems. 4.2.3 Ocean ecosystems It is the earth's largest salt water ecosystem that contains millions of species. There are different types of ocean ecosystems: i) Shallow water: Some tiny fish and coral only live in the shallow waters close to land. ii) Deep water: Big and even gigantic creatures can live deep in the waters of the oceans. Some of the strongest creatures in the world live right at the bottom of the sea. iii) Warm water: Warmer waters, such as those of the Pacific Ocean, contain some of the most impressive and intricate ecosystems in the world. iv) Cold water: Less diverse, cold waters still support relatively complex ecosystems. Plankton usually form the base of the food chain, following by small fish that are either eaten by bigger fish or by other creatures such as seals or penguins. 4.2.4 Ecosystems according to the degree of human intervention 1. Natural ecosystems: Man has not intervened in their formation, such as forests, lakes, deserts. 2. Artificial ecosystems: Man actively participates in its formation, such as dams, parks, gardens.

NSOU CC-ZO-09 60 4.3 Detailed description of a typical ecosystem - pond ecosystem A pond is a quiet body of water that is too small for wave action and too shallow for major temperature differences from top to bottom. It usually has a muddy or silty bottom with aquatic plants around the edges and throughout. However, it is often difficult to classify the differences between a pond and a lake, since the two terms are artificial and the ecosystems really exist on a continuum. Generally, in a pond, the temperature changes with the air temperature and is relatively uniform. Lakes are similar to ponds, but because they are larger, temperature layering or stratification takes place in summer and winter, and these layers turnover in spring. Ponds get their energy from the sun. As with other ecosystems, plants are the primary producers. The chlorophyll in aquatic plants captures energy from the sun for converting carbon dioxide and water to organic compounds and released oxygen through the process of photosynthesis. Nitrogen and phosphorus are important nutrients for plants. The addition of these substances may increase primary productivity. However, too many nutrients can cause algal blooms, leading to eutrophication. 4.3.1 Abiotic components of pond ecosystem The abiotic substances of pond ecosystem are formed as a result of the mixture of some organic and inorganic materials. The basic components are water, oxygen, carbon dioxide, salts of calcium and nitrogen etc. Only a small amount of these elements are present in soluble state in pond water, but a large amount is held in reserve solid form in the bottom sediments as well as within the organisms. Various organisms get their nourishment from these abiotic substances. The rate of release of reserve nutrients, the solar input and

the cycle of temperature, day length and other climatic conditions regulate

the function of the Pond

ecosystem. 4.3.2 Biotic components of pond ecosystem The biotic components of pond ecosystem consists of the followings: a) Producers: The producres are of

two types— (i) Macrophytes: larger rooted and floating vegetations; and (ii) Phytoplanktons: microscopic floating plants. Phytoplanktons are available upto the depth of water where light penetrates. The phytoplanktons are filamentous alga like Ulothrix, Oedogonium, Spirogyra, Anabena, Oscillatoria and minute floating plants like Microcystis, Gloeotrichina, volvox etc.

NSOU CC-ZO-09 61 The macrophytes include marginal emergent plants like Typha, Acerus, Ipomea submerged plants like Hydrilla, Utricularia, Trapa, Nymphrea etc; surface floating plants like Pistea, Lemna, Wolffia, Eichhornia, Salvinia etc. b) Consumers: Consumers of pond ecosystem are heterotrophs which depends for their nutrition on other organisms. Zooplanktons form primary consumers, include Brachionus, Asplanchna, Lechane (all rotifers) Colops, Dilepteus, Cyclops, Stenocypris (crustacean) ,who feed on phytoplankton. Nectic animals like insects, beetles, fishes form secondary consumers as they feed on zooplanktons. Benthic animals like snakes, big fishes live on nectic animals and are termed tertiary consumers. c) Decomposers: Most of the decomposers of pond ecosystem are saprophytes but some parasites are also found. Bacteria, fungi like Aspergillus cladosporium, Rhizopus, Alternaria, Fusarium, Saprolegnia etc. are decomposers. Generally the decomposers either live in the soil layer beneath water or in the mud. They act on dead and decayed organic matter of plants and animals and supply raw materials to the producers. 4.3.3 Energy flow in pond ecosystem Phytoplanktons are the producers of pond ecosystem along with other floating plants. The energy produced by the autotrophs is passed through "eat and being eaten chain". In pond, the larvae of insects consume autotrophs as food. According to law of energy flow the larvae assimilate energy from autotrophs. So larvae are primary consumers. These primary consumers are taken as food by prawns, small carnivorous fishes etc. and so they collect energy from larvae. They are, therefore secondary consumers. Large fishes consume secondary consumers, and are tertiary consumers. 4.4 Food chain The transfer of energy and nutrients

from the source in plants through a series of organisms

with repeated processes of eating and being eaten is called food chain. Example: Grass (Primary producers) → Cow (Primary consume)→Tiger (Secondary consumer) Wheat Seed (Primary Producers) → Mouse (Primary consumers) → Cat (Secondary consumers)

NSOU CC-ZO-09 62 Significance of food chain: i) The studies of

food chain help to understand the feeding relationship and the interaction between organisms in any ecosystem.

ii) They also help us to appreciate the energy flow mechanism and matter circulation in ecosystem and understand the movement of toxic substances in the ecosystem. iii)

The study of food chain helps us to understand the problems of

bio- magnifications. 4.4.1

Types of food chain Food chains are classified into two basic types: a) Grazing food chain: A food chain that always starts with green plants moves to grazing herbivores and on to carnivores is called grazing food chain. The total energy assimilated by primary carnivore is derived entirely from the herbivore. Thus, the grazing food chain is more effective as most of the primary production is passed on through different trophic levels and only a small fraction goes to the decomposer system. Therefore, grazing food chain can be represented as: Autotroph→Herbivore→Primary carnivore→Secondary carnivore→Tertiary camivore→Decomposer. Grazing food chain can be of two types: (i) Predator food chain: where the sequence of organisms are generally from smaller to larger. (ii) Parasitic food chain: where organisms tend to decrease in size from lower to higher trophic levels. b) Detritus food chain: The food chain that always starts with the dead, decaying organic matter or organic wastes (metabolic wastes and extrudates) is called detritus food chain. It is first handed over to microorganisms and finally to detritus feeding organisms known as detritivore. The energy stored in detritus serves as a source of energy for detritivore. This type of food chain is less efficient as the major portion of energy is lost to the ecosystem without being properly used.

