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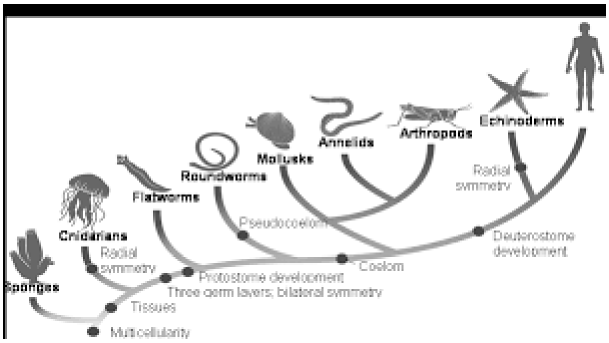

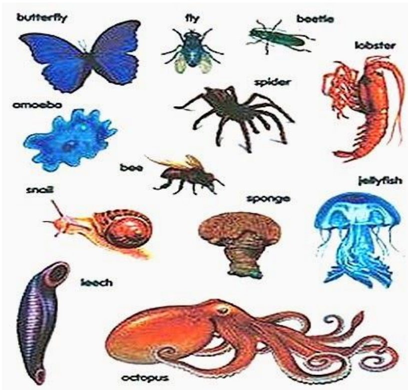

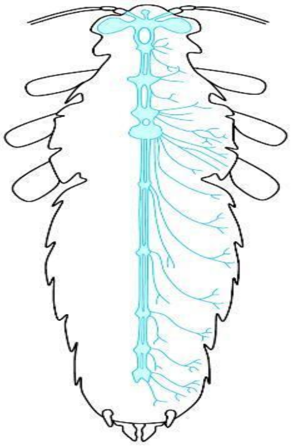

Biosystematics, Structure and Functions of Invertebrates

MZO-01

Vardhman Mahaveer Open University, Kota

Biosystematics, Structure and Functions of Invertebrates

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MZO-01

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Index

MZO-01

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Preface

The present book entitled "**Biosystematics, Structure and Functions of Invertebrates**" has been designed so as to cover the unit-wise syllabus of MZO-01 course for M.Sc. Zoology (Previous) students of Vardhman Mahaveer Open University, Kota. The basic principles and theory have been explained in simple, concise and lucid manner. Adequate examples, diagrammes , photographs and self-learning exercises have also been included to enable the students to grasp the subject easily. The unit writers have consulted various standard books and internet as their reference on the subject and they are thankful to the authors of these reference books.

Unit - 1

Principles of Animal Taxonomy

Structure of the Unit

1.0 Objectives

- To explain the theories and concept concerning animal taxonomy.
- Understanding the concept of species.
- Gaining knowledge about ICZN (international code of Zoological Nomenclature).
- To know various taxonomic procedures.
- To understand new trends in taxonomy.
- Emphasize (a) Cytotaxonomy

  (b) Molecular taxonomy

  (c) Sonotaxonomy- Identification and categorization based on acoustics.

1.1 Introduction

The biodiversity in life, in terms of the number of living organisms, their variation and their distribution is quite amazing, which includes microorganisms, plants and animals. So far one million animal species have been described and named. However another four ten million species still awaits discovery, description and naming, of which many will undoubtedly become extinct because of human misuse and abuse.

1.2 Classification and nomenclature

Since many identified and unidentified living forms are available, it certainly needs that every living organisms requires to be identified and categorized in a systematic order. The branch of biology dealing with this subject is called classification/ taxonomy/systematic. Absence of naming and classifying living organisms leads to many problems and worst confusion is being confounded, because of a single animal will be called in different names in different countries. Even within a single country it has several names in different regions, because of different languages and dialects.

The common or vernacular names are notoriously at variance even within the confines of one continent and one language for example; the American big cat, *Felis concolor* has different common names in different parts of America, like panther, puma, mountain lion, deer killer, Indian devil etc., all these appellations apply to the one and only species *Felis concolor* (Puma).

Another point is that some common names are quite misleading like; Silver fish, Jelly fish, Star fish, Cuttle fish etc. are not true fishes. All these problems can be resolved only when all living organisms are identified, classified and given scientific nomenclature. Classification is the curious outcome of human mind which aims to put things in an orderly way where similarity of one kind or another forms the basis of all classification.

For animals similarity of structure (morphology) has traditionally been the basis upon which the classification has been build. With the enunciation of the evolutionary principles by Charles Darwin (1859)it is considered that all animals are related to each other by descent. Consequently this type of classification aims to give genealogical relationship to groups of animals under consideration. Earlier classifications are clearly based on anatomy; embryology geographical distribution and fossils (paleontology) to bridge gaps between the living and extinct forms (Hyman, 1959).

Recently biochemistry, physiology, cytology and genetic studies have all begun to contribute towards classification of animals. But it still remains true that the most generally, accepted classification of animals. But it stills remains true that the most generally accepted classification is firmly grounded in morphological (structure) similarity (Moody, 1978).

1.3 The Science of Classification/Taxonomy

This study involves naming of organisms (nomenclature) and systematic placing of them into groups (taxa) on the basis of certain relationship between organisms. Though many Greek scholars have studied living plants and animals, the work of Aristotle (384-322 B.C.) stands unique, because he characterized animals according to their actions, way of living, body parts and habitats therefore he is called the "Father of Biological Taxonomy".

A more rational approach to the scientific method of classification, particularly on plants was carried out by John Ray (1627-1705). The most remarkable person to give an almost perfect 2-kingdom classification of plants and animals was the Swedish Naturalist, Carlous Linnaeus (1709-1778), rightly called the Father of Taxonomy for his outstanding contribution to systematics. He was the first to introduce the Binomial Nomenclature System, where every plant and animal will have two scientific names, the first word in the genus (where the first letter will be written in capital letter) and second word is the species (all words written in small letters. Example, *Pavo cristatus* (Peacock). He published his scheme of classification in the book entitled Systema Naturae in 1753. He strongly believed in the immutability or the fixation of the species.

1.4 Binomial system of Nomenclature

The binomial system classifies organisms into groups at various hierarchic levels, on the basis of easily observable and shared morphological features like shape, number and position of limbs etc. in a descending order of group size. As the word binomial suggests, the name of a species is made up of two parts: one indicating the genus and indicating the species. Binomial nomenclature means "two part name" or "system of two part names".

The person who popularized this system for use was Swedish Botanist and physician Carlous Linnaeus (1707-1778) who tried to name all things in the natural world and gave every species that he knew a two-part name. This kind of naming had been used before Linnaeus about everybody did.

In modern usage, the first letter of the first part of the name, the genus, is always capitalized in writing, while that of the second part is not, even when derived from a proper noun such as the name of a person or place similarly both parts are italicized when a binomial name occurs in normal text thus the binomial name of the human is *Homo sapiens* in zoology.

- "*Patella vulgata* Linnaeus, 1758". The name "Linnaeus" tells the reader who it was that first published a description and name for this species of sea snail; 1758 is the date of the publication in which the original description can be found (in this case the 10th edition of the book Systema Naturae).
- "*Passer domisticus* (Linnaeus, 1758)" The original name given by Linnaeus was *Tringilla domestica*; the parentheses indicated that the species is now considered to belong in a different genus. The ICZN does not require that the name of the person who changed the genus be given, nor the date on which the change was made although nomenclature catalogs usually include such information.

1.4.1 Value

The value of binomial nomenclature system derives primarily from its economy, its widespread use, and the uniqueness and stability of names it generally favours:

Economy: compared to the polynomial system which it replaced, a binomial name is shorter and easier to remember. It corresponds to the widespread system of family name plus given name used to name people in many cultures.

Widespread use: The binomial system of nomenclature is governed by international codes and is used by biologists worldwide. A few binomials have also entered common speech such as *Homo sapiens*, *E. coli* and *Tyrannosaurus rex*.

Clarity: Binomial names avoid the confusion that can be created when attempting to use common names to refer to a species. Common names often differ from one country to another or even from one part of a country to another. In English-speaking North America, a "robin" is *Turdus migratorius.* In English speaking parts of Europe, the "robin" is *Erithacus rubecula*. In contrast, the scientific name can be used all over the world, in all languages, avoiding confusion and difficulties of translation.

Uniqueness: Provided that taxonomists agree as to the limits of a species, it can have only one name that is correct under the appropriate nomenclature code, generally the earliest published if two or more names are accidently assigned to a species. However, establishing that two names actually refer to the same species and then determining which has priority can be difficult, particularly if the species was named by biologist from different countries. Therefore a species may have more than one regularly used name; these names are synonyms.

Stability: Although stability is far from absolute, the procedures associated with establishing binomial names, such as the principle of priority, tend to favour stability. Similarly, if what were previously thought to be two distinct species are demoted to a lower rank, such as subspecies, where possible the second part of the binomial name is as third part of the new name. thus the *Tenerife robin* may be treated as a different species from the *European robin*, in which case its name is *Erithacus superbus* or as only a subspecies, in which case its name is *Erithacus rubecula superbus*. The superbus element of the name it constant since taxonomist can legitimacy disagree as to whether two genera or two species are distinct or not, more than one name can be in use. The only reason a specific epithet may need to be changed is if that by transferring it to a new genus it becomes a junier homonym of an older specific epithet for an older specific epithet for a different species in the same genus.

1.4.2Problems: Binomial nomenclature for species has the effect that when a species is moved from one genus to another not only is its genus name changed but sometimes its species name must be changed as well (because the name is already used in the new genus, or to agree in gender with the new genus) some biologist have argued for the combination of the genus name and specific epithet into a single unambiguous name, or for the use of uninominal (as used in nomenclature of ranks above species).

1.4.3Relationship to classification and taxonomy

Nomenclature (including binomial nomenclature) is not the same as classification, although the two are related. Classification is the ordering of items into groups based on similarities and/or differences; in biological classification species are one of the binds of item to be classified. In principle, the names given to species could be completely independent of their classification. This is not the case for binomial names, since the first part of a binomial is the name of the genus into which the species is placed.

Above the rank of genus, binomial nomenclature and classification are partly independent; for example, a species retains its binomial name if it better fits a different genus in the same or different family, or it is split from its old genus and placed in a newly created genus. The independence is only partial since the names of families and other higher taxa are usually based on genera.

Taxonomy includes both nomenclature and classification. Its first stage (sometimes called alpha taxonomy) is concerned with finding, describing and naming species of living or fossil organisms. Binomial nomenclature is thus an important part of taxonomy as it is the system by which species are named. Taxonomists are also concerned with classification, including its principles, procedures and rules.

1.4.4 Derivation of binomial names

A complete binomial name is always treated grammatically as if it were a phase in the Latin language (hence the common use of the term "Latin name" for a binomial name). however, the two parts of a binomial name can each be derived from a number of source, of which Latin is only one. These include:

- Latin, either classical or medieval thus both parts of the binomial name *Homo sapiens* are Latin words, meaning "wise" (sapiens), human/man (Homo).
- Classical Greek the genus Rhododendron was named by Linnaeus from the Greek word which is itself derived from rhodos, rose and Dendron tree. Greek words are often converted to a Latinized form. Thus coca (the plant from which cocaine is obtained) has the name *Erythroxylun coca*. Erythroxylun is derived from the Greek words erythros, red and xylon, wood. The Greek neuter ending –ov(-on) is often converted to the Latin neuter ending –um.

Other language: The second part of the name *Erythroxylun coca* is derived from kuka, the name of the plant is Aymara and Quenchua. Since many dinosaur fossils were found in Mongolia, their names often use Mongolian words e.g. *Tarchia* from turki, meaning "brain" or Saichania meaning "beautiful one".

Name of people (often naturalist or biologists): the name *Magnolia campbellii* commemorates two people; Pierre Magnol , a French botanist, and Archibald Campbell, a doctor in British India.

Name of the place: The lone star tick, *Amolyomna americanum*, is wide spread in the United States.

Other sources: Some binomial names have been constructed from anagrams or other re-ordering of existing names. Thus the name of the Muilla is derived by reversing the name Allium. Name may also be derived from jokes or puns. For example, Ratcliffe described a number of species of Rhinoceros bettle, including *Cyclocephala nodanotheruon*.

The first part of the name, which identifies the genus, must be a word which can be created as a Latin singular noun in the nominative case it must be unique within each kingdom, but can be repeated between kingdoms. Thus *Huia recurvata* is an extinct species of plant, found in fossils in Yunnan, China, whereas *Huia masonii* is a species of frog found in Java, Indonesia.

The second part of a binomial may be an adjective. The adjective must agree with the genus in gender. Latin has three genders, masculine, feminine and neuter, shown by varying endings to nouns and adjectives. The house sparrow has the binomial name *Passer domesticus*. Here domesticus (Domestic) simply means "associated with the house" the sacred bamboo is *Nandina domestica* rather than Nandina domesticus, since tropical fruit langsat is a product of the plant *Lansium parasiticum* since lansium is neuter. Some common endings for Latin adjectives in these genders (masculine, feminine, neuter) are –us, -a, -um (as in the previous example of domesticus); -is, -e (e.g. tristis meaning sad), and –or, -us (e.g. minor, meaning smaller).

The second part of a binomial may be a noun in the nominative case. An example is the binomial name of the lion, which is *Panthera leo* grammatically the noun is said to be in opposition to to the genus name and the two nouns do not have to agree in gender, in this case, *Panthera* is feminine and Leo is masculine.

The second part of a binomial may be a noun in the genitive (possessive) case. The genitive case is constructed in a number of ways in Latin, depending on the declension of the noun. Common endings for masculine and neuter nouns are –ii or –I in the singular and –orum in the plural and for feminine nouns –ae in the singular and –arum in plural. The noun may be part of a person's name, often the surrounding as in the Tibetan antelope, *Pantholops hodgsonii*, the shrub *Magonolia hodgsonii* or the olive backed pipit *Anthus hodgsonii*. The meaning is "of the person named" so that magnolia hodgsonii means "Hodgson's magnolia". The –ii or –i endings show that in each case Hodgson was a man (not the same one); the person commemorated in the binomial name is not usually (if ever) the person who created the name; for example *Anthus hodgson.* Rather than person the noun may be related to a place, as with *Latimera chaulmnae*, meaning "of the Chaulmna River". Another use of genitive noun is in, for example, the name of the bacterium *Escherichia coli*, where coli mean "of the colon". This formation is common in parasites as in *Xenos vesparum*, where vesparum means “of the wasps” since *Xenos vesparum* is a parasite of wasps.

Whereas the first part of a binomial name must be unique within a kingdom, the second part is quite commonly used in two or more genera (as is shown by examples of hodgsonii above). The full binomial name must be unique within a kingdom.

1.4.6 Writing binomial names

By tradition, the binomial names of species are usually typeset in italics; for example, *Homo sapiens*. Generally the binomial should be printed in a font different from that used in the normal text; for example “several more Homo sapiens fossils were discovered”. When hand written, each part of a binomial name should be underlined; for example <u>Homo</u> <u>sapiens</u>.

The first part of the binomial, the genus name, is always written with an initial capital letter. In current usage, the second part is never written with an initial capital.

The binomial name should generally be written in full. The exception to this is when several species from the same genus are being listed or discussed in the same paper or report, or the same species is mentioned repeatedly; in which case the genus is written in full when it is first used, but may then be abbreviated to an initial (and a period/full stop) for example, a list of members of the genus can might be written as “*Canis lupus, C. aureus, C. simensis*”. In rare cases, this abbreviated form has spread to more general use; for example, the bacterium, *Escherichia coli* is often referred to as first *E. coli* and *Tyrannosaurus rex* is *T. rex* these two both often appearing in this form in popular writing even where the full genus name has not already been given.

The abbreviation “spp.” (Plural) indicates “several species”. These abbreviations are not italicized (or underlined) for example “Canis sp.” Means an unspecified species of the genus Canis, while “Canis spp.” Means “two or more species of the genus Canis” (The abbreviations sp.” and spp.” Can easily be confused with the abbreviations “ssp.” (Zoology) or “subsp.” (Botany), plurals “sspp.” or “subspp” referring to one or more subspecies.

The abbreviation “cf” (i.e. confer in latin) is used to compare individuals/taxa with known/described species conventions for use of the “cf” qualifier vary. In paleontology, it is typically used when the identification is not confirmed. For example “corvus cf nasicus” was used to indicate “a fossil bird similar to the Cuban crow but not certainly identified as this species”. In molecular systematic papers, “cf” may be used to indicate one or more undescribed species assumed related to a described species. For example, in a paper describing the phylogeny of small benthic fresh water fish called darters, five undescribed putative species (Ozark, Sheltowea, Wildcat, Ihiyo and Mamequit darters), notable for brightly coloured nuptial males with distinctive color patterns, were referred to as “Etheostoma cf spectabile” because they had been viewed as related to, but with distinct form, Etheostoma spectbile (orange throat darter). This view was supposed in varying degree by DNA analysis. The somewhat informed use of taxa names with qualifying abbreviations is referred to as open nomenclature and it is not subject to strict usage wells.

In some context the dagger (“f”) may be used before or after the binomial name to indicate that the species is extinct.

1.5 Species

In biology, a species (abbreviated sp., with the plural form species abbreviated spp.) is one of the basic units of biological classification and a taxonomic rank.

The scientific system of naming ‘kinds’ of plants and animals revolves around the species level. The term ‘species’ is Latin for ‘kinds’. Since ancient time; philosophers and naturalists realized the necessity for a basic unit by which biodiversity on this planet may be described and estimated. But the development of a scientific theory of classification is relatively recent phenomenon.

Simpson and Mayr have elaborated on the historical developments of taxonomy and its concepts early Greek Philosophers and Naturalist like Hippocrate, Plato and Aristotle also paid attention to biological classification Hippocrates (460-377 B.C.) described types of animals, but there is no indication of useful classification in his work. Plato (427-347 B.C) was, in the words of Mayr, ‘the great antihero of evolution as he believed in essentialism which is also referred to as the theory of forms. Aristotle (384-322 B.C) was the father of biological classification. As far as evolution is concerned, he gave the idea of ladder of lip a series in which organisms could be arranged in the order of increasing complexity. He studied morphology of animals and also paid attention to embryology, habits and ecology. He emphasized that all the attributes of animals such as living actions habits and bodily parts may be taken into consideration in classification. His idea was also a kind of typological or essentialism as far as species is concerned.

Linnaeus (1707-1778), a great taxonomist and sometimes called the ‘father of taxonomy’, adhered to downward classification. His thinking was that of an essentialist for whom species reflects the existence of fixed, unchangeable type (essence). He proposed binomial nomenclature. The typological definition of species based on the concept of Linnaeus is called essentialist species concept.

Occam and his followers suggested that nature produces individuals and nothing more, and species has no actual existence in nature; it is only a mental concept. It is the basis of nominalistic species concept which was popular in France in the eighteenth century.

A particular species concept is associated with a definition and definitions differ in different concept of species. It may be mentioned here that nearly all of the older definitions of the species, including those of Buffon, Lamark and Cuvier refer to the morphological similarities of individuals of the same species.

An entirely new species concept has begun to emerge in the seventeenth century. Ray believed in the morphological definition of species and his species characterization also contained the germ of biological species concept, which considers the reproductive relationship to be a principle species criterion. As early as 1760, Koelreuter mentioned that all the individuals which are able to interbreed and produce fertile progeny belong to the same species.

Hundred years before Darwin, Buffon in his Historie Naturelle describes everything known in the natural world and believed in organic change but did not provide any mechanism to explain the evolutionary change. Although initially he believed in morphological species concept, Buffon prepared the way for biological species concept using sterility barrier (instead of morphological similarities) as species criterion later on, the biological species concept was developed due to contribution of Merrem, Voigt, Walsh and many other naturalist and taxonomist of the Nineteenth century.

The biological species concept was clearly formulated by Jordan, Dobzhansky and Mayr. According to Mayr a species is a group of potentially or actually interbreeding natural population which are reproductively isolated from other such groups.

However, Dobzhansky, being an evolutionary geneticist defined species as a reproductive community of sexually and cross- fertilizing individuals which share a common gene pool. The biological species concept is the most widely accept, but it has certain difficulties in its application. Since biological species concept is applicable to non –dimensional situation, Simpson, faced with the problems of studying the evolutionary species concept in which a species is a lineage (an ancestral-descendent sequence of populations) evolving separately from others and with its own unitary evolutionary role and tendencies.

Darwin explains the mechanism of evolution in his book Origin of species and his theory has two components: (i) descent with modification- all species living and extinct have descended from one or a few original form of pre-existing species, and (ii) natural selection as casual agent of evolutionary change.

Darwin also recognized that species not only evolve but also divide. Darwin unquestionably had adopted a biological species concept ion the 1830s even though later he gave it up. He did not define species but appear to have a morphological concept of species which was central to his theory of natural selection.

According to Darwin, the term species is arbitarly used for sake of convenience to a set of individuals closely resembling each other and it does not differ from the term 'variety' which is given to less distinct and more fluctuating forms.

Probably Darwin believed that the concept of species is unnecessary because gradual evolutionary changes can account for the diversity of life. In his article a number of species concepts, including those which have been rejected and are also of historical significance, have been described. Further, various modes of speciation have also been discussed with suitable examples.

1.6 Concept of Species

Species concepts originate in taxonomy in which species is the basic unit of classification according to the international commission of Zoological nomenclature. Survey of taxonomic literature shows that there are a large number of species concepts which have been suggested by naturalists, taxonomists and evolutionary biologists from time to time. There are more than 20 species concept which are listed below:

Agamospecies: Asexual lineages, uniparental organisms (parthenogens and apomicts) that cluster together in term of their genome, may be secondarily uniparental from biparental ancestors.

Biological Species: Mendelian population of sexually reproducing organisms, interbreeding natural populations isolated from other such groups, depending upon reproductive isolating mechanisms.

Cladistic Species: Set of organisms between speciation events or between speciation and extinction events, or a segment of a phylogenetic lineage between modes.

Cohesion Species: Evolutionary lineage bounded by cohesion mechanisms that causes reproductive communities, particularly genetic exchange and ecological interchangeability.

Composite Species: All organisms belonging to an internodon and their descendents until a subsequent internodon (internodon is a set of organisms whose parent-child relations are not split.

Ecological Species: A lineage which occupies an adaptive zone minimally different from that of any other lineage in its range and which evolves separately from all lineages outside its range.

Evolutionary Species: A lineage (ancestral- descendent sequence of populations) evolving separately from others and with its own unitary evolutionary role and tendencies.

Evolutionary significant unit: A population (or group of population) that is substantially reproductively isolated from other conspecific population units and represents as important component in the evolutionary legacy of the species.

Geological concordance: Population subdivisions concordantly identified by multiple independent genetic units constitute the population units worthy of recognition as phylogenetic taxa.

Genetic Species: Group of organisms that may inherit characters from each other, common gene pool, reproductive community that forms a genetic unit.

Genotypic cluster definition: Clusters of monotypic or polytypic biological entities, identified using morphology or genetics, forming groups that have few or no intermediates when in contact.

Hennigian species: A tokogenetic community that arises when a stem species is dissolved into two new species and ends when it goes extinct or speciates.

Internodal species: Organisms are conspecific in virtue of their common membership of a part of a genealogical network between two permanent splitting events or a splitting event and extinction.

Morphological species: Similar to typological species concept of Linnaeus; species are the smallest groups that are consistently and persistently distinct and distinguishable by ordinary means.

Nominalistic species: Only individuals exist and nothing more. Species have no actual existence in nature.

Non-dimensional Species: Species delimitation in a non-dimensional system (a system without the dimensions of space and time).

Nothospecies: Species formed from the hybridization of two distinct parental species, often by polyploidy.

Phenetic species: A cluster of characters that statistically co-vary, a family resemblance concept in which possession of most characters is required for inclusion in a species, but not all. A class of organisms that share most of a set of characters.

Phylogenetic species: A species is the smallest diagnosable cluster of individual organisms within which there is a parental pattern of ancestry and descent.

Recognition species: A species is that most inclusive population of individuals, biparental organisms which share a common fertilization system.

Reproductive competition species: The most extensive units in the natural economy such that reproductive competition occurs among their parts.

Successional species: Arbitrary anagenetic stages in morphological forms, mainly in the palaeontological records.

Taxonomic species: Specimens considered by a taxonomist to be a member of a kind on the evidence or on the assumption that they are as alike as their offspring of hereditary relatives within a few generations.

Specifications of various species concepts mentioned above have been taken from Wilkins. Mayr and Ashlock have stated that 'The taxonomic literature reports innumerable species concepts, but they fall into four groups. The first two have mainly historical significance but are still upheld by a few contemporary authors'. These groups are: (i) typological species concept, (ii) nominalistic species concept, (iii) biological species concept and (iv) evolutionary species concept.

1.6.1 Typological species concept

This concept was proposed by Linnaeus and his followers and before that Plato and Aristotle also believed in this. The term 'Eidos' coined by Plato is also related to this. In nature, there are limited number of types or universals and members of a species form a class. It is also referred to as essentialism and the definition of species based on this concept is also called essentialist species concept. It is based on the degree of morphological differences used by the taxonomists. Under this concept, each species is entirely constant through time and thus the concept does not allow any change in a particular species. Since it is known that there are individual variations within the species and different species may be morphologically identical as in the case of sibling species (morphologically indistinguishable but reproductively isolated), the essentialist species concept has been rejected.

1.6.2 Nominalistic species concept

Occam and his followers did not believe in the existence of universals or types and for them only individuals existed and species had no real existence. This species concept was popular in France in the 18th century. According to Bessey , nature produces only individuals and nothing more. Species is merely a mental concept. But it is known that species are not human constructs. So this species concept has also been rejected.

1.6.3 Biological species concept

Jordan , Dobzhansky and Mayr clearly formulated the biological species concept. Mayr defined species as a group of potentially or actually interbreeding natural populations which are reproductively isolated from other such groups. Dobzhansky , being an evolutionary geneticist, added the term gene pool, and defined species as a reproductive community of sexually and cross-fertilizing individuals which share in a common gene pool. The members of a species form a reproductive community, an ecological unit and a genetic unit. These three properties (reproductive community, ecological and genetic units) show that species cannot be defined by the typological or nominalstic concepts. The biological species concept is the most widely accepted, but there are three main difficulties in its application: insufficient information, uniparental reproduction and evolutionary intermediacy. With regard to insufficient information in a particular species, there are individual variations due to sexual dimorphism, age differences, polymorphism and other types of morphological changes, but these difficulties may be overcome through a study of life histories and analysis of natural populations. In the biological species concept, interbreeding among the individuals of the same species and reproductive isolation from other species are the principal criteria. During the process of sexual reproduction, recombination of genetic materials takes place between parental individuals which leads to new combinations of genes in the progeny. However, there are many examples which do not come under this category such as hermaphroditism, automixis, parthenogenesis, gynogenesis and vegetative reproduction which show uniparental reproduction. There are numerous examples of such uniparental reproduction in invertebrates and vertebrates. Mayr has given a new terminology to such uniparental lineages, i.e. paraspecies, but Grant has designated such cases as agamospecies. Any terminology may be given to such cases, but they may not be considered as subdivision of biological species because they are quite different from biological species. There is difficulty in the application of biological species concept in those situations in which speciation is incomplete (evolutionary intermediacy). The species as a reproductive community exists in nondimensional situation of a deme. As soon as it extends in dimension of space and time, the stage is set for incipient speciation. The populations may be found in the process of becoming new species which have not yet acquired the characters of entirely new species. It is difficult to assign any stage to such populations, particularly when morphological distinctness is not correlated with the acquisition of reproductive isolation. Further, there may be acquisition of reproductive isolation without the development of equivalent morphological change. Numerous difficulties may be faced by the taxonomists for such cases of evolutionary intermediacy. There are several examples of such situations which are consequences of the gradual nature of the speciation process. It is difficult to assign species status to a given population in these cases of evolutionary intermediacy. This temporal inextensibility of biological species concept makes it non-evolutionary because of its non-dimensional character. Mayr has explained this limitation by stating that 'the species concept has its full meaning only where populations belonging to different species come into contact. This takes place in local situations without the dimension of space (geography) and time. The function of the species concept is to determine the status of co-existing individuals and populations.'

1.6.4 Evolutionary species concept

Because of non-dimensional character of the biological species concept, some palaeontologists are not satisfied with biological species definition. Their argument is that the species definition must involve evolutionary criteria. Simpson1 proposed the evolutionary species concept and defined the species as a lineage (an ancestral–descendent sequence of populations) evolving separately from others and with its own unitary evolutionary role and tendencies. Mayr has criticized the evolutionary species definition saying that it is the definition of a phyletic lineage, but not of the species. It is also applicable to incipient species or isolated populations. Further, it ignores the core of the species problem and tries to delimit species taxa in the time dimension. Wiley attempted to make certain improvement in evolutionary species concept by suggesting that no presumed separate, single, evolutionary lineage may be subdivided into a series of ancestral and descendent species. But this definition is of species taxon and not of species category. Thus Mayr did not accept the evolutionary species concept and he strongly advocated for the biological species concept in spite of certain difficulties in its application.

1.7 International Code of Zoological Nomenclature

1. The **International Code of Zoological Nomenclature** (**ICZN** or **ICZN Code**) is a widely accepted convention in zoology that rules the formal scientific naming of organisms treated as animals. The rules principally regulate:
2. How names are correctly established in the frame of bionomial nomenclature
3. Which name must be used in case of name conflicts
4. How scientific literature must cite names

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 judgment dictates otherwise. The Code is meant to guide only the nomenclature of animals, while leaving zoologists freedom in classifying new taxa.

In other words, whether a species itself is or is not a recognized entity is a subjective decision, but what name should be applied to it is not. The Code applies only to the latter, not to the former. A new animal name published without adherence to the Code may be deemed simply "unavailable" if it fails to meet certain criteria, or fall entirely out of the province of science .

The rules in the Code determine what names are valid for any taxon in the family group, genus group, and species group. It has additional (but more limited) provisions on names in higher ranks. The Code recognizes no case law. Any dispute is decided first by applying the Code directly, and not by reference to precedent.

The Code is also retroactive or retrospective which means that previous editions of the Code, or previous other rules and conventions have no force any more today and the nomenclatural acts published 'back in the old times' must be evaluated only under the present edition of the Code. In cases of disputes concerning the interpretation, the usual procedure is to consult the French Code, lastly a case can be brought to the Commission who has the right to publish a final decision.

Historical Background:

The origin of an internationally accepted Code of Rules for Zoological Nomenclature is a consequence of the confusion of names that occured in the zoological literature of the early part of the 19th century. Following the publication of the 10th edition of the *Systema Naturae* by Linnaeus in 1758, and his adoption in it of binominal names for species of animals, the next century saw the new system expanded and developed in different places, and in different ways for different animal groups. By the second quarter of the 19th century disparate usages were common and the need for an agreement to achieve universality in the scientific names of animals and a greater stability had become apparent everywhere.

Moreover, the great explosion in known species, caused by the growth of science and by active exploration in countries outside Europe, resulted in a multiplicity of names; many of these were synonyms resulting from the work of scientists researching independently. It became critical to devise universally accepted methods for choosing between them.

The most important of the early attempts to regulate zoological nomenclature was that by Hugh Strickland. The rules proposed by Strickland and his colleagues developed into what has since been called the British Association Code or the Stricklandian Code; its official title was *Series of Propositions for Rendering the Nomenclature of Zoology Uniform and Permanent*. Following its presentation at the British Association for the Advancement of Science in 1842, by a Committee that included such distinguished Zoologists as Charles Darwin, Richard Owen and John Westwood, that Code was translated and circulated widely and had great influence. It was published in France, Italy and the United States of America. It was received by the Scientific Congress at Padua in 1843, by the American Society of Geologists and Naturalists in 1845, and was adopted by the British Association for the Advancement of Science in 1846. It was revised in succeeding years, and provided the basis for the code formulated by Henri Douvillé (1881) which was adopted internationally by geologists, and for the American Ornithologists' Union Code (1886).

Following discussion at International Congresses of Geology (Paris, 1878; Bologna, 1881) it became clear that there was need for a formal international agreement to be made for rules to cover all zoological names, irrespective of which bodies or disciplines required to use them and applicable to both fossil and extant animals. At the 1st International Congress of Zoology (Paris, 1889), the Congress adopted, in part, rules drawn up by Maurice Chaper and Raphael

Blanchard and referred the matter for discussion at the 2nd Congress (Moscow, 1892). The 3rd Congress (Leiden, 1895) appointed a Commission of five zoologists (R. Blanchard, J.V. Carus, F.A. Jentink, P.L. Sclater and C.W. Stiles) to formulate a "codex" and to report to the 4th Congress (Cambridge, England, 1898). This was the birth of the present International Commission on Zoological Nomenclature. Following the addition of ten more members and further consideration, a report was adopted by the 5th Congress (Berlin, 1901) and a Code of rules embodying the decision of that Congress was published in French, English and German in 1905. This Code, entitled *Règles internationales de la Nomenclature zoologique*, with a series of amendments resulting from subsequent Congresses (Boston, 1907; Monaco, 1913; Budapest, 1927; Padua, 1930) remained in force until 1961 when it was replaced in its entirety by the first edition of the *International Code of Zoological Nomenclature*. This resulted from studies at Congresses following the 1939-45 War (Paris, 1948; Copenhagen, 1953; and London, 1958); a very detailed account of the work that culminated in the 1961 edition is given by Norman R. Stoll, Chairman of the Editorial Committee, in his Introduction to that edition. A second edition was published in 1964 incorporating amendments adopted at Washington (1963).

To most zoologists at the time, the 17th International Congress of Zoology (Monaco, 1972) appeared likely to be the last general Congress of Zoology. Decisions were taken there to amend the second (1964) edition, and in addition, to ensure mechanisms for continuity and future up-dating, a decision was taken to transfer responsibility for future Codes (and the Commission) from the International Zoological Congresses to the International Union of Biological Sciences (IUBS).

Responsibility for the Code and the Commission was accepted by IUBS at the XVIII IUBS General Assembly (Ustaoset, Norway, 1973). In response to proposals for major and substantive changes to the Code, made by the community of zoologists at that time, and to eliminate ambiguities, a third edition of the Code was prepared and was approved by the Commission, with the authority of IUBS, late in 1983 and published in 1985.

A more detailed account of the development of zoological nomenclature and the events leading to the modern Code are given by Richard Melville, former Secretary of the Commission, in the centenary history of the Commission which was published in 1995 entitled Towards stability in the names of animals.

The decades of the 1970s and 1980s witnessed further marked changes in professional orientation and education of zoologists, changes in the methodology of taxonomy mostly resulting from new genetic information and the application of computers, a burgeoning literature, and accelerating changes in information technology including electronic publishing. It became clear that the Commission should work towards a fourth edition to accommodate the consequences of these and other factors, including a greater ecumenism in biological science leading to pressure within IUBS for greater consistency between the various codes of nomenclature.

An Editorial Committee was appointed by the Commission in Canberra in October 1988, and proposals were canvassed and discussed at meetings of the Commission and of the IUBS Section of Zoological Nomenclature in Maryland (1990) and Amsterdam (1991), and at meetings of the Committee in Leiden (1991) and Hamburg (1993). Following these, a Discussion Draft was publicly issued in May 1995. Within a year this resulted in almost 800 pages of comments from some 500 sources, many of which consisted of groups of zoologists; a number of these comments were published in the *Bulletin of Zoological Nomenclature*. All the comments (mostly transmitted by electronic mail) and the text were considered by the Editorial Committee in Vicenza in June 1996, and in August of that year a report was presented to the Commission and the Section of Zoological Nomenclature in Budapest. The comments showed that some of the tentative proposals in the Discussion Draft (such as a proposal for mandatory "registration" of new names and the abolition of gender agreement within combinations of generic and specific names) were not sufficiently acceptable to zoologists to be adopted. A revised draft was accepted by the Commission by postal vote (1997) with minor amendment. The Commission, in voting, made a number of suggestions for clarification which have been incorporated in this edition.

1.7.1preamble Of Iucn

The International Code of Zoological Nomenclature is the system of rules and recommendations originally adopted by the International Congresses of Zoology and, since 1973, by the International Union of Biological Sciences (IUBS).

The objects of the Code are to promote stability and universality in the scientific names of animals and to ensure that the name of each taxon is unique and distinct. All its provisions and recommendations are subservient to those ends and none restricts the freedom of taxonomic thought or actions.

Priority of publication is a basic principle of zoological nomenclature; however, under conditions prescribed in the Code its application may be modified to conserve a long-accepted name in its accustomed meaning. When stability of nomenclature is threatened in an individual case, the strict application of the Code may under specified conditions be suspended by the International Commission on Zoological Nomenclature.

Precision and consistency in the use of terms are essential to a code of nomenclature. The meanings given to terms used in this Code are those shown in the Glossary. Both this Preamble and the Glossary are integral parts of the Code's provisions.

The International Commission on Zoological Nomenclature is the author of the Code.