NSOU CC-ZO-09 63 4.5 Energy flow in an ecosystem The process of transfer of energy through various trophic levels of the food chain is known as flow of energy. Producers (green plants) capture energy from the sun by the process of photosynthesis and use it to make food. Most of this energy is used to carry on the plant's life activities. The rest of the energy is passed on as food to the next level of the food chain (consumers). At each level of the food chain, about 90% of the energy is lost in the form of heat. The total energy passed from one level to the next is only about one-tenth of the energy received from the previous organism. Therefore, as you move up the food chain, there is less energy available. Animals located at the top of the food chain need a lot more food to meet their energy needs. The flow of energy and inorganic nutrients through the ecosystem can be summarized as follows: i) The ultimate source of energy (for most ecosystems) is the sun. ii) The ultimate fate of energy in ecosystems is for it to be lost as heat. iii) Energy and nutrients are passed from organism to organism through the food chain as one organism eats another. iv) Decomposers remove the last energy from the remains of organisms. The behavior of energy in ecosystem can be termed energy flow due to unidirectional flow of energy. Two models have been proposed for energy flow: a) Single-channel/ Linear energy model: This model is proposed where the nutritional availability of the energy source in high, and transfer efficiencies can be much higher. Both plants and animals produce enzymes to digest organic matter (cellulose, lignin chitin) together with chemical inhibitors, the average transfers between whole trophic levels average twenty percent or less. This model suggests one-way flow of energy, and there is progressive decrease in energy level at each trophic level. A simplified energy flow diagram depicting three trophic levels (boxes numbered 1,2,3) in a linear food chain is presented in the following figure. I-total energy input; LA-light absorbed by plant cover; PG-gross primary productivity; A-total assimilation; PN-net primary production; P-secondary (consumer) production; NU-energy nor used (stored or exported); NA-energy not assimilated by consumers (egested); R-respiration. Bottom line in the diagram shows the order of the magnitude of energy losses expected

NSOU CC-ZO-09 64 at major transfer point, starting with a solar input of 3,000Kcal per square meter per day. Fig.: Energy flow model (After E.P. Odum, 1983) b) Y-shaped energy flow model:

In Y-shaped energy flow model, one arm represents the herbivore food chain, and the other, the decomposer (detritus) food chain.

The

two arms differ fundamentally in which they can influence primary producers.

This

model is more realistic than the single-channel model because it conforms to the basic stratified structure of ecosystem,

direct consumption of living plants and utilization of dead organic matter

and macro consumers (phagotrophic animals) and micro consumers differ greatly in size of metabolic relations.

Fig.: The Y-shaped energy flow model showing linkage between the grazing and detritus food

chains. (After E.P. Odum, 1983)

NSOU CC-ZO-09 65 4.6 Food web Food chains in the ecosystem are not linear rather they are interconnected with one another.

A network of food chains which are interconnected at various trophic levels so as to form a network of feeding connections in a community called a food web. In the following a food web from the Pairy grassland has been demonstrated as an example. 4.7 Ecological / Eltonian pyramid The amount of living matter at any given time in an ecosystem is called standing crop. It can be expressed in terms of biomass, number or total amount of energy fixed at each step of the food chain. It gives a definite trophic structure to the ecosystem. Graphically it is represented with the producers at the base and the subsequent trophic levels as the tiers. This gives a gradually sloping pyramidal shape as the biomass, number and energy is reducing at each trophic level. This graphical representation of the standing crop expressed as number, biomass or energy is called ecological pyramid. a) Pyramid of number: For example in grassland, you have observed that the number of grasses is more than the total number of herbivores (grasshoppers and

NSOU CC-ZO-09 66 hare) that feed on them and the number of herbivores is more than the number of snakes and birds (carnivores). When an ecological pyramid is constructed on the basis of the number of individuals at each trophic level it is called a pyramid of number. The pyramid of number is a result of three phenomenon—(i) Geometrical - many small units are required to build up one big unit (units are organisms); (ii) Entropy -due to entropy at each step many small organisms are required to support a few large organisms, which is a basic principle of food chains; (iii) Inverse size metabolism pattern - smaller organism have higher metabolic rate than the larger organisms. Sometimes the pyramid of number is inverted. For example many caterpillars and insects feed on one plant/ tree. In this case, the number of herbivore is more than the number of autotroph. Similarly the number of phytoplankton is less than the herbivorous zooplankton in English Channel. This is because of the high turnover rate of phytoplankton in it. b)

Pyramid of biomass: This is the graphical representation of biomass at each trophic level.

For instance the total biomass of trees in the forests is greater than the total biomass of the herbivores supported by them. At the level of top carnivore in a community very little biomass is left to support any further trophic level. Pyramid of biomass can also be inverted like the pyramid of number. In a channel of water or a canal where the producers have short life cycles and are replaced rapidly by the new plants (high turnover rate), the biomass of producers is less than consumers who have longer life span like fishes. Pyramid of biomass is expressed as dry weight per unit area. c)

Pyramid of energy: The pyramid of energy represent the total amount of energy fixed at each trophic level.

These give the true functional structures to the ecosystem. They are never inverted and most informative. Energy is expressed in terms of rate such as kcal / unit area / unit time or cal / unit area / unit time. In a lake ecosystem, if the energy at producers level is 20,810, then in herbivore is 3,308 primary carnivore is 383 and secondary carnivore is 21 kcal/ m 2 / year. Energy pyramid provides a more suitable index for comparing any or all components of an ecosystem. The pyramid of number over emphasizes the smaller individuals, biomass gives more importance to the larger individuals and therefore, both cannot be used as reliable tools for comparing the functional role of the populations that differ widely in size and metabolism.

NSOU CC-ZO-09 67 The following figure demonsostrate different kinds of ecological pyramids. 4.8 Ecological efficiency The percentage ratio of the energy flow at different points along the food chain is called ecological efficiencies. Commonly if a poultry man speaks of 30 % efficiency in his poultry farm then the efficiency for him is the percentage ratio of input (feed) to the output in chicken (biomass). The ecological efficiency can be given in terms of Fig.: Different kinds of ecological pyramids (after Smith, 1977) 1.1×10 5 4×10 9 plankton A. Pyramid of numbers zooplankton and bottom fauna 21 g/m 2 pytoplankton 4 g/m 2 decomposer 5 g/m 2 second-level carnivore 1.5 g/m 2 first-level carnivore 11 g/m 2 harbivore 37 g/m 2 plankton 809 g/m 2 B. Pyramids of biomass (bacteria) 3890 kcal first-level carnivore 48 kcal harbivore 596 kcal net production = 8763 kcal/m 2 /year gross production = 36.380 kcal/m 2 /year C. Pyramid of energy C B A