1.7.2 Taxonomic Procedures:

Taxonomic deals with the naming and classification of organisms and is an integrative part of biological systematics , the science of biodiversity .The information provided by taxonomic research is a fundamental basis for all fields of biology.Current taxonomy focuses on multicharacter integrative approaches, considering all potentially useful sources of information provided by the various fields of biology .The resulting supraspecific classification should be based on the geneology of organisms , that is , on phylogenetic analysis , to be objectively testable. However , for pragmatical reasons , a classification based on overall similarity and diagonastically relevant characters might be a heuristically important step in taxonomy and should be perceived as an approximation to a classification tested on phylogenetic methods. The nested levels in a classification of organisms are usually not only named but also ranked , that is , a set of hierarchial terms , like genus , family and class , is applied to reflect the hiearchial structure of the classification . Assigning these o –called Linnaean categories to a classification is(1) a voluntary action to make a classification notionally more easy to access and (2) a linguistic activity that is done subsequent to obtaining the scientific results of the systematic analysis.

1.8 Modern Trends in Taxonomy

Taxonomy in Science and method of naming organisms is a fundamental basis for all biological Science and its application . The principal task of taxonomy is to describe , establish and give an account of the order that is an inherent property of biological diversity . The order of names provided by taxonomy is arranged as a hiearchial classification , which is considered to potray the hiearchy of species and more inclusive taxa as a result of the continuous chain of species splitting in the evolutionary history of life on earth . Generalizations on organisms as a basic principle in biology are only possible if the infinite number of items in Science is classified statements about the overwhelming diversity of nature would be impossible without methods for bringing order to this diversity .The world's biota is a vast library of information concerning any aspect of life and taxonomy is the cataloguing system that everybody must use to access its information .All kinds of biological Science and application link their specific data to species names and use these names for effective communication.

As Longino (1993) has paraphrased "taxonomy is the raw material from which hypothesis of phylogeny are derived". All kinds of comparative biology rely on sound phylogenetic hypotheses immediately depends on the reliability of the underlying taxonomic data.

Moreover society has an increasing need for reliable taxonomic information in oder to allow to manage and understood the world's biodiversity .Until recently , taxonomy was confronted with what Godfray called a new bioinformatics crisis evidenced " by a lack of prestige and resources that is crippling the continuing cataloguing of biodiversity ".Current biological taxonomy quite successfully adopt methods ,data structure and other demands of techniques and theories invented by new entrant to the biological Science as the fields of molecular biology .However ,all other useful sources of information are simultaneously gathered in modern taxonomy and this multicharacter integrative approach has been called integrative taxonomy . It allows taxonomists to create new common visions to meet changing demands of a changinh global view on global diversity and threats to it.

1.9 Cytotaxonomy

It is the branch of biology dealing with the relationship and classification of organism using comparative studies of chromosomes.

The structure , number and behavior of chromosomes is of great value in taxonomy , with chromosome number being the most widely used and quoted character .Chromosome numbers are usually determined at mitosis and quoted as the diploid number(2n) , unless dealing with a polyploidy series in which case the base number of chromosomes in the genome of the original haploid quoted.

Another useful taxonomic character is the position of the centromere .Meiotic behavior may show the heterozygosity of inversions. This may be constant for a taxon ,offering further taxonomic evidence .

The cytotaxonomy is more significant over physiological taxonomy because cytotaxonomy is dealing with the comparative study of chromosome and with this method minute variation among the individuals among the individuals can be detected . DNA are present in the chromosome and the variation in DNA are responsible for the variation among the individuals, species , genus and so on . The difference in physiological variation are too less among the individuals of same species and other higher taxa.

1.1 0 Molecular Taxonomy

Molecular Taxonomy is the classification of organisms on the basis of the distribution and composition of chemical substances in them.

Molecular techniques in the field of biology have helped to establish genetic relationship between the members of different taxonomic categories . DNA and protein sequencing, immunological methods, DNA-DNA or DNA-RNA hybridization methods are more informative in the study of different species. The data obtained from such studies are used to construct phylogenetic trees. Fitch and Margoliash ,(1967) made first phylogenetic tree based on molecular data .This tree was so close to the already established phylogenetic trees of the vertebrates that the taxonomists realized significance of molecular data and this made them understand that other traditional methods are although important but molecular evidences could be final or confirmatory evidences.

1.11 Bioacoustic tools: Sonotaxonomy

Field identification methods involving acoustic sampling for taxa such as birds, frogs, and crickets, and visual sampling based on diagnostic morphological characters are rapid and inexpensive, and they can be developed to be accurate (Riede, 1993). Morphological characteristics often are found insufficient for the identification of cryptic species. Several cryptic species of anurans display a high level of morphological similarities that often make them virtually impossible to distinguish on the basis of morphological parameters. The taxonomic status of some very poorly known groups of frogs of the family Dicroglossidae from the central Aravalli ranges of Western India and the family Microhylidae from the southern parts of India, is assessed by means of acoustic and statistical analyses of differences in temporal parameters of advertisement calls, such as the number of pulses and the call duration, as well as a spectral parameter, dominant frequency, harmonics, peak frequency, amplitude, and power, etc. As these species usually are misidentified or ignored because of their taxonomic complexity in both ecologically diversified regions, we have found bioacoustical diagnosis for each species in order to facilitate identification in the field. Differences in acoustic parameters support the specific status of Sphaerotheca breviceps, S. rolandae, Microhyla ornata, and M. rubra. Populations from these distinct biodiversity regions can be recognized by distinctive advertisement calls, usually corresponding to a recognized species. The individuals of family Dicroglossidae (S. breviceps and S. rolandae) and Microhylidae (M. ornata and M. rubra), being sympatric species, show great similarities in their morphological characteristics as well as eco-biological needs, but their advertisement call characteristics analyzed using sound analysis softwares, viz., Raven, Avisoft, and Sound Ruler, are very different and species-specific, and they are very useful, particularly in field identification and monitoring (Sharma, 2005). Furthermore, identification and monitoring of species using bioacoustics tools is a humane approach that avoids unnecessary killing of animals. 4.1 Sound analysis system The call analysis system includes the following steps: Transmitter > Medium (air) > Receiver. The transmitter, e.g., a male frog, emits the sound, which is transmitted through the medium, usually the air, as longitudinal pressure waves. The receiver processes the sound and presents the waves as visual spectrograms that are used for the identification of species. The system of call analysis includes: 1. Recording 2. Storage and conversion into a proper format 3. Generation of a spectrogram 4. Analysis of spectral pattern and development of classifiers Investigation of animal sounds includes signal recording with electronic recording equipment. Due to a wide range of signal properties and media they propagate, specialized equipment is used instead of the usual microphones. Video cameras are used for the confirmation of the call of a particular species. A sound bank is prepared to store calls in a format applicable to the software. Specific computer programming is designed for the storage and analysis of recorded data, and specialized sound analyses are used for describing and storing signals according to their intensity, frequency, duration, and other parameters. Before the analysis of an unknown call the software is calibrated with the help of audio-frequency generators. All the sound signals are analyzed on the same frequency and timescale to ensure that the recorded sound belongs to a different species or the same species. Data collection involves two main components: sampling followed by processing. Sampling depends on rate and resolution. Rate should be greater than twice the highest frequency to be sampled. Resolution depends on processor intake, i.e., 8-bit or 16-bit. The resolution of 8-bit code is 256 combination steps and that of 16-bit code is 65,536 combination steps. Most graphical display devices present sound as a time domain feature. The time domain display of sound waves has limitations in analysis. Frequency domain representatives of spectrum are an improved display system achieved by Fourier transform that provides better opportunities for sound analysis. The Fourier transform is a mathematical function that converts the time domain forms of a signal (produced by most measuring and graphical display devices) to a frequency domain representation or spectrum. The input to the DFT is a sequence of digitized amplitude values (xo. x1. x2. …. xN- 1) at N discrete points in time. The output is a sequence of amplitude values ((Ao. A1. A2. … AcNl2)-1) at N/2 discrete frequencies. The highest frequency, (Nl2)-1, is equal to half the sampling rate (=1/ (2T)), where T is the sampling period. The output could be plotted as a magnitude spectrum. Frequency composition of a signal changes over time and can be plotted as a sound spectrogram using spectrum generation and analysis software (Avisoft SAS PRO, Raven 1.4, Sound Ruler). The spectrograms produced by sound plot have frequency on the vertical axis versus time on the horizontal; the amplitude of a given frequency component at a given time is represented by color combinations as per the parameters of sub-menus of the software. 4.2 Micro-scale analysis of calls Furthermore, microanalysis of a spectrogram could be achieved by slicing the spectrogram (Raven 1.4). A spectrogram slice view is a plot of relative intensity versus frequency at a particular point in time within a signal. A spectrogram slice represents a vertical cross section through a spectrogram at a single time, but rotated 90° so that the frequency axis is horizontal. In fact, a spectrogram is built of a series of spectrogram slices stacked side by side (with their frequency axis running vertically). Whereas a spectrogram view shows a series of slices at successive points in time and represents power at each frequency by a color (by default, grayscale) value, a spectrogram slice view shows only one slice and represents power at each frequency on a line graph. Using a sound ruler, pulse rate, call rate, dominant frequency, fundamental frequency, etc., are recorded. Classifiers and filters are used to sort particular elements or symbols of a call. Generally, sound spectra are discrete in most species, and such diagnostic characteristics of the spectral pattern can be used for the identification of a species. Sound-based identification, classification of call, and spectral parameters can be developed as a strong tool in taxonomy as sono-taxonomy. Sonotaxonomy may be used independently for the identification and categorization of various taxa or as a supporting tool to the conventional taxonomy.

1.12 Summary

Classification is the curious outcome of human mind which aims to put things in an orderly way where similarity of one kind or another forms the basis of all classification.Taxonomy is the study of naming of organisms(nomenclature) and systemic placing of them into groups(taxa) on the basis of certain relationship between organisms. The binomial system of classification was popularized by Swedish Botanist and Physician Carlous Linnaeus.The value of binomial nomenclature system derives primarily from its economy, its widespread use and the uniqueness and stability of names it generally favors. Species is one of the basic units of biological classification and a taxonomic rank. There are various concepts of species. ICZN is a widely accepted convention in zoology that rules the formal scientific naming of animals.Cytotaxonomy, Moleculartaxonomy and Sonotaxonomy are the latest appraoaches to classify animals.

1.13 Glossory

- **ICZN**:International Code of Zoological Nomenclaure.
- **Cytotaxonomy**:Branch of Biology dealing with relationship and classification of organism using comparative studies of chromosomes.
- **Moleculartaxonomy:**Classification of organisms on the basis of the distribution and composition of chemical substances in them.
- **Sonotaxonomy:** Identification and categorization of organisms on the basis of acoustics.
- **Agamospecies:** Asexual lineages, uniparental organisms (parthenogens and apomicts) that cluster together in term of their genome, may be secondarily uniparental from biparental ancestors.
- **Biological Species:** Mendelian population of sexually reproducing organisms, interbreeding natural populations isolated from other such groups, depending upon reproductive isolating mechanisms.
- **Cladistic Species**: Set of organisms between speciation events or between speciation and extinction events, or a segment of a phylogenetic lineage between modes.

- **Cohesion Species:** Evolutionary lineage bounded by cohesion mechanisms that causes reproductive communities, particularly genetic exchange and ecological interchangeability.
- **Composite Species:** All organisms belonging to an internodon and their descendents until a subsequent internodon (internodon is a set of organisms whose parent-child relations are not split.
- **Ecological Species:** A lineage which occupies an adaptive zone minimally different from that of any other lineage in its range and which evolves separately from all lineages outside its range.
- **Evolutionary Species:** A lineage (ancestral- descendent sequence of populations) evolving separately from others and with its own unitary evolutionary role and tendencies.
- **Evolutionary significant unit:** A population (or group of population) that is substantially reproductively isolated from other conspecific population units and represents as important component in the evolutionary legacy of the species.
- **Geological concordance:** Population subdivisions concordantly identified by multiple independent genetic units constitute the population units worthy of recognition as phylogenetic taxa.
- **Genetic Species:** Group of organisms that may inherit characters from each other, common gene pool, reproductive community that forms a genetic unit.
- **Genotypic cluster definition**: Clusters of monotypic or polytypic biological entities, identified using morphology or genetics, forming groups that have few or no intermediates when in contact.
- **Hennigian species**: A tokogenetic community that arises when a stem species is dissolved into two new species and ends when it goes extinct or speciates.
- **Internodal species**: Organisms are conspecific in virtue of their common membership of a part of a genealogical network between two permanent splitting events or a splitting event and extinction.
- **Morphological species**: Similar to typological species concept of Linnaeus; species are the smallest groups that are consistently and persistently distinct and distinguishable by ordinary means.

- **Nominalistic species**: Only individuals exist and nothing more. Species have no actual existence in nature.
- **Non-dimensional Species:** Species delimitation in a non-dimensional system (a system without the dimensions of space and time).
- **Nothospecies:** Species formed from the hybridization of two distinct parental species, often by polyploidy.
- **Phenetic species:** A cluster of characters that statistically co-vary, a family resemblance concept in which possession of most characters is required for inclusion in a species, but not all. A class of organisms that share most of a set of characters.
- **Phylogenetic species:** A species is the smallest diagnosable cluster of individual organisms within which there is a parental pattern of ancestry and descent.
- **Recognition species**: A species is that most inclusive population of individuals, biparental organisms which share a common fertilization system.
- **Reproductive competition species**: The most extensive units in the natural economy such that reproductive competition occurs among their parts.
- **Successional species**: Arbitrary anagenetic stages in morphological forms, mainly in the palaeontological records.
- **Taxonomic species:** Specimens considered by a taxonomist to be a member of a kind on the evidence or on the assumption that they are as alike as their offspring of hereditary relatives within a few generations.

1.14 Self learning Exercises

Section A

1.What is the difference between classification and nomenclature?

2.Give the main points of Binomial Nomenclature.

3.Define Species.

4.Give the biological concepts of Species.

5.What are Cladistic Species?

6.Write a short note on ICZN.

7.What is Cytotaxonomy?

Section B

1.Explain the term Sonotaxonomy.

2.Give the 'value' of Binomial Nomenclature.

3.Explain Evolutionary concept of Species.

4.Write about any four different types of species you have studied.

Section C

1.Write in detail about ICZN enumerating about its preamble,code and structure.

2.Give an account of taxonomic procedures and modern trends in taxonomy.

1.15 References

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Unit- 2

Taxonomic characters: types of variations (qualitative and quantitative) within a single population, methods of arriving at taxonomic decisions on species level; preparation and use of taxonomic keys. phylogenetic groups, monophyly, polyphyly and paraphyly, phylogenetic reconstruction, cladistic and related methods, cladistics and cladogram

Structure of Unit

2.0 Objectives

After completing the unit, you will be able to understand about-

- Qualitative and quantitative variations (Mutations and Polygenic Inheritance)
- How to make taxonomic decisions.
- How can we preparation and use the taxonomic keys
- Types of keys
- Some definitions of different phylogenetic groups
- Brief idea about Monophyly, Polyphyly, Paraphyly
- What are Phylogenetic trees and their reconstruction.
- Cladistic and Cladograms

2.1 Introduction

Early Mendelian genetics focused on very simple genetic traits which could be explained by a single gene. By studying animals and the ways in which they mutated, early researchers were able to learn more about the gene which determined particular character. However, by the early twentieth century, people were well aware that most traits are far too complex to be determined by a single gene, and the idea of polygenic inheritance was born. By qualitative variations we meant the variations which are determined by single genes and by quantitative variations we meant the polygenic inheritance.

Qualitative variations

Qualitative variations are determined by single genes. In qualitative variations the introduction of the corresponding genes depends upon the nature of the genetic resources. An important factor in establishing genetic resources is the probability with which a particular gene is conserved. A qualitative trait is expressed qualitatively, which means that the phenotype falls into different categories. The pattern of inheritance for a qualitative trait is typically monogenetic, which means that the trait is only influenced by a single gene. Inherited diseases caused by single mutations are good examples of qualitative traits. Another is blood type. The environment has very little influence on the phenotype of these traits.

Mutation is the example of process resulting in qualitative variations at species level.

Mutation

A **mutation** is a permanent change of the nucleotide sequence of the genome of an organism, virus, or extrachromosomal DNA or other genetic elements. Mutations result from damage to DNA which is not repaired or to RNA genomes typically caused by radiation or chemical mutagens, errors in the process of replication, or from the insertion or deletion of segments of DNA by mobile genetic elements. Mutations may or may not produce discernible changes in the observable characteristics (phenotype) of an organism. Mutations play a part in both normal and abnormal biological processes including: evolution, cancer, and the development of the immune system, including junctional diversity.

Mutation can be caused by several different types of change in sequences. Mutations in genes can have no effect, alter the product of a gene, or prevent the gene from functioning properly or completely. One study on genetic variations between different species of *Drosophila* shows that, if a mutation changes a protein produced by a gene, the result is likely to be harmful, with an estimated 70 percent of amino acid polymorphisms that have damaging effects, and the remainder being either neutral or weakly beneficial.

Mutations can involve the duplication of large sections of DNA, usually through genetic recombination. These duplications are a major source of raw material for evolving new genes. Most genes belong to larger families of genes of shared ancestry. New genes are produced by several methods, commonly through the duplication and mutation of an ancestral gene, or by recombining parts of different genes to form new combinations with new functions.

The human eye uses four genes to make structures that sense light: three for colour vision and one for night vision; all four arose from a single ancestral gene. Another advantage of duplicating a gene or even an entire genome is that this increases redundancy; this allows one gene in the pair to acquire a new function while the other copy performs the original function. Other types of mutation occasionally create new genes from previously noncoding DNA.

A butterfly may produce offspring with new mutations. The majority of these mutations will have no effect; but one might change the colour of one of the butterfly's offspring, making it harder or easier for predators to see. If this colour change is advantageous, the chance of this butterfly's surviving and producing its own offspring are a little better, and over time the number of butterflies with this mutation may form a larger percentage of the population.

Nonlethal mutations accumulate within the gene pool and increase the amount of genetic variation. The abundance of some genetic changes within the gene pool can be reduced by natural selection, while other "more favourable" mutations may accumulate and result in adaptive changes.

Neutral mutations are defined as mutations whose effects do not influence the fitness of an individual. These can accumulate over time due to genetic drift. It is believed that the overwhelming majority of mutations have no significant effect on an organism's fitness. Also, DNA repair mechanisms are able to mend most changes before they become permanent mutations, and many organisms have mechanisms for eliminating otherwise-permanently mutated somatic cells. Beneficial mutations can improve reproductive success.

Classification of mutation types

Four classes of mutations are -

(1) Spontaneous mutations (molecular decay)

(2) Mutations due to error prone replication bypass of naturally occurring DNA damage (called error prone translesion synthesis)

(3) Errors introduced during DNA repair

(4) Induced mutations caused by mutagens

Scientists may also deliberately introduce mutant sequences through DNA manipulation for the sake of scientific experimentation

Spontaneous mutation

Spontaneous mutations on the molecular level can be caused by-

- Tautomerism — A base is changed by the repositioning of a hydrogen atom, altering the hydrogen bonding pattern of that base, resulting in incorrect base pairing during replication.
- Depurination — Loss of a purine base (A or G) to form an apurinic site (AP site).
- Deamination — Hydrolysis changes a normal base to an atypical base containing a keto group in place of the original amine group.
- Slipped strand mispairing — Denaturation of the new strand from the template during replication, followed by renaturation in a different spot ("slipping").

Error prone replication by-pass

The majority of spontaneously arising mutations are due to error prone replication (translesion synthesis) past a DNA damage in the template strand. As described in the article DNA damage (naturally occurring), naturally occurring DNA damages arise about 60,000 to 100,000 times per day per mammalian cell. In mice, the majority of mutations are caused by translesion synthesis.

Errors introduced during DNA repair

Naturally occurring double-strand breaks occur at a relatively low frequency in DNA and their repair often causes mutation. Non-homologous end joining is a major pathway for repairing double-strand breaks. Non-homologous end joining involves removal of a few nucleotides to allow somewhat inaccurate alignment of the two ends for rejoining followed by addition of nucleotides to fill in gaps.

Induced mutation

Induced mutations on the molecular level can be caused by:-

- Chemicals - Hydroxylamine, Base analogs, Alkylating agents, Agents that form DNA adducts, DNA intercalating agents, DNA crosslinkers, Nitrous acid
- Radiation - Ultraviolet radiation (UV light) can induce adjacent pyrimidine bases in a DNA strand to become covalently joined as a pyrimidine dimer. UV radiation, in particular longer-wave UVA, can also cause oxidative damage to DNA.

Classification of mutation types (On the basis of structure of genes)

- **Small-scale mutations**- These mutations affects a small gene in one or a few nucleotides, including:
  - **Point mutations**, often caused by chemicals or malfunction of DNA replication, exchange a single nucleotide for another. These changes are classified as transitions or transversions. Most common is the transition that exchanges a purine for a purine (A ↔ G) or a pyrimidine for a pyrimidine, (C ↔ T). A transition can be caused by nitrous acid, base mis-pairing, or mutagenic base analogs such as 5-bromo-2-deoxyuridine (BrdU). Less common is a transversion, which exchanges a purine for a pyrimidine or a pyrimidine for a purine (C/T ↔ A/G). An example of a transversion is the conversion of adenine (A) into a cytosine (C). A point mutation can be reversed by another point mutation, in which the nucleotide is changed back to its original state (true reversion) or by second-site reversion (a complementary mutation elsewhere that results in regained gene functionality).
  - **Insertions** add one or more extra nucleotides into the DNA. They are usually caused by transposable elements, or errors during replication of repeating elements
  - **Deletions** remove one or more nucleotides from the DNA. Like insertions, these mutations can alter the reading frame of the gene. In general, they are irreversible.
- **Large-scale mutations**- If mutations occurs in chromosomal structure, including:

- **Amplifications** (or gene duplications) leading to multiple copies of all chromosomal regions, increasing the dosage of the genes located within them.
- **Deletions** of large chromosomal regions, leading to loss of the genes within those regions.
- Mutations whose effect is to put side by side previously separate pieces of DNA, potentially bringing together separate genes to form functionally distinct fusion genes (e.g., bcr-abl). These include:
    - **Chromosomal translocations**: interchange of genetic parts from nonhomologous chromosomes.
    - **Interstitial deletions**: an intra-chromosomal deletion that removes a segment of DNA from a single chromosome, thereby apposing previously distant genes.
    - **Chromosomal inversions**: reversing the orientation of a chromosomal segment.
- **Loss of heterozygosity**: loss of one allele, either by a deletion or a recombination event, in an organism that previously had two different alleles.

Quantitative variations

A quantitative trait shows continued variation. This is because the trait is the sum of several small effects caused by the gene. An example of this is an animals metabolism, which is under the influence of many different genes. The final products of the metabolism, as for instance milk yield or growth rate, are good examples of quantitative traits. If several small gene effects are present, the phenotype values for a population will typically have a normal distribution. In some cases the phenotype values are not distributed normally, even though the trait has a polygenetic inheritance.

Polygenic inheritance refers to a single characteristic that is controlled by more than two genes. It is also called as multifactorial inheritance. By increasing the number of genes controlling a trait, the number of phenotype combinations also increase, until the number of phenotypes to which an individual can be assigned are no longer discrete, but continuous.

In comparison to qualitative variations quantitative variations are usually the result of an interaction of many genes or combination of genes. It is therefore more or less unsuccessful to attempt to restore such traits from conserved individual genes. As far as quantitative variations are concerned chances are low for the controlled short-term exploitation of a conserved breed. The application of molecular biological techniques should allow characterization of individual genes and even gene combinations responsible for polygenic variations in the future, which would significantly improve the current situation. Such polygenic traits are obtained if entire genomes have been conserved and reactivated although it may not be possible to exploit these genetic combinations in a form isolated from the residual genome.

One easily understood example of quantitative variations is height. People are not just short or tall; they have a variety of heights which run along a spectrum. Height is also influenced by environment; someone born with tall genes could become short due to malnutrition or illness, for example, while someone born with short genes could become tall through genetic therapy. Basic genetics obviously wouldn't be enough to explain the wide diversity of human heights, but polygenic inheritance shows how multiple genes in combination with a person's environment can influence someone's phenotype, or physical appearance.

Skin color is another example of quantitative variations, as are many congenital diseases. The colour of human skin is determined by the amount of dark pigment (melanin) it contains. At least four (possibly more) genes are involved in melanin production; for each gene one allele codes for melanin production, the other does not. The combination of melanin producing alleles determines the degree of pigmentation, leading to continuous variation

Methods of arriving at taxonomic decisions on species level

Taxonomy identifies and enumerates the different components of biological diversity providing basic knowledge. Unfortunately, taxonomic knowledge is far from complete. Taxonomists have named about 1.78 million species of animals, plants and micro-organisms, yet the total number of species is unknown and probably between 5 and 30 million.

Taxonomy is the science of naming, describing and classifying organisms and includes all plants, animals and microorganisms of the world. Using morphological, behavioural, genetic and biochemical observations, taxonomists identify, describe and arrange species into classifications, including those that are new to science.

Species

The various kinds of animals, fungi and plants and microorganisms are called different 'species'. The species shows a real biological difference – a species is defined as a potentially interbreeding group of organisms that can produce viable offspring that themselves can interbreed. Thus animals of two different species, like a horse and a zebra, cannot interbreed, while animals of the same species can. Taxonomists provide unique names for species, labels that can help us find out more about them, and enable us to be sure that we are all talking about the same thing. The given names for organisms can be from many languages, but it is important, for example, when discussing the hedgehog to know whether one is talking about the small spiny insectivore *Erinaceus europaeus*, other members of the same family, cacti of the genus Echinocerus, or the orange fungus *Hydnum repandum*, all of which have the same 'common' name in English. For this reason the Latin 'scientific' name, is given as a unique universal identifier.

The Taxonomic Process

Methods of arriving at taxonomic decisions

First of all the taxonomists begin by sorting specimens to separate sets which they believe to represent species. Once the specimens are sorted the next step is to see whether or not they already have names. This may involve working through identification guides, reading descriptions written perhaps 200 years ago, and borrowing named specimens from museums or herbaria to compare with the sample. Such comparison may involve external characters, need to dissect internal structures, or even molecular analysis of the DNA. If there is no match the specimens may represent a new species, not previously given a name. The taxonomist then has to write a description, including ways in which the new species can be distinguished from others, and make up a name for it, in a Latin format. The name and the description must then be properly published so that other taxonomists from other parts of world can also see what has been done, and be able to identify the species themselves. From finding the specimens to the name appearing in print can take several years.

Preparation and use of taxonomic keys

Taxonomic keys

A key is a device, which when properly constructed and used, enables a user to identify an organism.In lifesciences, an identification key is a printed or computer-aided device that aids the identification of biological entities, such as plants, animals, fossils, microorganisms, and pollen grains. Identification keys are also used in many other scientific and technical fields to identify various kinds of entities, such as diseases, soil types, minerals, or archaeological and anthropological artifacts.

Traditionally identification keys have most commonly taken the form of **single-access keys**. These work by offering a fixed sequence of identification steps, each with multiple alternatives, the choice of which determines the next step. If each step has only two alternatives, the key is said to be **dichotomous**, else it is **polytomous**. Modern **multi-access** or **interactive** keys allow the user to freely choose the identification steps and their order.

At each step, the user must answer a question about one or more features (characters) of the entity to be identified. For example, a step in a zoological key for insect identification may ask about the number of bristles on the rear leg.

The need for taxonomic keys

We share the planet with at least 1.5 million other species. In order to communicate, retrieve, store, and accumulate information about our co-inhabitants, it has been necessary for biologists and others to: (1) identify these organisms; (2) name them; and (3) place the organisms into groups that reflect our current knowledge of their evolutionary relationships. As we know, collectively these activities - identification, nomenclature and classification - make up the discipline of taxonomy.

Construction of a Taxonomic Key

Principles of good key design

Identification errors may have serious consequences in both pure and applied disciplines, including ecology, medical diagnosis, pest control, forensics, etc. Therefore, identification keys must be constructed with great care in order to minimize the incidence of such errors.

Whenever possible, the character used at each identification step should be diagnostic; that is, each alternative should be common to all members of a group of entities, and unique to that group. It should also be differential, meaning that the alternatives should separate the corresponding subgroups from each other. However, characters which are neither differential nor diagnostic may be included to increase comprehension (especially characters that are common to the group, but not unique).

Whenever possible, redundant characters should be used at each step. For example, if a group is to be split into two subgroups, one characterized by six black spots and the other by four brown stripes, the user should be queried about all three characters (number, shape, and color of the markings) — even though any single one of them would be sufficient in theory. This redundancy improves the reliability of identification, provides a consistency check against user errors, and allows the user to proceed even if some of the characters could not be observed. In this case, the characters should be ordered according to their reliability and convenience.

The terminology used in the identification steps should be consistent in meaning and should be uniformly used. The use of alternative terms for the same concept to achieve more "lively prose" should be avoided. Positive statements should be used in preference to negative statements. The wording of the alternatives should be completely parallel sentences.

Geographic distribution characters should be used with caution. Species that have not been observed in a region may still occasionally occur there. Also, the organism may have been transported, particularly to locations near ports and airports, or it may have changed its range (e. g., due to global warming). Identification may be correct even though a species is very rare.

Characteristics used for preparing a Taxonomic Key

The classification of organisms into groups is known as taxonomy. The value of a taxonomy is that it allows biologists to distinguish relationships between different organisms. Taxonomists place organisms within a system of groupings, or taxa (kingdom, phylum, class, order, family, genus and species), which reflect their perceived evolutionary (or phylogenetic) relationships. An outgrowth of a classification system is a taxonomic key, which is a major tool used to identify organisms. Taxonomic keys can commonly be found in "field guide" books used widely by naturalists to identify plants, birds, reptiles, insects, and other organisms.

Process of Classification Organisms

Modern taxonomy emphasizes on distinguishing evolutionary, or Phylogenetic, relationships between different organisms. Biological classification is usually based upon anatomical characteristics of modern and sometimes extinct organisms. Characteristics of organisms that reflect evolutionary relationships are most useful for biological classification. However, similar appearances are not always a reliable indicator of evolutionary relationships. For example the platypus is a semiaquatic creature. It has hair and milk glands like a mammal, a rubbery bill and webbed feet like a bird, and lays leathery eggs in burrows like a reptile. It was very difficult to decide that in which group should the platypus be placed and importance must be given to which characters. Previously during the 1800's, the platypus was placed in different group alternately as taxonomists argued these points. Today it is generally agreed that the presence of hair and milk glands indicate that the platypus is a primitive type of mammal.

The presence of hair and milk glands deemed to be more important to the classification of the platypus than the other features because these traits arise during evolution. When two organisms share a body structure that was passed down from a common ancestor, the traits are referred to as homologous. An example of a homologous structure is the thumb on the hands of chimpanzees and humans, both were inherited from a common primate ancestor. Similarly the milk glands in the platypus and other mammals are believed to have arisen from a common ancestor.

Sometimes similarity in structure can also evolve independently in unrelated different organisms. When different organisms possess body structures that serve similar functions, but which arise independently during evolution, the structures are referred to as analogous. The wings of a bat and a bird are analogous because these organisms did not arise from a common ancestor that possessed wings. Similarly, the webbed feet of the platypus and a duck are now believed to be analogous, having evolved independently to facilitate swimming in water.

Taxonomists are most interested in homologous traits when classifying organisms. Many modern taxonomists now study the genetic code carried in the DNA of organisms to better understand their phylogenetic relationships.

Some anatomical traits often reflect homologous similarities

- **Body symmetry**

  The shape of most animals is either bilaterally or radially symmetrical, although a few primitive organisms are asymmetrical. An object that is said to possess bilateral symmetry if only a single plane will divide the object into two identical halves. In contrast, an object that possesses radial symmetry can be divided by more than two planes that yield identical halves. Many straight lines could be drawn through the star, all of which will produce identical halves.

- **Type of body skeleton**

  The skeleton provides a framework that supports the internal organs, and to which are attached the muscles and ligaments that make possible body movements. Animals such as a worm or sea anemone do not possess a rigid skeleton. The bodies of these organisms are supported by the pressure exerted by internal fluids, referred to as a hydroskeleton.

  Some organisms, such as insects and spiders evolved a hard outer skeleton called an exoskeleton. An exoskeleton provides protection from predators and a waterproof covering that is crucial in an arid environment.

- Animals such as humans evolved an internal framework called an **endoskeleton**. The endoskeleton is composed of a calcified bony matrix, the endoskeleton of vertebrates is capable of enlarging with the organism as growth and development progress.

- **Segmentation; multiple body units**

  Many organisms are composed of distinct units called as segments. In simpler organisms, like earthworms, most of the segments are identical while in more advanced organisms certain segments evolved specialized functions and structures, such as the head, thorax and abdomen of an insect.

- **Body covering**

  The body covering like the presence of fur, feathers or scales are other useful characteristics. Some animals possess a **shell** along with other body coverings, which is different than an exoskeleton.

- **Presence of body appendages**

  The presence of various body appendages like legs, tentacles and antennae are examples of some of the various appendages that animals possess. These appendages serve many different functions like movement, sensory function.

Types of taxonomic keys

A taxonomic key is a device, which when properly constructed and used, enables a user to identify an organism. There are two types of keys-

(a) Dichotomous

(b) Polyclave

Dichotomous keys. (di - two; chotomy - forked) - These keys, which are the most common, were probably first published by Jean Baptiste-Lamarck in 1778. They consist of a series of paired statements, termed couplets, that describe some feature of the organism. The statements, or leads, are in direct contrast (i.e., mutually exclusive). To use the key, begin with the first couplet and select the statement that best fits our specimen. This will direct us to another couplet and ultimately provide the identity of our specimen.

Writing of dichotomous key

First collect our data by: (a) laying out the animals to be keyed infront of us; and/or (b) recording data on note cards or in a computer spreadsheet or database; and/or (c) creating a table listing the species to key along one side and the characters to study along the other side. Once we have collected our data, start to group the objects. It is best to start with a feature that separates the things to be keyed into two groups of similar number and then subdivide these groups until individuals are distinguished.

Polyclave/Random Access/Synoptic Keys.

Second type of key is termed multiple access or polyclave or synoptic key. The advantage of these keys is that they allow the user to enter the key at any point. These keys are a relatively new alternative to dichotomous keys and are becoming increasingly popular, especially because of the ease of computerizing them.

Identifying organisms with a polyclave is a process of elimination. In a written polyclave key there is a series of characters and character states. Each state is followed by a number or code for the species that possess that feature. The user selects any character and then copies down the list of species that possess the feature. Then the user selects another character and eliminates any species not common to both lists. This process continues until the specimen is identified.

Advantages

The advantages of a polyclave (multiple-access) key are –

- Easy to use;
- Multi-entry - meaning the user can start anywhere. This is a significant advantage because the user can rely on characters that are most easy to

observe, rather than having to deal with characters that may not be present in the specimen or are poorly developed;

- Order-free - meaning the user can work in any direction with character;
- Faster; and
- Easily computerized. In fact, these keys are most commonly used in this form. Paper versions are typically large and unwieldy because each character needs to list all possible taxa.

A taxonomic key is a tool that is used to identify different types of organisms. An example of a key that could be used to identify different types of microorganisms is provided below. A taxonomic key contains a series of statements that describe the traits of the organisms, as shown in the sample key presented below. The statements are grouped into 2 or 3 alternative descriptions (such as 1a and 1b) for each trait. Each group of statements represents only single trait. To use the key, appropriate traits of the unknown organism are identified while following the steps of the key. When the description in the key and trait of the organism match, we are instructed to proceed to another set of descriptions or given an identification. Correctly following the steps of the key eventually leads to identification of the unknown organism.

Step number	Description of trait	Instruction	Classification
1a.	Organism is green............................	Go to 2	
1b.	Organism is not green.......................	Go to 3	
2a.	Cells contain internal organelles..		Algae
2b.	Cells do not contain organelles..		Cyanobacteria
3a.	Cells are not filamentous...................	Go to 4	
3b.	Cells of organism are filamentous, round spores may be present....................................		Fungi
4a.	Organism is multicellular..		Animal
4b.	Organism is unicellular..		Protozoa

Working in groups, obtain one specimen of each species, and construct a dichotomous key to the specimens. Do not use body size as a characteristic, since the key must be useful for small specimens of species that do become large. Limit the use of color as a character. Color may fade in preserved specimens, and may vary among individuals. Use morphological characters such as body shape, position of fins, presence or absence of scales or spines in fin supports, etc.