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NSOU CC-ZO-09 68 various parameters such as growth, production and assimilation. Lindeman (1942) defined these ecological efficiencies for the first time and proposed 10% rule as discussed in energy flow model. However, there are slight variations to this law in different ecosystem and ecological efficiencies may range from 5 to 35%. Ecological efficiency is also called Lindeman's Efficiency and can be represented as: Production efficiency = P = production / assimilation × 100 (Similarly assimilation efficiency is percentage conversion of food into protoplasm). In the above mentioned example, if 10 gm food is given to the chicken its biomass would increase by 3 gm. Therefore, 3 × 100 = 30 % is the production efficiency. This is an example of human modified system and also it is assumed that all the food is assimilated in the body of chicken. In natural ecosystems this efficiency will be much less. Ecological efficiency increases at higher trophic levels. Ecological efficiency can be given as production efficiency, assimilation efficiency, growth efficiency or tissue growth efficiency. 4.9 Biogeochemical cycle In ecosystem, flow of energy is linear but that of nutrients is cyclic. This is because energy flows downhill i.e., it is utilized or lost as heat as it flows forward. The nutrients on the other hand cycle from dead remains of organisms released back into the soil by detritivores which are absorbed again i.e., nutrient absorbed from soil by the root of green plants are passed on to herbivores and then carnivores. The nutrients locked in the dead remains of organisms and released back into the soil by detritivores and decomposers. This recycling of the nutrients is called biogeochemical or nutrient cycle (Bio = living; geo = rock; chemical = element). There are more than 40 elements required for the various life processes by plants and animals. The entire earth or biosphere is a closed system i.e., nutrients are neither imported nor exported from the biosphere. There are two important components of a biogeochemical cycle (1) Reservoir pool: Atmosphere or rock, which stores large amounts of nutrients. (2) Cycling pool or compartments of cycle: They are relatively short storages of carbon in the form of plants and animals. Biogeochemical cycles connect living things to the earth. The four chemicals that make up 95% of biomolecules are: carbon, hydrogen, oxygen and nitrogen. These elements are constantly being cycled through living and non-living organic matter.

NSOU CC-ZO-09 69 4.9.1 Nitrogen cycle Nitrogen is an essential component of protein and required by all living organisms including human beings. Our atmosphere contains nearly 79% of nitrogen but it cannot be used directly by the majority of living organisms. Broadly like corbon dioxide, nitrogen also cycles from gaseous phase to solid phase then back to gaseous phase through the activity of a wide variety of organisms. Cycling of nitrogen is vitally important for all living organisms. There are five main processes which essential for nitrogen cycle are elaborated below. (a) Nitrogen fixation: This process involves conversion of gaseous nitrogen into ammonia, a form in which it can be used by plants. Atmospheric nitrogen can be fixed by the following three methods:- (i) Atmospheric fixation: Lightening, combustion and volcanic activity help in the fixation of nitrogen. (ii) Industrial fixation: At high temperature (400°C) and high pressure (200 atm.), molecular nitrogen is broken into atomic nitrogen which then combines with hydrogen to form ammonia. (iii) Bacterial fixation: There are two types of bacteria: 1. Symbiotic bacteria: e.g. Rhizobium in the root nodules of leguminous plants. 2. Freeliving or symbiotic: e.g. Nostoc, Azobacter, Cyanobacteria can combine atmospheric or dissolved nitrogen with hydrogen to form ammonia. (b) Nitrification: It is a process by which ammonia is converted into nitrates or nitrites by Nitrosomonas and Nitrococcus bacteria respectively. Another soil bacterium Nitrobacter can covert nitrate into nitrite. (c) Assimilation: In this process nitrogen fixed by plants is converted into organic molecules such as proteins, DNA, RNA etc. These molecules make the plant and animal tissue. (d) Ammonification: Living organisms produce nitrogenous waste products such as urea and uric acid. These waste products as well as dead remains of organisms are converted back into inorganic ammonia by the bacteria. This process is called ammonification. Ammonifying bacteria help in this process.

NSOU CC-ZO-09 70 (e) Denitrification: Conversion of nitrates back into gaseous nitrogen is called denitrification. Denitrifying bacteria live deep in soil near the water table as they like to live in oxygen free medium. Denitrification is reverse of nitrogen fixation. This following figure will give an overall idea about the nitrogen cycle within the environment. 4.10 Summary An ecosystem is a dynamic process that consists of community of living organisms in association with the abiotic components of their environment. The transfer of energy and nutients
from the source in plants through a series of organisms
with repeated processes of eating and being eaten is called food chain. The ultimate source of energy is the sun. The flow of energy in the ecosystem is unidirectional. Food chain in the ecosystem is not linear rather they are interconnected with one another The percentage ratio of the energy flow at different points along the food chain is called ecological efficiences.

NSOU CC-ZO-09 71 4.11 Model questions i) Define ecosystem. ii) What are the types of ecosystem according to prevailing environment? iii) What are the types of ecosystem based on human intervention? iv) Differentiate between food chain and food web. v) Differentiate between detritus and grazing food chain. vi) Describe the significance of food chain. vii) Describe the structure of an ecosystem in detail. viii) What is biogeochemical cycle? Describe nitrogen cycle in detail. ix) What is ecological pyramid? Describe the upright and inverted pyramids of number and biomass respectively. x) Why the pyramid of energy is always upright? xi) What are ecological efficiencies? xii) Describe the linear and Y-shaped model of energy transfer in an ecosystem. 4.12 Suggested reading 1. Basu, R.N. (2004). A Compendium of Terms in Ecology and Environment. Naya Udyog. 2. Chapman, R.
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NSOU CC-ZO-09 72 Unit 5 Wildlife conservation Structure 5.0 Objectives 5.1 Introduction 5.2 Strategies for wild life conservation 5.3 Types of conservation 5.3.1 In-situ conservation 5.3.2 Ex-situ conservation 5.4 Tiger conservation 5.5 Protection laws for wild life conservation 5.5.1 The wild life protection Act, 1972 5.5.2 The Indian forest Act, 1927 5.5.3 The forest conservation Act, 1980 5.5.4 The environment protection Act, 1986 5.5.5 The Biological diversity Act, 2002 5.5.6 National wild life action plan (2002-2016) 5.5.7 National forest policy (1998) 5.6 Questions 5.7 Suggested reading 5.0 Objectives After studying this unit, the learners will be able to do the following— To know about the aim and strategies of wild life conservation. To know about different types of conservation, i.e., in-situ and ex-situ conservation. To learn about tiger conservation. 72
NSOU CC-ZO-09 73 To know about protective laws for wild life conservation. 5.1 Introduction As the human population increases, more and more lands are brought under its control and, as a result, the amount of natural vegetation has diminished considerably and so also the habitat of various species. The vast expanses of tropical forest and its inhabiting species have become increasingly threatened in the last few decades. Even in the oceans, fishing is so intensive that fish populations are diminishing rapidly. We have become too efficient as predators. Sometimes we hunt species for luxury items! For example, the elephants for their tusk, the rhinoceroses for their horns etc. Sometimes we capture exotic species such as various birds, coral reef fishes etc. for the pet trade. Thus, we have become a species which is no longer in co-evolved balance with its environment. 5.2 Strategies for wild life conservation a) Protection of natural habitats. b) Maintenance of the viable number of species in protected areas. c) Establishment of biosphere reserves. d) Protection through legislation. e) Imposing restriction on export of rare plant and animal species and their products. f) Improving the existing conditions of protected areas. g) Mass education. h) To declare some animals, trees, flowers as national and state symbol. 5.3 Types of conservation
Conservation can broadly be divided into two types: 5.3.1 In-situ conservation
In-situ conservation, which is also known as "on-site conservation", refers to the conservation of wild species in their natural habitats and environment. It aims to conserve the natural habitats of the living creatures and maintain to recover wild
NSOU CC-ZO-09 74 species, especially the endangered species. The national parks, wildlife sanctuaries and biosphere reserve are some of the examples of in-situ conservation. This method of conservation allows animals flourish in their natural habitat and food chain and offers more mobility to the animals. It is suitable for the conservation of animals that are found in abundance. Example: National parks, wildlife sanctuaries, biosphere reserves etc. 5.3.2 Ex-situ conservation Ex-situ conservation, which is also known as "off-site conservation", refers to the conservation of endangered species in the artificial or man-made habitats that imitate their natural habitats, e.g. zoo, aquarium, botanical garden etc. It offers less mobility to the animals as it is smaller in area than the area of in-situ conservation. This method of conservation is suitable for the animals which are not found in abundance. It provides protection to animals against predators, unfavourable climatic conditions and other hostile factors. Furthermore, proper food and care is provided under good supervision. Example: Botanical gardens, zoos etc. Advantages of ex-situ preservation a.