Phylogenetic groups

- Clade – a group composed of an ancestor and all of its descendants.
- Monophyletic group -- a group composed of an ancestor and all of its descendants (=clade). Example: Reptilia is a monophyletic group if (and only if) it includes birds.
- Paraphyletic group – a group composed of an ancestor and only some of its
- descendants, where the missing ones have been placed in another group. Example: "Reptilia" is a paraphyletic group if birds are excluded from it. The names of paraphyletic groups are often placed in quotation marks by convention.
- Taxon – a named group and its constituent members. Normally a taxon will be a named clade.
- Phylogenetic definition (of a group) – a definition for a group that is based on
- common ancestry. Example - Tetrapoda is the group composed of the last common ancestor of living amphibians and amniotes and all taxa more closely related to that clade than to lungfish.
- Character-based definition (apomorphy-based definition) – a definition for a group where membership is defined by possession of a derived trait. Example - Tetrapoda is the group containing living amphibians and amniotes that have evolved digits on the fore and hind limbs.
- Diagnosis – the characters that can be used to recognize members of a group, regardless of how the group is defined.
- Crown group definition – a phylogenetically defined group that is composed of all the descendants of the last common ancestor of the living members of the group. Example-Tetrapoda is the group consisting of the last common ancestor of living amphibians and amniotes and all the descendants of that ancestor.
- Stem group definition – a phylogenetically defined group that is composed of all the taxa that are more closely related to the living members of the group than to the living members of other groups. Example - Tetrapoda is the group of taxa more closely related to living amphibians and amniotes than to lungfish or coelacanths.

A taxon is any group of organisms, a monophyletic taxon is one that includes a group of organisms descended from a single ancestor , whereas a polyphyletic taxon is composed of unrelated organisms descended from more than one ancestor. A monophyletic taxon is defined as one that includes the most recent common ancestor of a group of organisms, and all of its descendents. Such groups are sometimes called holophyletic. It is also possible to recognize a paraphyletic taxon as one that includes the most recent common ancestor, but not all of its descendents. A polyphyletic taxon is defined as one that does not include the common ancestor of all members of the taxon.

The best example of monophyletic taxa is **Mammalia** and **Aves** (modern birds), recognizable as all feathered vertebrates, respectively. Paraphyletic taxa include **Pisces** and **Reptilia**, the former comprising all ray-finned fish but excluding terrestrial descendants of fleshy-finned fish, and the latter comprising all scaly tetrapods but excluding mammals and birds with their modified scales. Polyphyletic taxa once in common usage include **Agnatha** for jawless lampreys and hagfish, and **Insectivora** for various toothless, insect-eating mammals such as anteaters and armadillos. Note that these latter groups are defined by 'absence' characters, and that although redwood trees are jawless and toothless, they are not included in those taxa.

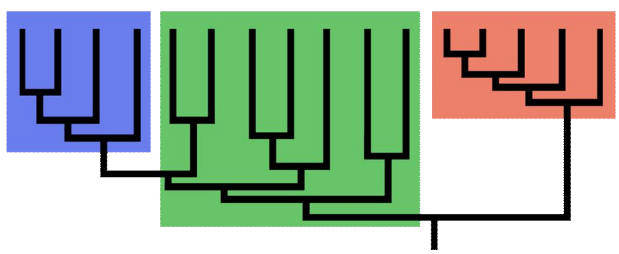

Figure - Phylogenetic tree, the left and right groups represent monophyletic groups, the central is paraphyletic.

Monophyly

Willi Hennig (1966:148) defined monophyly as groups based on synapomorphy (in contrast to paraphyletic groups, based on symplesiomorphy, and polyphyletic groups, based on convergence). Some define monophyly to include paraphyly as any two or more groups sharing a common ancestor. However, this broader definition encompasses both monophyletic and paraphyletic groups as defined above. Therefore, most scientists today restrict the term "monophyletic" to refer to groups consisting of all the descendants of one hypothetical common ancestor. However, when considering taxonomic groups such as genera and species, the most appropriate nature of their common ancestor is unclear. Assuming that it would be one individual or mating pair is unrealistic for sexually reproducing species, which are by definition interbreeding populations.

A monophyletic group is a group of organisms which forms a clade, meaning that it consists of an ancestral species and all its descendants. The term is synonymous with the uncommon term holophyly. Monophyletic groups are typically characterized by shared derived characteristics called as synapomorphies.

Monophyly is contrasted with paraphyly and polyphyly. A paraphyletic group consists of all of the descendants of a common ancestor minus one or more monophyletic groups. A paraphyletic group is thus 'nearly' monophyletic. A polyphyletic group is characterized by convergent features or habits (e.g., night-active primates, trees, aquatic insects); the features by which the group is differentiated from others are not inherited from a common ancestor.

Example: Mammalia and Aves (modern birds).

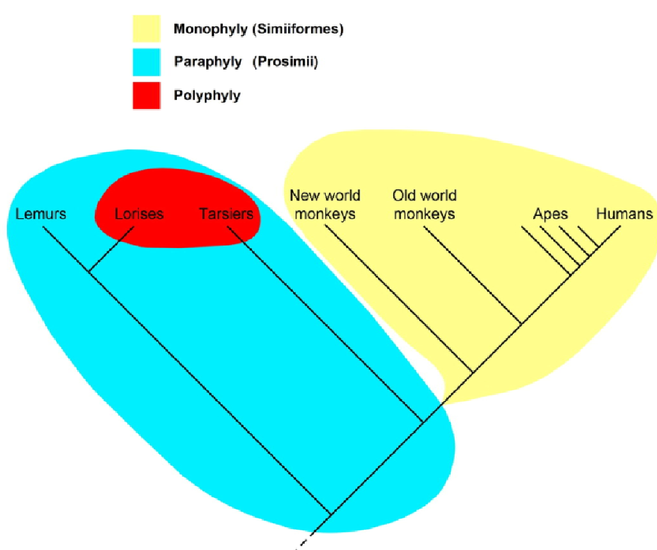

Figure - Cladogram of the primates, showing a monophyletic group (the simians, in right side), a paraphyletic group (the prosimians, in left, including the oval patch), and a polyphyletic group (the night-active primates, the lorises and the tarsiers, in oval patch)

Polyphyly

A polyphyletic ("of many races") group is characterized by one or more phenotypes which have converged or reverted so as to appear to be the same but which have not been inherited from common ancestors. Alternatively, polyphyletic is used to describe multiple ancestral sources regardless of convergence.

Polyphyly is usually avoided in many schools of taxonomy, the existence of polyphyletic groups in a classification is discouraged. Monophyletic groups (that is, clades) are considered by these schools of thought to be the most important grouping of organisms.

Polyphyletic groups can often be delimited in terms of clades, for example "the flying vertebrates consist of the bat, bird, and pterosaur clades". Because polyphyletic groups can frequently be defined as a sum of clades, some consider them less fundamental than monophyletic clades.

Examples:

- The group consisting of warm-blooded animals is polyphyletic because it contains both mammals and birds, but the most recent common ancestor of mammals and birds was cold-blooded. Warm-bloodedness evolved separately in the ancestors of mammals and the ancestors of birds.
- Other examples of polyphyletic groups are protozoans and algae.

Paraphyly

In taxonomy, paraphyletic group means if it consists of all the descendants of the last common ancestor of the group's members minus a small number of monophyletic groups of descendants, typically just one or two such groups. Such a group is said to be paraphyletic with respect to the excluded groups. The term is commonly used in phylogenetics and in linguistics.

Paraphyly is common in speciation, leaving the ancestral population a paraspecies. The reptiles, which as traditionally defined, is paraphyletic with respect to the mammals and birds: it contains the last common ancestor of the reptiles—including the extant reptiles as well as the extinct mammal-like reptiles—along with all descendants of that ancestor except for mammals and birds. Other commonly recognized paraphyletic groups include fish and lizards.

Monophyletic groups are said to be include all the descendants of a common ancestor. A paraphyletic group is a monophyletic group from which one or more subsidiary clades (monophyletic groups) is excluded to form a separate group. For example, dinosaurs are paraphyletic with respect to birds because birds possess many features that dinosaurs lack and occupy a distinctive niche.

Examples:

- The order Artiodactyla (even-toed ungulates), because it excludes Cetaceans (whales, dolphins, etc.). In the ICZN Code, the two taxa are orders of equal rank. Molecular studies, however, have shown that the Cetacea descend from the Artiodactyl ancestors, although the precise phylogeny within the order remains uncertain. Without the Cetacean descendants the Artiodactyls must be paraphyletic.

- The class Reptilia, because it excludes birds (class Aves) and mammals (class Mammalia). In the ICZN Code, the three taxa are classes of equal rank. However, mammals hail from the mammal-like reptiles and birds are descended from the dinosaurs (a group of Diapsida), both of which are reptiles.

- Alternatively, reptiles are paraphyletic because they gave rise to (only) birds. Birds and reptiles together make Sauropsids.

- Osteichthyes, bony fish, are paraphyletic because they include Actinopterygii (ray-finned fish) and Sarcopterygii (lungfish, etc.). However, tetrapods are descendants of the nearest common ancestor of Actinopterygii and Sarcopterygii, and tetrapods are not in Osteichthyes, hence Osteichthyes is paraphyletic

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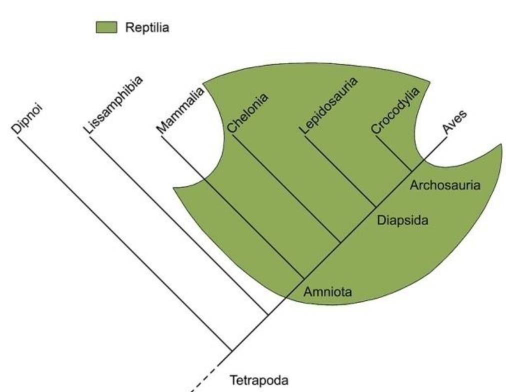


Figure - The traditional class Reptilia (shaded field) is a paraphyletic group comprising all amniotes other than the mammals and birds. The clade Amniota, in contrast, is monophyletic

The phylogenetic species concept requires species to be monophyletic, but paraphyletic species are common in nature. Research indicates that 20 percent of all animal species and between 20 and 50 percent of plant species are paraphyletic. As speciation typically occurs paraphyletically by populations branching off from the mother species without the latter going extinct.

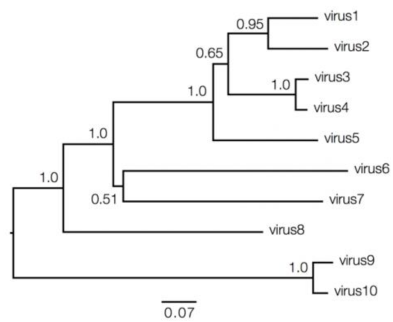
When the appearance of significant traits has led a subclade on an evolutionary path very divergent from that of a more inclusive clade, it often makes sense to study the paraphyletic group that remains without considering the larger clade. For example, the Neogene evolution of the Artiodactyla (even-toed ungulates, like deer) has taken place in an environment so different from that of the Cetacea (whales, dolphins, and porpoises) that the Artiodactyla are often studied in isolation even though the cetaceans are a descendant group.

Important:-

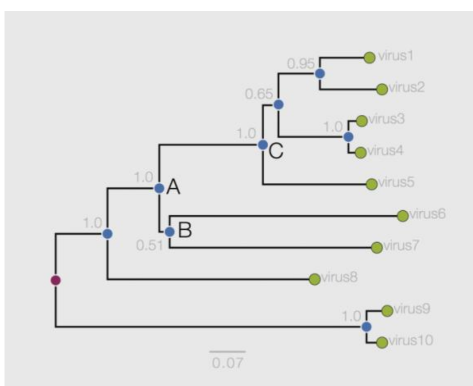
- Quadrupedal archosaurs are not a paraphyletic group. Bipedal dinosaurs like *Eoraptor*, ancestral to quadrupedal ones, were descendants of the last common ancestor of quadrupedal dinosaurs and other quadrupedal archosaurs like the crocodilians.
- Amphibious fish are polyphyletic, not paraphyletic. Although they appear similar, several different groups of amphibious fishes such as mudskippers and lungfishes evolved independently in a process of convergent evolution in distant relatives faced with similar ecological circumstances.
- Flightless birds are polyphyletic because they independently (in parallel) lost the ability to fly.
- Animals with a dorsal fin are not paraphyletic, even though their last common ancestor may have had such a fin, because the Mesozoic ancestors of porpoises did not have such a fin, whereas pre-Mesozoic fish did have one.

Phylogenetic tree

Phylogenetics trees have a lot of information about the inferred evolutionary relationships between a set of organisms. Decoding that information is not always straightforward and requires some understanding of the elements of a phylogeny and what they represent. Here is an example fictional phylogeny of virus.



In this figure the horizonal dimension gives the amount of genetic change. The horizonal lines are branches and represent evolutionary lineages changing over time. The longer the branch in the horizonal dimension, the larger the amount of change. The bar at the bottom of the figure provides a scale for this. In this case the line segment with the number '0.07' shows the length of branch that represents an amount genetic change of 0.07. The units of branch length are usually nucleotide substitutions per site – that is the number of changes or 'substitutions' divided by the length of the sequence. The vertical dimension in this figure has no meaning and is used simply to lay out the tree visually with the labels evenly spaced vertically. The vertical lines therefore simply tells us which horizontal line connects to which and how long they are is irrelevent.

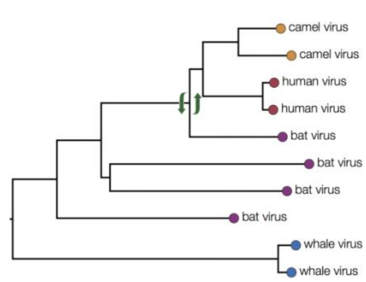


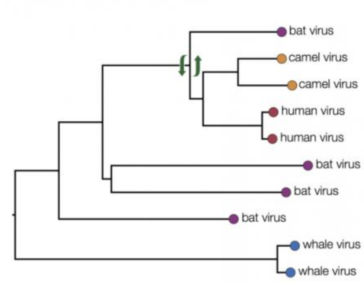
Now, we will consider tree structure itself. This can be broken down into nodes (represented in the above tree in form of circles) and branches (the lines connecting them). There are two types of nodes; external nodes, also called 'tips' or 'leaves', and internal nodes. The tips are represented by circles at ends and these represent the actual viruses sampled and sequenced. These are our data and we usually know information about these, beyond the actual sequence, such as when they were collected, what host they were in, where that host was found, clinical features of the disease. The internal nodes are represented by connectors circles and these represent putative ancestors for the sampled viruses. Ancestors in this context is an infected host at sometime in the past that in turn infected 2 or more new hosts producing chains of infections that lead to the sampled viruses. The branches then represent this chain of infections. This tree is rooted which suggests we know where the ultimate common ancestor of all the sampled viruses was the leftmost first downward circle). This gives the tree an order of branching events in the horizonal dimension - Ancestor 'A' exists prior to ancestors 'B' and 'C' and time is flowing from left to right.

Reconstructing phylogenetic tree

When the true evolutionary history is not known, a variety of tests can be used to assess the results of a phylogenetic reconstruction method. When the reconstruction method has selected the ideal tree for a dataset, that tree should represent all of the underlying data. The reconstructed phylogenetic tree exhibits all of the underlying data perfectly, or they could simply be an average of multiple conflicting datasets.

Each method used to construct phylogenetic trees has its advantages and disadvantages. Some researchers favor one method over another on principle. Now we will reconstruct the above phylogenetic tree, here is the same tree as above but with the tips are labelled by the type of host/source from which they were isolated. Here structures with viruses are grouped according to their host. For example the two viruses from humans have a closer common ancestor with each other than they do with any other virus. At first glance it may seem that human viruses are more closely related to bat viruses than camel viruses because they sit next to each other but remember that the vertical dimension is meaningless. In fact the viruses can be swapped round at any internal node and the tree is the same.





In fact the human and camel viruses are more closely related to each other and equally related to the bat viruses. This means we can't say from this tree if camels are the source of the human viruses or vice-versa, or just as likely, bats are independently the source of both human and camel outbreaks. We can however suggest that bats were the ultimate source of both camel and human viruses because of the much greater diversity of bat viruses. Another way to look at this is that the common ancestors of the human and camel viruses lie within the diversity of all the bat viruses.

Cladistic and related methods

Synapomorphies are the basis for cladistics

Cladistics is a particular method of hypothesizing relationships among organisms. Like other methods, it has its own set of assumptions, procedures, and limitations. Cladistics is now accepted as the best method available for phylogenetic analysis, for it provides an explicit and testable hypothesis of organismal relationships.

The basic idea behind cladistics is that members of a group share a common evolutionary history, and are "closely related," more so to members of the same group than to other organisms. These groups are recognized by sharing unique features which were not present in distant ancestors. These shared derived characteristics are called synapomorphies.

It is not enough for organisms to share characteristics, in fact two organisms may share a great many characteristics and not be considered members of the same group. For example, consider a jellyfish, starfish, and a human; which two are most closely related? The jellyfish and starfish both live in the water, have radial symmetry, and are invertebrates, so you might suppose that they belong together in a group. This would not reflect evolutionary relationships, however, since the starfish and human are actually more closely related. It is not just the presence of shared characteristics which is important, but the presence of shared derived characteristics. In the example above, all three characteristics are believed to have been present in the common ancestor of all animals, and so are trivial for determining relationships, since all three organisms in question belong to the group "animals." While humans are different from the other two organisms, they differ only in characteristics which arose newly in an ancestor which is not shared with the other two.

Cladistics Analysis

There are three basic assumptions in cladistic analysis:

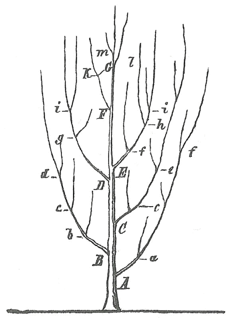
1. Any group of organisms are related by descent from a common ancestor.

2. There is a bifurcating pattern of cladogenesis.
3. Change in characteristics occurs in lineages over time.

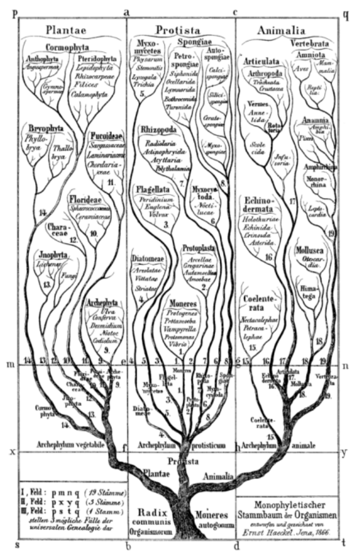
The first assumption is a general assumption made for all evolutionary biology. It essentially means that life arose on earth only once, and therefore all organisms are related in some way or other. Because of this, we can take any collection of organisms and determine a meaningful pattern of relationships, provided we have the right kind of information. Again, the assumption states that all the diversity of life on earth has been produced through the reproduction of existing organisms.