It is useful for declining population of species. b. Endangered animals on the verge of extinction are successfully breed. c. Threatened species are breed in captivity and then released in the natural habitats. d. Ex-situ centers offer the possibilities of observing wild animals, which is otherwise not possible. e. It is extremely useful for conducting research and scientific work on different species. The key differences between in-situ and ex-situ conservation are as follows: In-situ Conservation Ex-situ Conservation It

means onsite conservation. It means offsite conservation. It is the conservation of wild species It is conservation of species in the man- in their natural habitats in order to made habitats that imitate the natural maintain and recover endangered habitats of species. species.

NSOU CC-ZO-09 75 It is more dynamic as it involves natural It is less dynamic as it involves man- habitats of organisms. made habitats. It provides protection to endangered It provides protection against all hostile species against predators. factors. It is suitable for animals that are found It is suitable for animals that are not in abundance. found in abundance. It is not suitable in the event of a rapid It is an ideal option in case of rapid decline in the number of a species due decline in the number of a species due to environmental, genetic or any other to environmental or any other reason. factor. Wildlife and livestock conservation It can be used to conserve crops and involve in-situ conservation. their wild relatives. Examples include national parks, wildlife Examples include zoo, aquarium sanctuaries, biospheres reserve etc. and botanical garden. It involves designation, management It involves sampling, storage and and monitoring of the target species in transfer of target species from their their natural habitat. natural habitats to man-made habitats. It helps to maintain the ongoing process It separates the animals form the ongo- of evolution and adaptation within the ing process of evolution and adapta- natural environment of the species. tions within their natural environment. 5.4 Tiger conservation Tiger conservation programme was launched in April 1973 by the Government of India at Jim Corbet National Park. The main aims of project tiger were: a) To reduce factors that lead to the reduction of tiger habitats and to mitigate them by suitable management. The damages done to the habitat were to be rectified so as to facilitate the recovery of the ecosystem to the maximum possible extent. b) To ensure a viable tiger population for economic, scientific, cultural, aesthetic and ecological values. In-situ Conservation Ex-situ Conservation

NSOU CC-ZO-09 76 The formation of tiger reserves in the country were based on the 'core-buffer' strategy: a) Core area: The core areas are free of all human activities. It has the legal status of a national park or wildlife sanctuary. It is kept free of biotic disturbances and forestry operations like

collection of minor forest produce, grazing, and other human disturbances are not allowed

within core area. b) Buffer areas: The buffer areas are subjected to 'conservation-oriented land use'. They comprise forest and non-forest land. It is a multi-purpose use area with twin objectives of providing habitat supplement to spillover population of wild animals from core conservation unit and to

provide site specific co-developmental inputs to surrounding villages for relieving their impact on core area.

The important thrust areas for the Tiger project are: i) Setting up networking surveillance of tigers. ii) Voluntary relocation of people from core/critical tiger habitat. iii) Use of information technology in wildlife crime prevention. iv) Developing a national respirator of camera trap tiger photographs. v) Strengthening the regional offices of the National Tiger Conservation Authority. vi) Creation of new tiger reserves. vii) Elimination of all forms of human exploitation and biotic disturbance from the core area. 5.5 Protection laws for wildlife conservation It is a general conception that India does not have strong wildlife conservation laws. On the contrary, we have some of the most stringent legislations to protect wildlife and habitats. The Government of India has introduced various types of legislation in response to the growing destruction of wildlife and forests. These are: 5.5.1 The Wildlife Protection Act, 1972 The Wildlife Protection Act (WLPA), 1972 is an important statute that provides a powerful legal framework for: * Prohibition of hunting.