The second assumption is the most controversial perhaps that is, the new kinds of organisms may arise when existing species or populations divide into exactly two groups. There are many biologists who hold that multiple new lineages can arise from a single originating population at the same time, or near enough in time to be indistinguishable from such an event. It is not currently known how often this has actually happened. The other objection raised against this assumption is the possibility of interbreeding between distinct groups. This, however, is a general problem of reconstructing evolutionary history, and although it cannot currently be handled well by cladistic methods, no other system has yet been devised which accounts for it.

The final assumption that characteristics of organisms change over time is the most important assumption in cladistics. When characteristics changes only then we are able to recognize different lineages or groups. The "original" state of the characteristic plesiomorphic and the "changed" state apomorphic. The terms "primitive" and "derived" have also been used for these states.



Branching tree diagram from Heinrich Georg Bronn'swork,(1858)



Phylogenetic tree suggested by Haeckel(1866)

Methodology of a Cladistic Analysis

Cladograms construction

Outline of the steps necessary for completing a cladistic analysis-

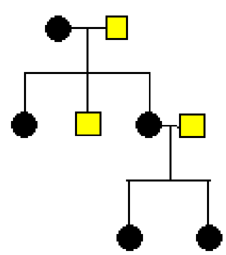
1. **Choose the taxa** whose evoutionary relationships we have to present. These taxa must be clades for probable results.
2. **Determine the characters** (features of the organisms) and examine each taxon to determine the character states (decide whether each taxon does or does not have each character). All taxa must be unique.
3. **Determine the polarity of characters** (whether each character state is original or derived in each taxon).
4. **Group taxa by synapomorphies** (shared derived characteristics) not plesiomorphies (original, or "primitive", characteristics).
5. **Build cladogram**, which is not an evolutionary tree, following these rules:

- All taxa go on the endpoints of the cladogram, never at nodes.
- All cladogram nodes must have a list of synapomorphies which are common to all taxa above the node (unless the character is later modified).
- All synapomorphies appear on the cladogram only once unless the character state was derived separately by evolutionary parallelism.

Implications of Cladistics

Understanding branching diagrams

The cladograms give an output from a phylogenetic analysis is a hypothesis of relationship of different taxa. This hypothesis can be represented by a cladogram, a branching diagram. Cladograms bear a lot in common with the notion of family trees. In a family tree we trace back our ancestry. For example, in the family tree below, the ancestors of all the rest of the family are the initial dot and square. These ancestors give rise to three children, one of which mates and has two children. We can all trace our lineages back to one set of ancestors.

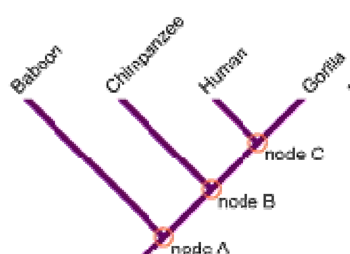


All species have ancestors too. So, for example, sometime in the past an ancestral species (father) of *Homo sapiens* walked the earth. This ancestor went extinct (died), but left descendent species (children). In family trees, we can talk coherently about real ancestors. In biology, the ancestors are often gone sometimes without a trace. All we have left are the children. Reading cladograms is much like reading a family tree. Both are rich in information. Cladograms, like family trees, tell the pattern of ancestry and descent. Unlike family trees, ancestors in cladistics ideally give rise to only two descendent species. Also unlike family trees, new species form from splitting of old species. In speciation the formation of the two descendent species is called a splitting event. The ancestor is usually assumed to "die" after the splitting event.

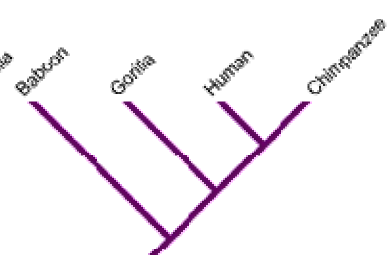
In the first tree, labelled *A*, notice the small circles. These mark the nodes of the tree. The stems of the tree end with the taxa under consideration. At each node a splitting event occurs. The node therefore represents the end of the ancestral taxon, and the stems, the species that split from the ancestor. The two taxa that split from the node are called sister taxa. They are called sister taxa because they are like the siblings from the parent or ancestor. The sister taxa must each be more closely related to one another than to any other group because they share a close common ancestor. In the same way, you are most closely related to your siblings than to anyone else since you share common parents. Lets focus on *node C* in *A*. At the node, the ancestor goes extinct but leaves two siblings hypothesized to be humans and gorillas. Humans and gorillas are sister taxa and are more closely related to one another than either is to chimpanzees or baboons.

At node B the ancestor of the humans and gorillas split from the chimpanzees. Therefore the chimpanzees sister taxon is the human/gorilla ancestor. A sister taxon can be an ancestor and all its descedents. We call an ancestor plus all its descendents a clade. A cladogram shows us hypothesized clades.

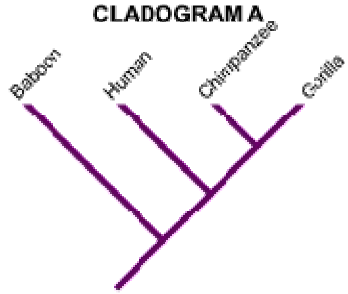
Finally we come to *node A*. Here, we find the splitting event that led to the baboons and the ancestor to the chimpanzees, humans and gorillas. By working our way down the cladogram we have learned the pattern of splitting. We have found out that chimpanzees, humans and gorillas are more closely related to each other than to baboons. In this example, baboons are the outgroup.



CLADOGRAM A



CLADOGRAM B



CLADOGRAM C

If it we chose another hypothesis like Cladogram B or Cladogram C we would change the pattern of speciation events. In Cladogram B, humans and chimpanzees are sister taxa and in Cladogram C, chimps and gorillas are sister taxa.

We can't say that which of the three cladograms presented above is correct because none of the cladograms can be proved correct, but Cladogram B is the best supported of the three based on character data and is therefore hypothesized to best reflect the true branching pattern. Manufacturing cladograms which show hypotheses of ancestry and descent requires that we analyze characters and find those characters that unite clades.

Need for Cladistics-

Cladistics is useful for creating systems of classification.

Cladistics is now the most commonly used method to classify organisms. The diverse variety of organisms that have ever lived on Earth, from jellyfish to bacteria paleontologists, with other biologists, communicates their ideas about such a diverse topic as the history of life. Well, it's important that a system of classification is needed. That is, we need words like beetle or conifer so that we can talk about many organisms at one time. Today, cladistics is the method of choice for classifying life because it recognizes and employs evolutionary theory.

Cladistics predicts the properties of organisms.

Cladistics, a model which is most useful when it not only describes what has been observed, but when it predicts that which has not yet been observed. Cladistics hypothesizes about the relationships of organisms in a way that, unlike other systems, predicts properties of the organisms. This can be especially important in cases when particular genes or biological compounds are being sought. Such genes and compounds are being sought all the time by companies interested in improving crop yield or disease resistance, and in the search for medicines.

Cladistics helps to elucidate mechanisms of evolution.

By evolution point of view cladistics examine the way in which characters change within groups over time — the direction in which characters change, and the relative frequency with which they change. It is also possible to compare the descendants of a single ancestor to look at patterns of origin and extinction in these groups, or to look at relative size and diversity of the groups.

The most important feature of cladistic is its use in testing long-standing hypotheses about adaptation. For many years, since even before Darwin, it has been popular to tell "stories" about how certain traits of organisms came to be. With cladistics, it is possible to determine whether these stories have merit, or whether they should be abandoned in favor of a competing hypothesis. For example, it was long said that the orb-weaving spiders, with their intricate and orderly webs, had evolved from spiders with cobweb-like webs. The cladistic analysis of these spiders showed that, in fact, orb-weaving was the primitive state, and that cobweb-weaving had evolved from spiders with more orderly webs. This situation has been repeated in many groups with many traits, including studies of parasitism, geographic distribution, and pollination.

Cladogram

A **cladogram** term is derived from Greek word *clados* "branch" and *gramma* "character". It is a diagram used in cladistics which shows relations among organisms. A cladogram is not only an evolutionary tree because it does not show how ancestors are related to descendants or how much they have changed; many evolutionary trees can be inferred from a single cladogram. A cladogram uses lines that branch off in different directions ending at groups of organisms. There are many shapes of cladograms but they all have lines that branch off from other lines. The lines can be traced back to where they branch off. These branching off points represent a hypothetical ancestor which would have the combined traits of the lines above it. This hypothetical ancestor might then provide clues about what to look for in an actual evolutionary ancestor. Although traditionally such cladograms were generated largely on the basis of morphological characters, DNA and RNA sequencing data and computational phylogenetics are now very commonly used in the generation of cladograms.

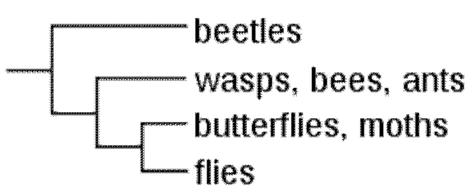


Figure - A horizontal cladogram, with the ancestor (not named) to the left

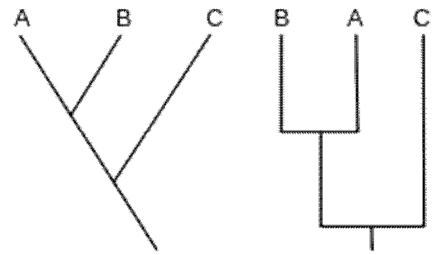
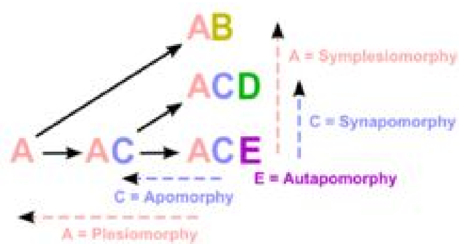


Figure - Two vertical cladograms, the ancestor at the bottom

Molecular versus morphological data

The characteristics used to create a cladogram can be roughly categorized as either morphological-(synapsid skull, warm blooded, notochord, unicellular, etc. or molecular - DNA, RNA, or other genetic information. Prior to the advent of DNA sequencing, all cladistic analysis used morphological data. As DNA sequencing has become cheaper and easier, molecular systematics has become a more and more popular way to reconstruct phylogenies.



Apomorphy in cladistics

Plesiomorphies and synapomorphies

Researchers must decide which character states were present before the last common ancestor of the species group (plesiomorphies) and which only arose in the last common ancestor (synapomorphies) and do so by comparison to one or more outgroups. The choice of an outgroup is a crucial step in cladistic analysis because different outgroups can produce trees with profoundly different topologies. Only synapomorphies are of use in characterizing clades.

Homoplasies

A homoplasy is a character that is shared by multiple species due to some cause *other* than common ancestry. The two main types of homoplasy are convergence (appearance of the same character in at least two distinct lineages) and reversion (the return to an ancestral character). Use of homoplasies when building a cladogram is sometimes unavoidable but is to be avoided when possible.

Example of homoplasy due to convergent evolution is the character, "presence of wings". Though the wings of birds, bats, and insects serve the same function, each evolved independently, as can be seen by their anatomy. If a bird, bat, and a winged insect were scored for the character, "presence of wings", a homoplasy would be introduced into the dataset, and this would confound the analysis, possibly resulting in a false evolutionary scenario.

Cladogram selection

There are several algorithms available to identify the "best" cladogram. Some algorithms are useful only when the characteristic data are molecular and other algorithms are useful only when the characteristic data are morphological. Other algorithms can be used when the characteristic data includes both molecular and morphological data. Biologists sometimes use the term parsimony for a specific kind of cladogram generation algorithm and sometimes as an umbrella term for all cladogram algorithms.

Algorithms that perform optimization tasks like building cladograms can be sensitive to the order in which the input data (the list of species and their characteristics) is presented. Inputting the data in various orders can cause the same algorithm to produce different "best" cladograms. In these situations, the user should input the data in various orders and compare the results. The basal position is the direction of the base (or root) of a rooted phylogenetic tree or cladogram. A basal clade is the earliest clade (of a given taxonomic rank) to branch within a larger clade.

Phylogenetics Terms and Definitions

- **Analog** -- A feature that appears similar in two taxa which have originated from two different ancestors.
- **Ancestor** -- Any organism, population, or species from which some other organism, population, or species is descended by reproduction.
- **Apomorphy** -- specialized (=derived) characters of an organism.
- **Basal group** -- The earliest diverging group within a clade; for instance, to hypothesize that sponges are basal animals is to suggest that the lineage(s) leading to sponges diverged from the lineage that gave rise to all other animals.

- **Biological classification** -- The orderly arrangement of organisms in hierarchical system that ideally reflects evolutionary history.
- **Character** -- Heritable trait possessed by an organism.
- **Character state** -- characters are usually described in terms of their states, for example: "hair present" vs. "hair absent," where "hair" is the character, and "present" and "absent" are its states.
- **Clade** -- A monophyletic taxon; a group of organisms which includes the most recent common ancestor of all of its members and all of the descendants of that most recent common ancestor. From the Greek word "klados", meaning branch or twig.
- **Cladogenesis** -- The development of a new clade; the splitting of a single lineage into two distinct lineages; speciation.
- **Cladogram** -- A diagram, resulting from a cladistic analysis, which depicts a hypothetical branching sequence of lineages leading to the taxa under consideration. The points of branching within a cladogram are called nodes. All taxa occur at the endpoints of the cladogram.
- **Convergence** -- Similarities which have arisen independently in two or more organisms that are not closely related. Contrast with homology.
- **Diversity** -- Term used to describe numbers of taxa, or variation in morphology.
- **Evolutionary tree** -- A diagram which depicts the hypothetical phylogeny of the taxa under consideration. The points at which lineages split represent ancestor taxa to the descendant taxa appearing at the terminal points of the cladogram.
- **Extinction** -- When all the members of a clade or taxon die, the group is said to be extinct.
- **Homolog** -- A feature that appears similar in two or more taxa with a common ancestor that also possessed that feature.
- **Homology** -- Two structures are considered homologous when they are inherited from a common ancestor which possessed the structure. This may be difficult to determine when the structure has been modified through descent.
- **Hypothesis** -- A concept or idea that can be falsified by various scientific methods.

- **Ingroup** -- In a cladistic analysis, the set of taxa which are hypothesized to be more closely related to each other than any are to the outgroup.
- **Lineage** -- Any continuous line of descent; any series of organisms connected by reproduction by parent of offspring.
- **Monophyletic** -- Term applied to a group of organisms which includes the most recent common ancestor of all of its members and all of the descendants of that most recent common ancestor. A monophyletic group is called a clade.
- **Outgroup** -- In a cladistic analysis, any taxon used to help resolve the polarity of characters, and which is hypothesized to be less closely related to each of the taxa under consideration than any are to each other.
- **Paraphyletic** -- Term applied to a group of organisms which includes the most recent common ancestor of all of its members, but not all of the descendants of that most recent common ancestor.
- **Parsimony** -- Refers to a rule used to choose among possible cladograms, which states that the cladogram implying the least number of changes in character states is the best.
- **Phylogenetics** -- Field of biology that deals with the relationships between organisms. It includes the discovery of these relationships, and the study of the causes behind this pattern.
- **Phylogeny** -- The evolutionary relationships among organisms; the patterns of lineage branching produced by the true evolutionary history of the organisms being considered.
- **Plesiomorphy** -- A primitive character state for the taxa under consideration.
- **Polarity of characters** -- The states of characters used in a cladistic analysis, either original or derived. Original characters are those acquired by an ancestor deeper in the phylogeny than the most recent common ancestor of the taxa under consideration. Derived characters are those acquired by the most recent common ancestor of the taxa under consideration.
- **Polyphyletic** -- Term applied to a group of organisms which does not include the most recent common ancestor of those organisms; the ancestor does not possess the character shared by members of the group.

- **Primitive** -- Describes a character state that is present in the common ancestor of a clade. A primitive character state is inferred to be the original condition of that character within the clade under consideration. For example, "presence of hair" is a primitive character state for all mammals, whereas the "hairlessness" of whales is a derived state for one subclade within the Mammalia.
- **Radiation** -- Event of rapid cladogenesis, believed to occur under conditions where a new feature permits a lineage to move into a new niche or new habitat, and is then called an adaptive radiation.
- **Rank** -- In traditional taxonomy, taxa are ranked according to their level of inclusiveness. Thus a genus contains one or more species, a family includes one or more genera, and so on.
- **Relatedness** -- Two clades are more closely related when they share a more recent common ancestor between them than they do with any other clade.
- **Reticulation** -- Joining of separate lineages on a phylogenetic tree, generally through hybridization or through lateral gene transfer. Fairly common in certain land plant clades; reticulation is thought to be rare among metazoans.
- **Selection** -- Process which favors one feature of organisms in a population over another feature found in the population. This occurs through differential reproduction -- those with the favored feature produce more offspring than those with the other feature, such that they become a greater percentage of the population in the next generation.
- **Sister group** -- The two clades resulting from the splitting of a single lineage.
- **Stem group** -- All the taxa in a clade preceding a major cladogenesis event. They are often difficult to recognize because they may not possess synapomorpies found in the crown group.
- **Sympleisiomorphy** – A ancestral character shared by the taxa under consideration
- **Synapomorphy** -- A character which is derived, and because it is shared by the taxa under consideration, is used to infer common ancestry (shared derived state).
- **Synteny** -- Portions of chromosomes in which gene order is conserved.

- **Systematics** -- Field of biology that deals with the diversity of life. Systematics is usually divided into the two areas of phylogenetics and taxonomy.
- **Taxon** -- Any named group of organisms, not necessarily a clade.
- **Taxonomy** -- The science of naming and classifying organisms.

2.14 Summary

Qualitative variations are determined by single genes. In qualitative variations the introduction of the corresponding genes depends upon the nature of the genetic resources. A quantitative trait shows continued variation by polygenic inheritance refers to a single characteristic that is controlled by more than two genes.

Taxonomy is the science of naming, describing and classifying organisms and includes all plants, animals and microorganisms of the world. A taxonomic key is a device, which when properly constructed and used, enables a user to identify an organism. There are two types of keys-Dichotomous & Polyclave.

Phylogenetics trees have a lot of information about the inferred evolutionary relationships between a set of organisms. Cladistics is a particular method of hypothesizing relationships among organisms. Cladistics is now accepted as the best method available for phylogenetic analysis, for it provides an explicit and testable hypothesis of organismal relationships. The cladograms give an output from a phylogenetic analysis is a hypothesis of relationship of different taxa. It is a diagram used in cladistics which shows relations among organisms.