NSOU CC-ZO-09 77 * Protection and management of wildlife habitats. * Establishment of protected areas. * Regulation and control of trade in parts and products derived from wildlife. * Management of zoos. National parks and Tiger Reserves are by law more strictly protected, allowing no human activity except that which is in the interest of wildlife conservation. The amended WLPA does not allow for any commercial exploitation of forest produce in both national parks and wildlife sanctuaries, and local communities can collect forest produce only for their bonafide needs. The statute prohibits the destruction or diversion of wildlife and its habitat by any method unless it is for improvement or better management and this is decided by the State Government in consultation with the National and State Boards for Wildlife. The WLPA provides for investigation and prosecution of offences in a court of law by authorized officers of the forest department and police officers. 5.5.2 The Indian Forest Act (1927) The main objective of the Indian Forest Act (1927) was to secure exclusive state control over forests to meet the demand for timber. Most of these untitled lands had traditionally belonged to the forest dwelling communities. The Act defined state ownership, regulated its use, and appropriated the power to substitute or extinguish customary rights. The Act facilitates three categories of forests, namely, (i) reserved forests; (ii) village forests; (iii) protected forests. Reserved forests are the most protected within these categories. No rights can be acquired in reserved forests except by succession or under a grant or contract with the Government. Felling trees, grazing cattle, removing forest products, quarrying, fishing, and huhting are punishable with a fine or imprisonment. Although the Indian Forest Act is a federal act, many states have enacted similar forest acts but with some modifications. 5.5.3 The Forest Conservation Act (1980) In order to check rapid deforestation due to forestlands being released by state Governments for agriculture, industry and other development projects (allowed under the Indian Forest Act) the federal Government enacted the Forest Conservation Act in 1980 with an amendment in 1988. The Act made the prior approval of the federal
NSOU CC-ZO-09 78 Government necessary for de-reservation of reserved forests, logging and for use of forestland for non- forest purposes. 5.5.4 The Environment (Protection) Act (1986) The Environment Protection Act is an important legislation that provides for coordination of activities of the various regulatory agencies, creation of authorities with adequate powers for environmental protection, regulation of the discharge of environmental pollutants, handling of hazardous substances, etc. The Act provided an opportunity to extend legal protection to nonforest habitats ('Ecologically Sensitive Areas') such as grasslands, wetlands and coastal zones. 5.5.5 The Biological Diversity Act (2002) India is a party to the United Nations Convention on Biological Diversity. The provisions of the Biological Diversity Act are in addition to and not in derogation of the provisions in any other law relating to forests or wildlife. 5.5.6 National Wildlife Action Plan (2002-2016) It replaces the earlier plan adopted in 1983 and was introduced in response to the need for a change in priorities given the increased commercial use of natural resources, continued growth of human and livestock populations, and changes in consumption patterns. The plan most closely represents an actual policy on protection of wildlife. It focuses on strengthening and enhancing the protected area network, on the conservation of endangered wildlife and their habitats, on controlling trade in wildlife products and on research, education, and training. 5.5.7 National Forest Policy (1998) The National Forest Policy (NFP), 1988, is primarily concerned with the sustainable use and conservation of forests, and further strengthens the Forest Conservation Act (1980). It marked a significant departure from earlier forest policies, which gave primacy to meeting Government interests and industrial requirements for forest products at the expense of local subsistence requirements. The NFP prioritizes the maintenance of ecological balance through the conservation of biological diversity, soil and water management, increase of tree cover, efficient use of forest produce, substitution of wood, and ensuring peoples' involvement in achieving these objectives.
NSOU CC-ZO-09 79 5.6 Questions i) Why there is need to conserve wildlife? ii) Differentiate between the ex-situ and in-situ conservation. iii) What is tiger project? Describe the management strategies for tiger conservation. iv) Write a short note on the protection laws for wildlife conservation. v) Mention the advantages of ex-situ and in-situ conservation. 5.7 Suggested reading 1. Basu, R.N. (2004). A Compendium of Terms in Ecology and Environment. Naya Udyog. 2. Chapman, R.
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NSOU CC-ZO-09 80 Unit 6 Ecological, Faunal and Floral Characteristics Structure 6.0 Objectives 6.1 Introduction 6.2 Tropical rain forest 6.2.1 Floral characteristics 6.2.2 Faunal characteristics 6.3 Mangrove ecosystem 6.3.1 Floral and formal characteristics 6.4 Island ecosystem 6.4.1 Floral and faunal characteristics 6.5 Desert ecosystem 6.5.1 Floral and faunal characteristics 6.6 Model questions 6.7 Suggested reading 6.0 Objectives After studying this unit, the learner will be able to do the following— To know about tropical rain forest. To learn about mangrove ecosystem. To know about different floral and faunel characteristics of island ecosystem. To know about desert ecosystem. 6.0 Introduction The group of ecosystems sharing the same characteristics and are well adapted to the prevailing abiotic factors are called biomes. Any earth surface that has got a very large ecological system characterized by dominant forms of plant and animal 80 NSOU CC-ZO-09 81 life forms adapted to the prevailing climate and other environmental factors is termed as a biome. Biomes include both the abiotic and biotic factors.

The climate and geography of a region determines what type of biome can exist in that region. Major biomes include deserts, forests, grasslands, tundra, and several types of aquatic environments.

Each biome consists of many ecosystems whose communities have adapted to the small differences in climate and the environment inside the

biome. In this unit we will study the ecological, faunal and floral characteristics of some selected ecosystems. 6.2 Tropical rain forest The tropical rainforest is a hot, moist biome found near Earth's equator. There are two types of rainforests, tropical and temperate. Tropical rainforests are found closer to the equator where the environment is warm. Temperate rainforests are found near the cooler coastal areas further north or south of the equator. The world's largest tropical rainforests are in South America, Africa, and Southeast Asia. Tropical rainforests receive from 60 to 160 inches of precipitation that is fairly evenly distributed throughout the year. The combination of constant warmth and abundant moisture makes the tropical rainforest a suitable environment for many plants and animals. Tropical rainforests contain the greatest biodiversity in the world. Over 15 million species of plants and animals live within this biome. The hot and humid conditions make tropical rainforests an ideal environment for bacteria and other microorganisms. Because these organisms remain active throughout the year, they quickly decompose matter on the forest floor. In other biomes, such as the deciduous forest, the decomposition of leaf litter adds nutrients to the soil. But in the tropical rainforest, plants grow so fast that they rapidly consume the nutrients from the decomposed leaf litter. As a result, most of the nutrients are contained in the trees and other plants rather than in the soil. Most nutrients that are absorbed into the soil are leached out by the abundant rainfall, which leaves the soil infertile and acidic. 6.2.1 Floral characteristics Although tropical rainforests receive 12 hours of sunlight daily, less than 2% of that sunlight ever reaches the ground. The tropical rainforest has dense vegetation, often forming three different layers—the canopy, the understory, and the ground layer. Frequently, people think of the tropical rainforest as a "jungle" where plant growth is dense even at ground level. However, the canopy created by the tall trees (100-120

NSOU CC-ZO-09 82 feet) and the understory, prevents sunlight from reaching the ground. The soil is, therefore, always shaded, and very little vegetation is able to survive at ground level. Vegetation can become dense at ground level near riverbanks and on hillsides. Hillsides have more plant growth because the angle of the growing surface allows sunlight to reach lower layers of the forest. Riverbeds break up the forest canopy so that smaller plants can get the needed sunlight. Plant survival in a tropical rainforest depends on the plant's ability to tolerate constant shade or to adapt strategies to reach sunlight. Fungus is a good example of a plant that flourishes in warm, dark places created by the forest canopy and understory. Competition for sunlight by plants is sometimes deadly. The strangler fig needs sunlight to grow and reproduce. Seeds falling to the ground quickly die in the deep shade and infertile soil of the tropical rainforest. So it has adapted. Its seeds are deposited on branches of host trees by birds and small animals that have eaten the fruit of the strangler fig. The seeds sprout and send a long root to the ground. This root rapidly increases in diameter and successfully competes for the water and nutrients in the soil. As the strangler fig matures, branches and leaves grow upwards creating a canopy that blocks sunlight from the host tree. Additional roots are sent out and wrap around the host tree, forming a massive network of roots that strangle and eventually kill the host. 6.2.2 Faunal characteristics Tropical rainforests support a greater number and variety of animals than any other biome. One of the reasons for this great variety of animals is the constant warmth. Tropical rainforests also provide a nearly constant supply of water and a wide variety of food for the animals. Small animals, including monkeys, birds, snakes, rodents, frogs, and lizards are common in the tropical rainforest. Many of these animals and a multitude of insects never set foot on the ground. The animals use the tall trees and understory for shelter, hiding places from their predators, and a source of food. Because there are so many animals competing for food, many animals have adapted by learning to eat a particular food eaten by no other animal. Toucans have adapted by developing long, large bill. This adaptation allows this bird to reach fruit on branches that are too small to support the bird's weight. The bill also is used to cut the fruit from the tree. The Sloth uses a behavioral adaptation and camouflage to survive in the rainforest.

NSOU CC-ZO-09 83 It moves very, very slowly and spends most of its time hanging upside down from trees. Blue-green algae grow on its fur giving the Sloth a greenish color and making it more difficult for predators to spot. 6.3 Mangrove ecosystem A Mangrove swamp is a coastal, wetland ecosystem that is made up of small halophytic trees and is found in tropical and subtropical areas. The term "mangrove" refers to a tidally influenced wetland ecosystem within the intertidal zone of tropical and subtropical latitudes. Mangrove also designates the marine tidal forest that includes trees, shrubs, palms, epiphytes and ferns. The distinctive community of plants and animals associated with mangroves is sometimes referred to as the 'mangal'. Mangrove ecosystems are heterogeneous habitats with an unusual variety of animals and plants adapted to the environmental conditions of highly saline, frequently inundated, soft-bottomed anaerobic mud. Plants that are confined to the mangrove are called true mangroves; plants that can also occur elsewhere are called mangrove associates. Mangrove associates never grow in true mangrove communities and may occur in terrestrial vegetation. The mangrove fauna includes terrestrial, marine, temporary and permanent animal species, all of which have different adaptations to cope with the mangrove environment. The diversity of mangroves is high, but the variety of mangrove ecosystems also makes it difficult to produce general guidelines for conservation and management of mangroves because each system is unique. 6.3.1 Floral and faunal characteristics Mangroves support unique ecosystems, especially on their intricate root systems. The mesh of mangrove roots produces a quiet marine region for many young organisms. In areas where roots are permanently submerged, they may host a wide variety of organisms, including algae, barnacles, oysters, sponges, and bryozoans, which all require a hard substratum for anchoring while they filter feed. Shrimps and mud lobsters use the muddy bottom as their home. Mangrove crabs improve the nutritional quality of the mangal muds for other bottom feeders by mulching the mangrove leaves. In at least some cases, export of carbon fixed in mangroves is important in coastal food webs. The habitats also host several commercially important species of fish and crustaceans. The coastal horseshoe crab, Tachypleus gigas, Oriental pied- hombill, Anthracoceros albirostris, Malayan water monitor, Varanus salvator (and