2.15 Self Assessment Questions

1. Describe the essentiality of taxonomy
2. Explain the construction of taxonomic keys in detail
3. What is Txonomic key? Describe its different types.
4. What are the cladograms?
5. Write a short note on - Monophyly Polyphyly Paraphyly
6. How phylogenetic tree is reconstructed?
7. What are the characteristics used in preparing a toaxonomic key?
8. Describe the qualitative variations in detail?
9. Write an essay on Quantitative variations.
10. Describe the need of keys briefly.
11. What is cladistics ?

2.16 Reference Books

- Principles of systematic zoology – Ernst Mayr- Mc Graw Hill
- Principles of animal taxonomy - G.G.Simpson- Columbia University Press
- Theory And Practice Of Animal Taxonomy - V C Kapoor, Science Pub Inc

Unit - 3

Invertebrate body forms; organization of coelom : acoelome, pseudocoelom and coelomate ; protostome and deuterostome and their use in classification

Structure of the Unit

3.0 Objectives

After going through this unit you will be able to understand

- How embryological features are used to classify animals called Embryogeny.
- Level of body organization (unicellular, multicellular, tissue, organ and organ system).
- Variety of body forms (symmetries).
- Different types of body cavities (spongocoel, coelnteron, acoelome, psudocoelom and true coelom).
- Two fundamental types of cleavage in embryo(spiral and radial).
- Fate of blastopore (deuterostom, protostome) and blastomere (determinate, Indeterminate) in embryo.
- Use of above in classifying animals ie Embryogeny.

3.1 Introduction

This is the most essential lesson for a student before you start reading about invertebrates and vertebrates. Let's start from very basic, all animals have a level of body organization : Unicellular , multicellular, tissue level , organ level and lastly organ system level. Whether the animals are made up of two germ layers (diploblastic) or three (triploblastic).

Then comes the body form which is classified based on outside structure arranged around the imaginary central axis of the animal called symmetry which is fundamental in understanding the organization of an animal. Symmetry in animals is balanced distribution of paired body parts. During the course of evolution, animals acquired several body forms all of which fall into few types of symmetry.

Animals have different types of cavities inside their bodies, simple to complex and how these cavities develop in embryo. You will learn about them in this chapter.

Another important character , that forms basis of classification is under what pattern embryo divides- spiral or radial? You will learn in this chapter.

During development of embryo, what does blastopore form mouth or anus? Accordingly animals are classified under two categories-deuterostom and protostome.There are embryos in which fate of blastopore is predetermined ie what these cells will make as embryo grows and in some it's not determined.

lastly, you will learn, how animal body is divided on its anterio -posterior axis? Is it just on the outside(superficial) or through and though (metameric) .Learn all this ,in this fundamental chapter.

3.2 Level of body/structural organization

1.2.1 Unicellular

1.2.2 Multicellular

1.2.3 Tissue level

1.2.4 Organ level

1.2.5 Organ system level

1.2.6 Diploblastic, Triploblastic

Levels of Body /Structural Organization:

There is a structural hierarchy of life- Atoms form molecules, molecules form supra molecular structures, and they form cell ; The cell is the lowest level of organization that can live as an organism ; The hierarchy of multicellular organisms is: cell form tissues form organs form organ systems.

3.2.1 Unicellular

Unicellular are those creatures which are formed of one cell. For example organisms of phylum protozoa. You will learn about them and their system if further chapters of this booklet.

3.2.2 Multicellular

Multicellular are those organisms which are formed of more than one cell for example all animals except protozoans.

3.2.3 Tissue level

When few similar looking cells gather and start working together, it's called a tissue , its first seen in phylum porifera.

3.2.4 Organ level : When few tissues gather and start working together, it's called an organ eg testis and ovary in coelenterates.

3.2.5 Organ System level

Last comes the most evolved method of carrying out physiological functions in a body when different organs work together to execute a common function eg digestive system (mouth, esophagus, stomach, intestine, rectum and anus along with salivary glands, liver and pancreas).

3.2.6 Diploblastic, Triploblastic

In porifera, Coelentera tissues are arranged in two distinct layers : **Ectoderm** and **Endoderm , they** are called **diploblastic**. Higher then this group in phylogenic tree developed distinct third layer called **Mesoderm** and they are called **triploblastic** . These layers are actually called as germ layers. In triploblastic animals Endoderm - **the innermost tissue** - forms the digestive tract ; Mesoderm - **the middle tissue** - forms the musculature, blood, bone, reproductive and excretory systems and lastly Ectoderm - **the outermost tissue** - forms the skin, nervous tissue and sensory organs.

Hope you are understanding how these structures are gradually evolved from simple to complex as animals evolved ? To understand better, for diagrams you can refer to chapters ahead in this booklet.

3.3 Types of Body Forms / Symmetry

3.3.1 Asymmetrical

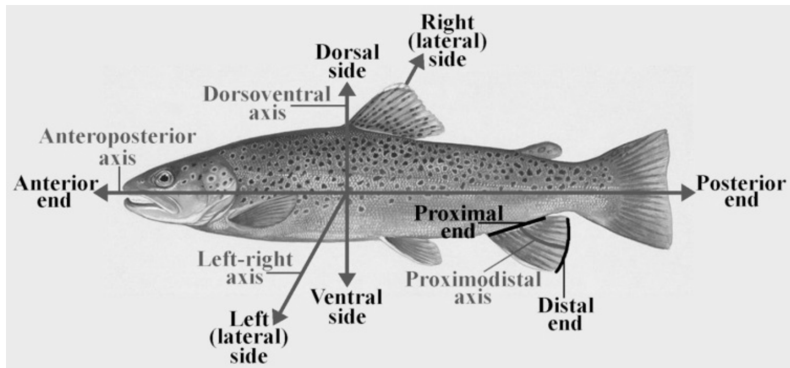
3.3.2 Spherical (Homaxial Apolar Symmetry)

3.3.3 Bilaterally symmetrical

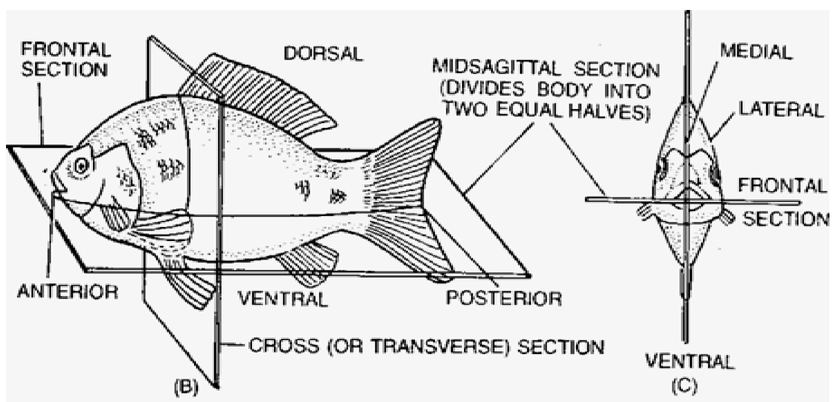
3.3.4 Radial symmetry(**Maximal or** monaxial heteropolar**)**

3.3.5 Biradial symmetry

Before understanding this you must know how many axis and body planes a body has . See the following diagrams:



(a) Different body Axis



(b) and 9 c) Different planes

By looking at diagram (a) you will know that a body has anterior, posterior, dorsal, lateral and ventral sides and antero-posterior, dorso-ventral, left - right, proximo-distal axis. Diagram (b) and (c) depict that there are frontal, cross(transverse), mid-Sagittal and medial (para-sagittal) sections/planes.

3.3.1 Asymmetrical

The animals, which cannot be cut into two equal parts passing through any plane or axis are called Asymmetrical. Their body lack a definite form , the body cannot be divided into mirror halves by any plane ,they do not develop complex sensory and locomotory functions. E.g : Amoeba, most of the Sponges, and adult Gastropods.

As oppose to this the animals which can be cut into two or more equal parts, or anti-meres passing through one or more planes passing through the principal axis of the body are called 'symmetrical animals'.

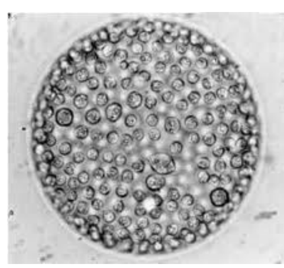
3.3.2 Spherical symmetry(Homaxial apolar symmetry):

spherical symmetry occurs in an organism if it is able to be cut into many identical halves through that runs through the organism's center. Organisms which approximate spherical symmetry include the freshwater green alga *Volvox*. Spherical symmetry is considered as homaxial apolar symmetry. It is a rare symmetry. Spherically symmetrical animals :

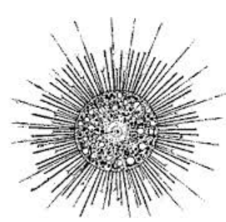
Have the body of a sphere/ ball.

Similar body parts are arranged concentrically around a central point.

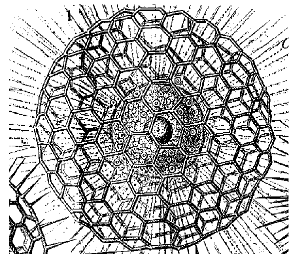
- All axes passing through the central point are apolar.
- Any one of the infinite number of planes that pass through the central point divides the body into anti-meres.
- Spherical forms are best suited for floating and rolling. It is found in some Protozoan only. E.g: Helizoans Radiolarians.



Volvox



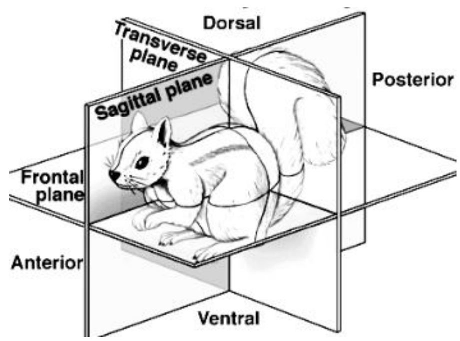
Haliozoan



Radiolarian

3.3.3 Bilateral symmetry

When only one plane (Median Sagittal plane) that passes through the central axis (anterior – posterior axis) divides an organism into two identical mirror parts , it is called bilateral symmetry.



- Bilateral symmetry is the principal type of symmetry in the triploblastic animals.
  Bilaterally symmetrical animals are more efficient than the other animal in seeking food, locating mates and escaping from predators. Cephalization is the most advanced feature in bilaterally symmetrical animals.
  As a result of cephalization, these animals can sense the new environment and respond more efficiently and quickly.
- Cephalization (formation of head) is associated with bilateral symmetry
- A head, mid body, and tail - have different functions, make animal more efficient for locomotion and a head with sensory structures and coordination of the nervous.
- Bilateral animals generally move actively from place to place. Their central nervous system enables them to co-ordinate complex movements involved in crawling, burrowing, flying or swimming.

• The principal axis is the anterior – posterior axis. It is heteropolar, with differentiated anterior and posterior ends. Sagittal axis is heteropolar, with differentiated dorsal and ventral surfaces. Whereas, the transverse axis is apolar Eg: Triploblastic animals.

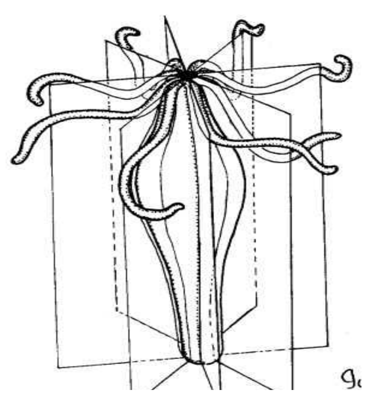
3.3.4 Radial symmetry

(Maximal or monaxial heteropolar)

When any Plane passing through the oro-aboral axis of the body divides an Organism into two and more anti-meres (identical polars), it is called Radial Symmetry.

Radial symmetry is known as Maximal or Monaxial heteropolar symmetry.

- It is present in Hydra and Jelly fish. These animals do not have antero-posterior axis, instead they have oral-aboral axis. The body or organisms is cylindrical (e.g: Hydra), Vase-like (e.g: Sponges) or Umbrella-Shaped (e.g: Jelly fish) or star shaped (star fish).
- These animals are either sessile (sponge) , Sluggish , planktonic or crawling forms.
- The principal axis is oral-aboral axis. It is heteropolar (two ends are unlike)
- Anterior, Posterior ends and dorsal, ventral, lateral surfaces are not differentiated.
- Various body parts are arranged around a central point . Eg Hydra, Jelly fishes, and adult forms of **echinoderms** which have pentamerous radial symmetry.

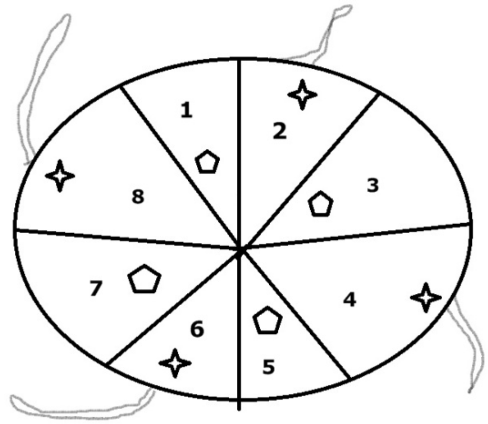


Radial symmetry is an advantage to sessile or planktonic or slow-moving Organisms. In Radial symmetry the sensory and feeding structures are uniformly distributed around the body. They can interact with their environment equally in all the directions they can capture prey approaching from any directions.

3.3.5 Biradial symmetry :

This symmetry is a combination of radial and bilateral symmetry, as in the Ctenophores. Here, the body components are arranged with similar parts on either side of a central axis, and each of the four sides of the body is identical to the opposite side but different from the adjacent side. This may represent a stage in the evolution of bilateral symmetry "from a presumably radially symmetrical ancestor.

- Paired arrangement at some structures in radially symmetrical animals results in biradial symmetry.
- There are two planes of symmetry, one passing along the oral- aboral axis and the long axis of mouth, The other passing along the oral- aboral axis and the short axis of mouth.
- The anti-meres on either side of one plane are different from the anti-meres on either side of the other plane.
- The principal axis is the oro-aboral axis Eg: Ctenophores and few sea anemones.
- In Ctenophores most of the body parts are radially arranged but the tentacles and other structures are not radially arranges. If you see the following diagram, you will notice that, opposite parts are similar but adjoining parts are different. Such an arrangement of some structures in radially symmetrical animals results in biradial symmetry.



1,
3,5,and 7 and similar and 2,4,6 and 8 are similar. Look at no 1, adjoining it 2 and 8 are not similar to it. So on and so forth. This is called Biradial symmetry. It's found in minor phyla ctenophore.

Table 1 compares four major types of symmetries found in animals.

1. Compare various types of Symmetry.

Type of Symmetry	Shown by	Chances of getting antimeres		Special feature
		Axis	Plane	
1.Spherical	Radiolarians Heliozoans	Any	Any	Homaxial apolar. Rare . Floating animals
2.Radial	Hydrozoans Scyphozoans	Only one axis Antero-posterior Longitudinal	Any	Monaxial heteropolar
3. Biradial	Anthozoans Ctenophors	Only one axis	Two planes Passing through mouth	Elongated, Oval mouth
4.Bilateral	Triploblastic animals	Only one Antero-posterior	One. Median Sagittal plane	Cephalization is present Advanced animals Show quick movements

3.4 Body Cavity

Animals have a cavity inside their body. The primitive form can be seen in porifera and coelenterates.

3.4.1 Spongocoel ,Coelenterons,

3.4.2 Definition of True Coelom

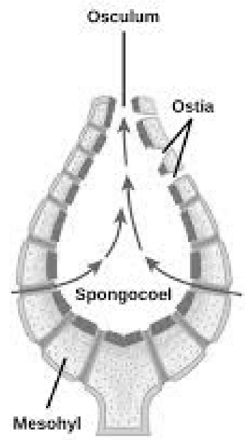
3.4.3 Acoelom

3.4.5 Psudocoelom

3.4.5 True coelom : Schizocoelous and Enterocoelous

3.4.1 Spongocoel :

Animals of porifera are multicellular, asymmetrical and diploblastic. Please see the longitudinal section passing through a sponge given below:

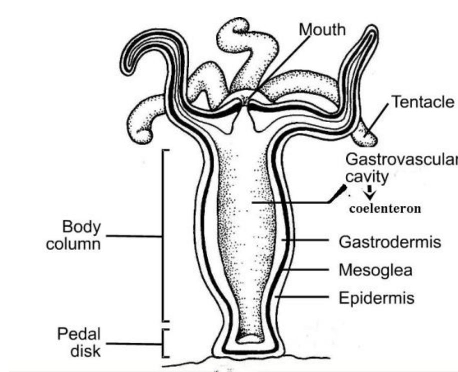


In above diagram, you see a cavity in the centre ? It is called **spongocoel.**

It is a plain cavity, it is not what you are going to study ahead in this chapter about "coelom ". You will learn how coelom is different than these simple cavities.

In sponges, water enters through Ostia along with food and oxygen it washes spongocoel where food is captured and gases are exchanged then water leaves through Osculum.

Coelenteron : Animals of coelenterate are multicellular, radially symmetrical and diploblastic . cavity inside the body of coelenterates is called coelnteron. Also known as gastro vascular cavity. see the diagram given below :

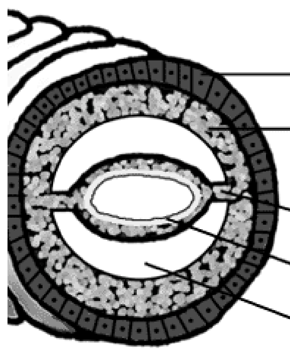


In coelenterates, the water enters through hypostome takes food and oxygen, the water circulates inside coelnteron capturing microscopic food and exchanging gases.

Now come the question is -**what is a true coelom** ?

3.4.2 True Coelom

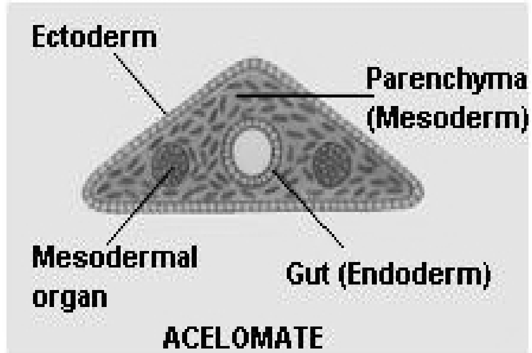
A cavity found between the body wall (ectoderm) and alimentary canal (endoderm) and it is lined by the mesoderm from its both sides. See the diagram below:



if you have understood what is true coelom it would be much easier to understand acoelome, psudocoelom , schizocoelous and enterocoelous coelom.