NSOU CC-ZO-09 84 other species of monitor lizards), Nipah palm, Nypa fruticans, mangrove plant. Mudskipper, fiddler crabs are some commonly found organisms in mangrove ecosystem. 6.4 Island ecosystem An island is an area of land that is surrounded by water. Islands and their surrounding waters cover around one sixth of Earth's surface. Islands have played an important role in our understanding of ecology and evolution, with the most famous example being the exploration of the Galapagos Islands by English naturalist Charles Darwin (1809-1882). Islands have long been of interest to ecologists. Their isolation from the mainland means that species tend to live undisturbed by invasion from non- native plants and animals. Over time, they evolve to adapt to their environment, creating an ecosystem unique to that island. Island ecosystems are vulnerable, particularly if they are small and remote. Limited resources means that species are more likely to become extinct on an island than they are on the mainland. Therefore, islands are home to many of the world's endangered species. An island is sometimes colonized by new species dispersing there, especially if it is not far from the mainland. There are many conservation projects underway around the world that supports island ecologies by monitoring the health of species and protecting their habitats. 6.4.1 Floral and faunal characteristics The islands are home to the richest butterfly diversity in the world and the islands are home to some of the largest butterflies globally. The islands are also a bird watching hot spot with hundreds of species of birds. Some most important birds are wood pigeon, hornbill scops owl, the blue-eared kingfisher and the fulvous breasted woodpecker. Different species of wild boars, elephants, sea turtles and wild salt water crocodiles make the islands a wildlife hotspot. 6.5 Desert ecosystem Desert ecosystems are defined by scarcity of water, heat stress and limitations of food and nutrients resources. Desert regions are found globally in the subtropical high pressure belts, in the rain shadow of mountain ranges or the continental interior, and bordering cold ocean currents. Even though primary productivity by plants and microorganisms is relatively low, species richness and taxonomical diversity can be fairly high. Taxonomically different organisms evolved traits to cope with water stress and often similar life forms arose due to convergent evolution. Typical desert organisms
NSOU CC-ZO-09 85 show traits that allow them to avoid periods of extreme aridity in inactive stages and/ or to store water for use during drought; a few organisms evolved traits to tolerate the lack of water altogether. Microbial decomposition in deserts is limited due to aridity and the energy flow in desert ecosystems is dominated by detritivores that form the base of the food chain. Humans show adaptations to hot desert climates and a number of cultural practices arose that enable human populations to live near or in deserts. 6.5.1 Floral and faunal characteristics Most desert species have found remarkable ways to survive by evading drought. Desert succulents, such as cacti or rock plants for example, survive dry spells by accumulating moisture in their fleshy tissues. They have an extensive system of shallow roots to capture soil water only a few hours after it has rained. Additionally, many cacti and other stem-succulent plants of hot deserts present columnar growth, with leafless, vertically- erect, green trunks that maximize light interception during the early and late hours of the day, but avoid the midday sun, when excessive heat may damage plant tissues. One of the most effective drought-survival adaptations for many species is the evolution of an ephemeral life-cycle. An ephemeral life cycle is characterized by a short life and the capacity to leave behind very hardy forms of propagation. This ability is found not only in plants but also in many invertebrates. Desert ephemerals are amazingly rapid growers capable of reproducing at a remarkably high rate during good seasons. Birds and large mammals can escape critical dry spells by migrating along the desert plains or up into the mountains. Smaller animals cannot migrate but regulate their environment by seeking out cool or shady places. In addition to flying to other habitats during the dry season, birds can reduce heat by soaring. Many rodents, invertebrates, and snakes avoid heat by spending the day in caves and burrows searching out food during the night. Animals active in the day reduce their activities by resting in the shade during the hotter hours. 6.6 Questions i) Describe the ecological conditions, faunal and floral characteristics of tropical rain forest. ii) Discuss the adaptations of flora and fauna of tropical rain forest.
NSOU CC-ZO-09 86 iii) Describe the ecological conditions, faunal and floral characteristics of Mangrove ecosystem. iv) Discuss the floral adaptations of Mangrove ecosystem. v) Describe the ecological conditions, faunal and floral characteristics of Island ecosystem. vi) Describe the ecological conditions, faunal and floral characteristics of desert ecosystem. vii) Discuss the adaptations of flora and fauna of desert ecosystem. 6.7 Suggested reading 1. Basu, R.N. (2004). A Compendium of Terms in Ecology and Environment. Naya Udyog. 2. Chapman, R.
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NSOU CC-ZO-09 87 Unit 7 Zoogeography Structure 7.0 Objectives 7.1 Introduction 7.2 Zoogeographical realms 7.2.1 Palaerctic realm 7.2.2 Nearctic realm 7.2.3 Neo-tropical realm 7.2.4 Ethiopian realm 7.2.5 Oriental realm 7.2.6 Australian realm 7.3 Theories pertaining to distribution of animals 7.3.1 Continental drift hypothesis 7.3.2 Centre of origin hypothesis 7.4 Questions 7.5 Suggested reading 7.0 Objectives After studying this unit, the learners will be able to do the following— To know the basic idea of zoogeography. To know what is Wallaces line. To have a basic idea about zoogeographical realm. To know about geography, climate, ecology and fauna of different zoogeographical realm. To know about the theories pertaining to distribution of animals. 87
NSOU CC-ZO-09 88 7.1 Introduction The distribution of plants (flora) and animals (fauna) throughout the earth shows a differential pattern. This difference is based on the adaptation of organisms to its immediate environmental conditions. Therefore, based on the geographic distribution (presence and absence of several organisms), the earth can be divided into some regions called realms. Several scientists proposed several scheme of realms. Sclater (1857), on the basis of the distribution of birds divided the geographical areas of the Earth into six parts. After that, Alfred Russel Wallace in 1876 published a paper on zoogeographical realms. He retained the 'six area concept' of Sclater, but included in his study all the terrestrial vertebrates and invertebrates. The only change, he made was in renaming the Indian region of Sclater to Oriental region. The realms, which they described were all separated by distinctive barriers from each other. The scheme of division proposed by Wallace is presented here and the realms are separated by dotted lines on world map, which are known as Wallace's line. 7.2 Zoogeographical realms In this section we will discuss about the geographical boundary, climatic and ecological cotulitions and characteristic faunal composition of six zoogeographical realms in detail. 7.2.1 Palaearctic realm Geographical boundary: Geographically this realm consists of whole of Europe,
NSOU CC-ZO-09 89 Northern part of Africa and Asian Himalaya and Nan ling range of China. Sub-divisions: This realm is further divided into four sub-divisions by Wallace. (i) European sub-region: Northern and Central Europe, Black Kokesus. (ii) Mediterranean sub-region: Part of Africa, Asia, Europe, Arab, Afghanistan and Baluchistan. . (iii) Siberian sub-region: Northern part of Himalaya, i.e., Northern Asia. (iv) Manchurian kub-region: Mongolia, Korea, Manchuria, Japan. Climatic condition: Extreme cold of Siberia and extreme hot of Sahara desert are characteristic climate of this region. Ecological condition: Deciduous forest, large grassland, coniferous forest and mixed forest. Tundra area is also present in this region. Characteristic vertebrate fauna: (i) Fish: Carp, Salmon, Pike, Sticklebacks are common in freshwater of this region (ii) Amphibia: European Salamander, Proteius, Hynobius, Bombinator, Alytes, Didocus etc. (iii) Reptiles: Sand boa, lizard - Trigonophis and Alligator. (iv) Birds: Arctic tern, Pheasant, Wrens, Finches, Warblers, Geese etc. (v) Mammals: Among 39 families of characteristic mammals, family - Seluinidae and Ailuropodie are endemic. Other mammals are porcupine, dog, wild ass, European bison, polar cat, deer, etc. . 7.2.2 Nearctic realm Geographical boundary: This region consists, on its north the entire of North America, in south up to Mexico, in East Greenland and in west Aleutian islands. Sub-divisions: It is also sub-divided into four sub-regions. (i) Californian sub-region: Vancouver Island part of British Colombia, Nevada and some partf of Cascade hill region are the areas of this region. It is commonly known as the low biodiversity area.
NSOU CC-ZO-09 90 (ii) Rocky mountain sub-region: Eastern side of California has a high and rocky mountain range. This region contains a rich zoo-diversity among Nearctic region. (iii) Allegheny sub-region: This sub-region is situated at the eastern side of the rocky mountain sub-region. Its northern part is bounded by Great lakes. This sub-region is with moderate zoo property. (iv) Canadian sub-region: This sub-region consists of North America and Greenland and is not renowned for its animal contents. Climatic condition: Like Palaearctic region this region also has extreme cold and hot climate. Ecological condition: Deciduous forest range, huge grassland, coniferous forest, dry land and Tundra regions are prominent ecological zonations. Characteristic vertebrate fauna (i) Fishes: Lepisosteus, Polydon, Acipenser and varieties of perches. (ii) Amphibia: Siren, Amphiuma, Cryptobranchus, Ambystoma, Ascaphys and Axolotl larva. Most of them belong to caudata. (iii) Reptiles: Conophis, Chilomeniscus, Pituophis, Farancia are prominent snakes. Phrynosoma, Uta are lizards and Aromochelys and Chelydra are turtles. (iv) Birds: Turkey, pelican, crow, cuckoo, pigeon, saras, swan, kite, rel, owl, hawk, etc. Most of them are migratory birds. (v) Mammals: Didelphis, Armadillo, Caribou, pronghorn, srew, mole, bear, wolf, monkey, deer, bat, goat, mask ox, bison, etc. The mammalian family Aplodontidae and Pronghorn are endemic. 7.2.3 Neo-tropical realm Geographical Boundary: South and central America lower Mexico and West Indies are the constituents of this region. This region is connected with Nearctic region by central American isthmus and other parts are bordered by the sea. Sub-divisions: This is also sub-divided into four sub-regions:

NSOU CC-ZO-09 91 (i) Chilean sub-region: Western part of South America, Peru, Bolivia and Andes mountain range are the different parts of this region. It is not so rich in faunal content. (ii) Brazilian sub-region: It covers whole of Brazil and extends up to the Panama canal.It is very rich in faunal composition. (iii) Mexican sub-region: This sub-region is situated within North and South America, i.e., northern side of the Panama isthmus. It contains some important fauna. (iv) Antillean sub-region: Entire West Indies except Trinidad and Tobago is included inthis sub-region. Very few animal content is the characteristics of this sub-region. Climatic condition: Most parts of this region is covered by tropical dry lands. Only southern part of America experiences temperate climate. Ecological condition: In the Amazon valley there is tropical rain forest. Temperate region consists of Savannah and grassland. Western part of South America is dry and has desert like ecosystem. Argentina comprises mostly of grassland. Characteristic vertebrate fauna (i) Fishes: 120 genus of the three families (Polycentridae, Gymnotidae and Trigonidae) are present in this region. The prominent fishes are Lepidosiren, eel, catfish, etc. (ii) Amphibia: Caecilia, Siphonopsis, Hyla, Salamander, frog, toad, etc. (iii) Reptiles: Dromicus, Boa, Epicrates, Snakes, Gecko, Alligator, Chelys, etc. (iv) Birds: Total 700 genus of birds are recorded in this region. Among these rea, tenemus, screamus, whatgin, to wean, thrush, parakeet. (v) Mammals: Total 32 families are recorded of which Opossum, Caenolestes, Sloth, Armadillo, rodents, American tapir, bat, spider monkey, lama, etc. are important. 7.2.4 Ethiopian realm Geographical boundary: It consists of southern part of the Tropic of cancer, most of the African mainland, southern part of Arabia and Madagascar.

NSOU CC-ZO-09 92 Sub-divisions: It is also sub-divided into four sub-regions. (i) East African sub-region: Hot and dry region of Africa and Arabia are included in this sub-region. (ii) West African sub-region: Western part of the Ethiopian region is extended up to Kongo in this sub-region. (iii) South African sub-region: Whole of the southern part of Africa is included in this sub-region. (iv) Malagasy: Whole of Madagascar is included in this sub-region. Climatic condition: Mainly temperate in most of the areas, but remains hot during most time of the year. Ecological condition: The areas on the equinoctial line and West Africa possess rain forest along the sides of large rivers. Most of the other parts are dry deciduous forest. Northern and Southern parts of the region are transformed into desert. Characteristic of vertebrate fauna: (i) Fishes: Cat fishes, lung fishes (Protopterus, Polypterus) and several fresh water fishes are present. (ii) Amphibia: Xenopus and several species of caecilians are present. The group caudata is completely absent. (iii) Reptiles: Among snakes, Leptorhynchus, Ramnophis, etc.; among lizards, Monotrophis, Cordylus, Agama, Chameleon, etc. are prominent species. (iv) Birds: 67 families of Aves are recorded. Some important species, are ostrich, cuckoo, parakeet, eagle, kite, pigeon, hombill etc. (v) Mammals: The recorded families are 51 of which 15 are endemic. The remarkable species are Zebra, Gorilla, Antilope, Leopard, two homed Rhinoceros, Hippopotamus, Lemur, Gnu, Beboon, Lion, Giraffe, Chimpanzee, Loxodonta etc. 7.2.5 Oriental realm Geographical boundary: Most of the Asian countries which are situated at the southern side of Himalaya are included in this realm. India, Burma, Indo-China,

NSOU CC-ZO-09 93 Malay, Sumatra, Java, Bali, Borneo and Filipines, etc. are within this realm. Sub-divisions: It is composed of four sub-regions. (i) Indian sub-region: From the base of Himalaya the whole of the Indian subcontinent is under this sub-region. Indian sub-region was separated on the basis of distribution of molluscs, reptiles, birds and mammals by Wallace (1876). (ii) Ceylonese sub-region: Part of the Indian peninsula and Sri Lanka are covered under this sub-region. (iii) Indo-Chinese sub-rcgion: South China, Burma, Thailand and Indochina fall within the border of this sub-region. (iv) Indo-Malayan sub-region: This is eastern part of the oriental realm. Malay and East-Indies islands are included in this sub-region. Climatic condition: Most part experience temperate atmosphere. Annual rainfall more than 1500 mm. Ecological condition: Eastern part contains dense rain forest. Western part possess a desert. Other parts are having moderate forest. Characteristic vertebrate fauna: (i) Fishes: Different types of carp, catfish, notopteridae, osteoglocid, cipriniformes, etc. (ii) Amphibians: Varieties of anurans, some salamanders and caecilians are present. (iii) Reptiles: Various types of snakes like, Viper, Pit Viper, Kraits, etc.; lizards- like, Gekko, Aagamid, Varanus, Chamellion, Crocodiles, Gavialis. Platystemidae family of turtles are present. (iv) Birds: Pigeons, Owls, Finches, Phesants, Peacock, Saras, etc., are present. (v) Mammals: Srew, rabbit, dog, cat, boar, rodents, flying lemur, elephants, ox, tiger, orangutan, gibbon, tapir, pangolin, Rhinoceros unicorns, etc., are important members. Out of 30 families only 4 are endemic.

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NSOU CC-ZO-09 94 7.2.6 Australian realm Geographical boundary: Australia, New Zealand, New Guinea, Tasmania and some islands of adjacent areas are included in this realm. Sub-divisions: This is divided into four sub-regions. (i) Austro-Malayan sub-regions: Malay archipelago including New Guinea, Moluccas and Solomon island are covering this sub-region. (ii) Australian sub-region: Tasmania and Australia are the parts of this sub- region. (iii) Polynesian sub-region: Polynesia and Sand-wick islands are included in this sub-region. (iv) New Zealand sub-region: New Zealand, Norfolk island, Auckland, Campbell and Macquarie islands comprises this sub-region. Climatic condition: Hot and temperate, both types of climate are present here. Average rainfall in a year is 75 mm. Ecological condition: Rain forest, grassland, eucalyptus forest are prominent ecological characters. Characteristic vertebrate fauna (i) Fishes: Neoceratodus (Lung fish), Osteoglocidos, Gadopcidae, etc. (ii) Amphibia: Xenorhinidae family is present in New Guinea only. Helioporus, Pelodyrus are other important members. Total 11 families are recorded. (iii) Reptiles: Important snake families are Phithonidae and Elapidae: Pizopidae, Apracidae, Liadidae are prominent lizards. Sphenodon of Rhynchocephalidae family is the famous relict of reptiles present in New Zealand. (iv) Birds: Casuary, liar bird, magpie, emu, kiwi, scrab, bawar are important members of this region. Nine hundred and six species of birds are recorded from this region. (v) Mammals: Omithorhynchus (a marsupial), Tachyglossus (ant eater), Kangaroo, Dendrolagus (climbing kangaroo), Petaurus (flying opossum), wolf are the remarkable members. For simplicity in understanding you may go through the table below that describes the six zoogeographical realms in short:
NSOU CC-ZO-09 95 7.3 Theories pertaining to distribution of animals Basically two theories explain the spreading of animals all over the globe: 7.3.1. Continental drift hypothesis Proposed by Wagner and according to him the earth was one whole mass when it was originated, but about 135 million years ago (Cretaceous Period) the land mass fragmented in to continents. With the fragmentation of land mass animals were also distributed in their respective continents. 7.3.2 Centre of origin hypothesis: According to this theory the individuals of a species spread out from the center
NSOU CC-ZO-09 96 of their origin because of their high reproductive capacity. 7.4 Questions i) What is zoogeography? ii) What are the zoogeographical realms? What is Wallace line? iii) Describe the distribution, ecological conditions, flora and faunal characteristics of the zoogeographical realms. iv) Write a short note on the theories pertaining to distribution of animals. v) Discuss continental drift hypothesis. 7.5 Suggested readings 1. Basu, R.N. (2004). A Compendium of Terms in Ecology and Environment. Naya Udyog. 2. Chapman, R.
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