3.4.3 Acoelom

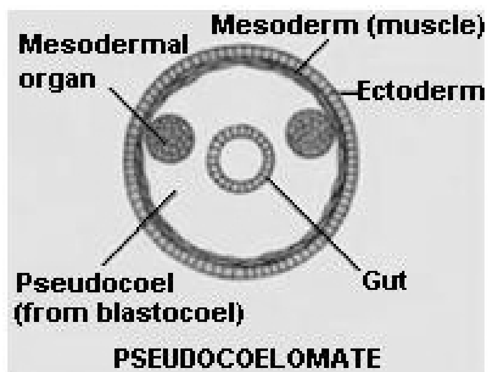
A cavity found between the body wall (ectoderm) and alimentary canal (endoderm) and mesoderm, instead of lining it (as per definition) , fills the cavity, leaving no space. When you see the following diagram , you will understand it better.



This kind of coelom is found in animals of platyhelminthes.

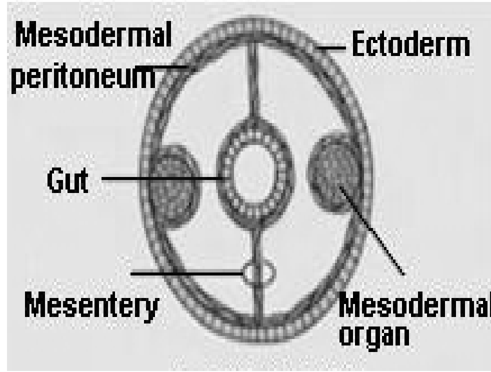
3.4.4 Psudocoelom

It is the body cavity found between the ectoderm and endoderm, but mesoderm does not line it from both sides, instead, mesoderm is found in patches, making it a false cavity. Therefore, it is called psudocoelom. It is found in animals of phylum nematoda.



3.4.5 True coelom : Schizocoelous and Enterocoelous

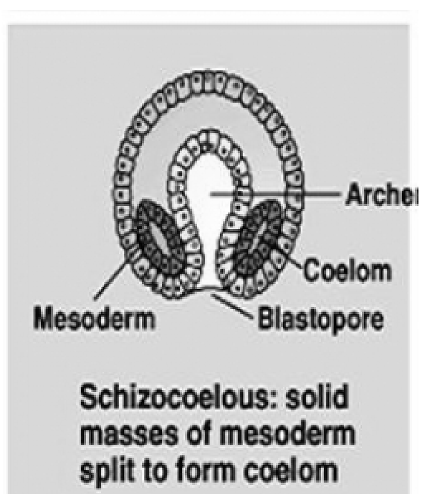
Please read the definition of coelom under 1.4.2 - A cavity found between the body wall (ectoderm) and alimentary canal (endoderm) and it is lined by the mesoderm from its both sides. Following diagram makes it clear:



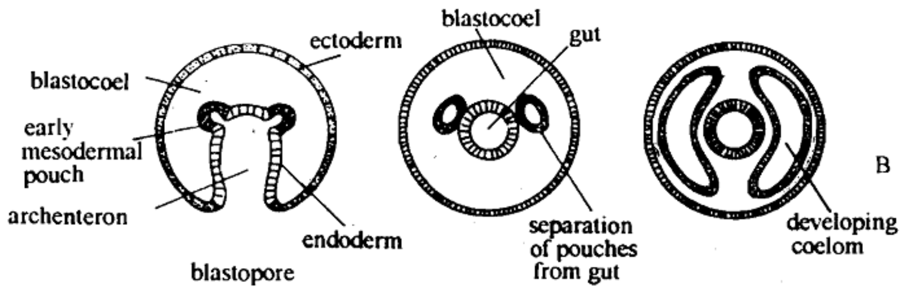
Difference between schizocoelous and enterocoelous types can only be seen during embryonic development, once the coelom is fully developed they cannot be differentiated.

Schizocoelous coelom : Is found in Annelids, Arthropods and molluscs.

- A single micromere or mesentoblast cell pinches off from archenteron and it multiplies and proliferates to from mesodermal patches between the developing archenteron (endoderm) and the body wall (ectoderm)
- A split appears within each patch making them hollow and creating a cavity
- The cavity formed by the splitting of mesodermal band is the Schizocoelom.



Enterocoelous coelom : It is found in Echinoderms and all vertebrates



- In this, two small pouches appear from archenteron called mesodermal pouches they grow inside the cavity, get separated from gut and develop a cavity between the body wall(ectoderm) and the gut (endoderm); this cavity is lined by mesoderm from its both sides. This is called enterocoelous coelm.

Coelom holds, protects mesodermal derivatives ie all visceral organs.

Functions of coelom : A coelom is used for (i) storage of energy rich compounds (fat)

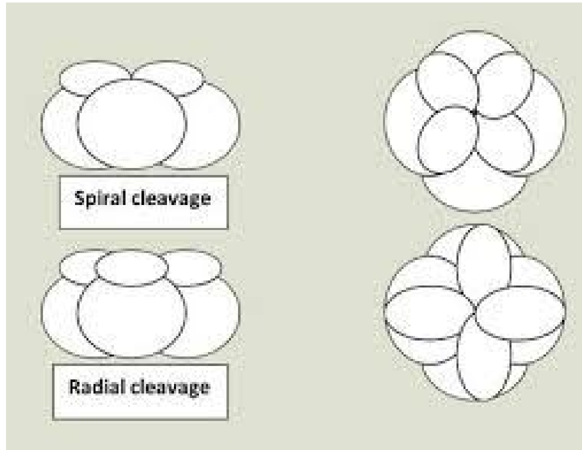
(ii) reproductive products – eggs, sperm, embryos (iii) Organs can develop with separation from other tissues (iv) Allows for specialization of regions of the digestive system (v) Water filled space can be used to move body parts (vi) allows for circulation of fluids around organs(vii) hydrostatic skeleton; housing and cushioning of internal organs/organ systems. (viii)The circulatory system is closed, and is contained within the coelom (ix) reduces vestigial space around the heart, gonads, part of the intestine and reproductive organs . In echinoderms coelom gives rise to the water-vascular system, used for locomotion and in some species, prey capture .

In chordates coelom houses the internal organs, and provides fluid cushioning for organs and organ systems. (Your own coelom is the space lined by your peritoneum (the mesodermal tissues anchoring your internal organs in their proper place in the abdomen) as well as the mesodermally lined space in your thoracic cavity.)

3.5 Types of cleavage

3.5.1 Spiral

3.5.2 Radial



3.5.1 Spiral Cleavage

Spiral cleavage is seen in annelids, Arthropoda and Mollusca. It occurs in such a manner that the resulting daughter cells are not located exactly on top of one another; instead, they are located at a slight angle. Spiral cleavage is a characteristic of Protostomes(you are just about to study about this in following paragraphs) , and results in determinant cells (Cell that have a determined embryological fate early on during the development of the embryo- this also is coming soon after this). In other words, determinant cells are programmed to become a specific type of cell, early on during the process.

3.5.2 Radial Cleavage

Radial cleavage is found in echinoderms and vertebrates. It occurs in such a manner that the resulting daughter cells are located exactly on top of one another. Radial cleavage is a characteristic of Deutrostomes, and results in indeterminant cells (Cells that can individually give rise to a complete embryo, and they don't have a determined embryological fate early on during the development of the embryo). In other words, you can take a single cell from a developing embryo, and given the right condition, that single cell can give rise to a whole embryo (If you've taken embryology classes you've definitely heard of experiments like this done with frog embryo).

3.6 Fate of Blastopore and Blastomere

3.6.1 Protostome

3.6.2 Deuterostome

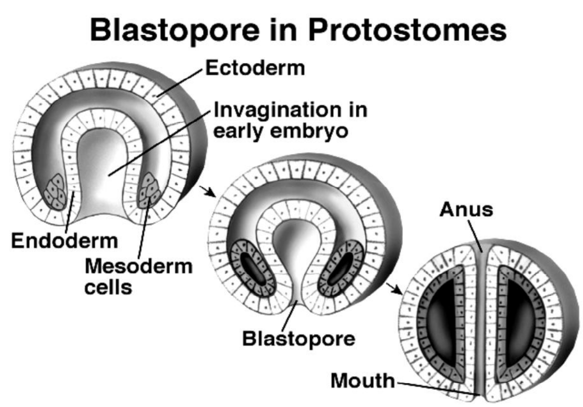
3.6.3 Determinate

3.6.4 Indeterminate

One of the most fundamental differences between Protostomes and Deuterostome is that their early embryos have a fundamentally different pattern of early cleavage.

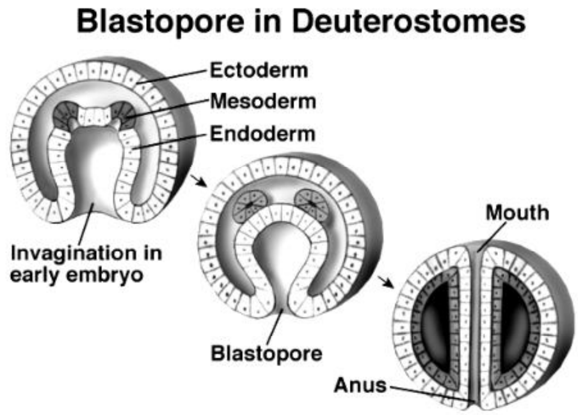
3.6.1 Protostome

- Protostomes have spiral cleavage is an early cleavage pattern in which cleavage planes are not parallel or perpendicular to the animal-vegetal pole axis of the egg. Cleavage takes place at oblique angles, forming a spiral pattern of daughter blastomeres. Protostomia represents those animals in which the blastopore finally becomes the oral aperture (mouth). Members of phylum Annelida, phylum Arthropoda and phylum Mollusca exhibit this condition.



3.6.2 Deuterostome

- Deuterostomia go through an early pattern of cleavage called radial cleavage. in this type cleavage, the organism viewed from above (dorsal, animal pole) essentially radial in symmetry – where a dorso-ventral slice in any plane will yield a set of mirror images. Deuterostomia represent those animals in which the blastomere finally forms the anus. The oral aperture appears much later as a separate slit. Members of the phylum Echinodermata and Chordata exhibit this condition.

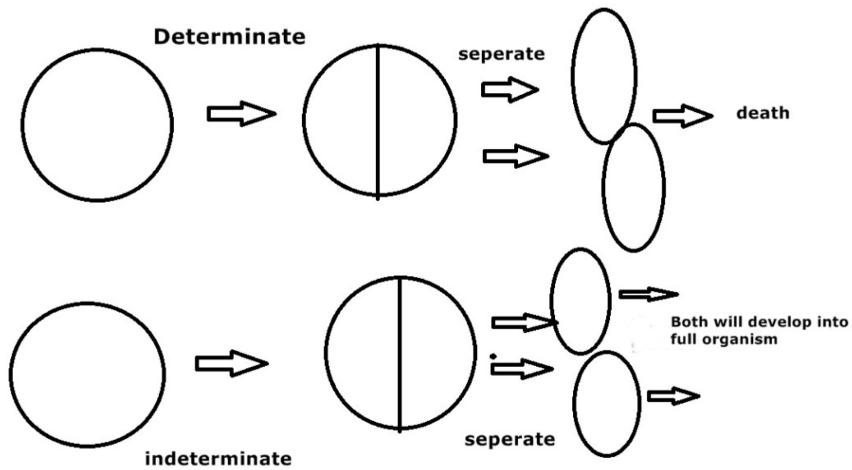


3.6.3 Determinate

Determinate is the form of cleavage in most Protostomes. In this, developmental fate of the cells is set early in the embryo development. Each cell produced by early embryonic cleavage develops into a predetermined structure of adult body. The cells do not have the capacity to develop into any other type. Hypothetically, if you remove few cells from an embryo, that part of the adult body will never develop, in other words that embryo will not grow normally and will die. Or at two cell stage- if you separate two blastomeres, this embryo will die .It is considered primitive and is found in Annelida, Arthropoda and Mollusca.

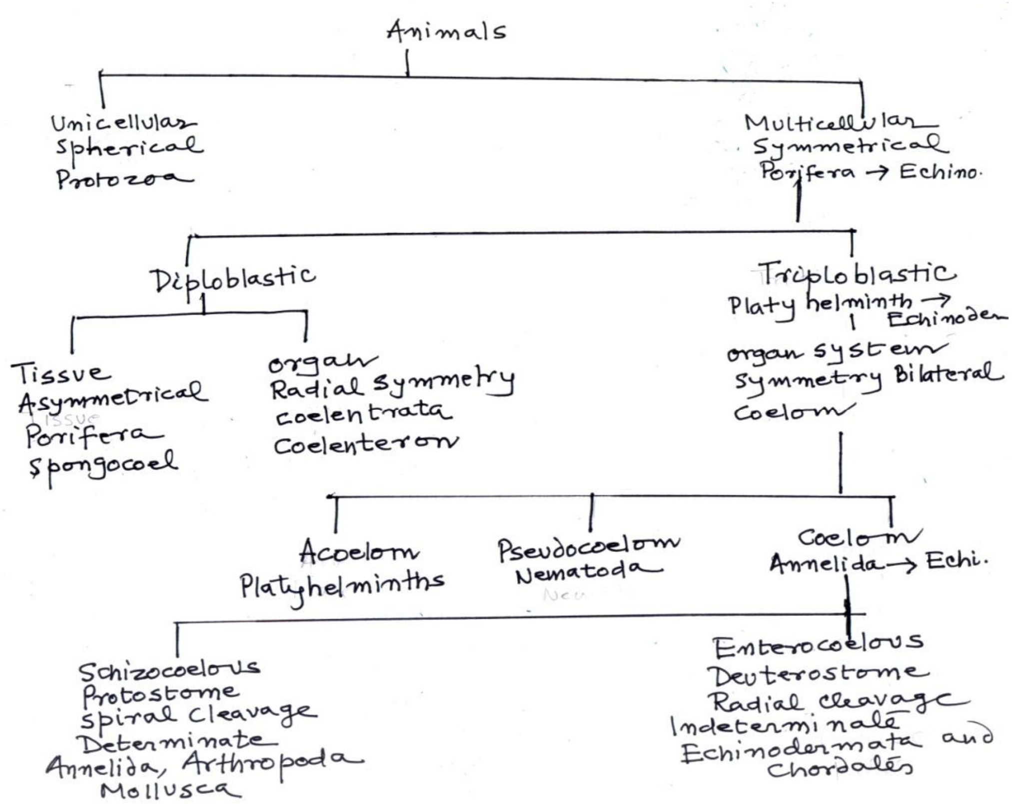
3.6.4 Indeterminate

Opposite to this, in indeterminate type cells have a complete set of undisturbed animal/vegetal cyto-architectural features. It is considered advanced and is characteristic of higher animals eg echinoderms and chordates; which are Deuterostomes. In this case, at two blastomere stage, it you separate them, each one will individually develop into a whole organism.



3.7 Embryogeny (use of above characters in classifying animals):

The chart below is self explanatory, see how the characters have been used to classify animals.



3.8 Summary

After going through this unit you have understood :

How embryological features are used to classify animals , this is called Embryogeny (not embryology); level of body organization (unicellular, multicellular, tissue, organ and organ system); Variety of body forms (symmetries); different types of body cavities (spongocoel, coelnteron, acoelome, psudocoelom and true coelom); two fundamental types of cleavage in embryo (spiral and radial); fate of blastopore (deuterostom, protostome) and fate of blastomere(determinate, Indeterminate) in embryo and finally their use in classifying animals .

This is the most essential lesson for a student before you start reading about invertebrates and vertebrates. Let's start from very basic, all animals have a level of body organization : Unicellular , multicellular, tissue level , organ level and lastly organ system level. Whether the animals are made up of two germ layers (diploblastic) or three (triploblastic). Then comes the body form which is classified based on outside structure arranged around the imaginary central axis of the animal called symmetry which is fundamental in understanding the organization of an animal. Symmetry in animals is balanced distribution of paired body parts. During the course of evolution, animals acquired several body forms all of which fall into few types of symmetry. Animals have different types of cavities inside their bodies, simple to complex and how these cavities develop in embryo. You will learn about them in this chapter. Another important character, that forms basis of classification is under what pattern embryo divides- spiral or radial? During development of embryo, what does blastopore form mouth or anus? Accordingly animals are classified under two categories-deuterostom and protostome.There are embryos in which fate of blastopore is predetermined ie what these cells will make as embryo grows and in some it's not determined.

3.9 Glossary

- **Unicellular**: Organisms made up of single cell
- **Multicellular**: Organisms/animal made of many cells
- **Tissue**: Structurally and functionally similar group of cells
- **Organ** : Different tissues perform towards single function

- **Organ system**: Different organs perform together to execute a physiological function
- **Asymmetrical** : Organism/animal that can not be cut into two identical halves
- **Spherical** : Organism/animal that can be cut into many identical halves
- **Bilaterally symmetry**: Animal that can only be cut into two identical halves
- **Radial symmetry**: Animal that can be cut into more than two, three or five identical halves
- **Biradial symmetry**: Organism that can be cut into more then two, three or five identical halves, but adjacent halves are not similar.
- **Spongocoel:** Body cavity found in sponges
- **Coelenteron**: Body cavity found in coelenterates
- **Coelom** : Body cavity found between the body wall and alimentary canal and is lined by mesoderm from both sides.
- **Acoelom**: Body cavity filled by mesoderm
- **Psudocoelom**: Body cavity which in not lined by mesoderm
- **Schizocoelous**: The cavity formed by the splitting of mesodermal band
- **Enterocoelous** : Cavity formed from mesodermal pouches
- **Spiral cleavage**: Resulting daughter cells are not located exactly on top of one another; instead, they are located at a slight angle
- **Radial cleavage**: Resulting daughter cells are located exactly on top of one another
- **Protostome**: Blastopore of embryo forms mouth in adult
- **Deuterostom**: Blastopore of embryo form anus in adult
- **Determinate**: Blastomeres in embryo forms determined structures in embryo
- **Indeterminate**: Blastomeres in embryo are capable of forming any other structure in adults

3.10 Self-Learning Exercise

Section -A (Very Short Answer Type)

1. Body cavity found in sponges is called ....

2. Schizocoelous coelom is formed by the ....

3. Radial symmetry is known as ....symmetry

4. Define coelom

5. Deuterostom: Blastopore of embryo forms anus in adult T/F

6. Biradial symmetry is seen in ....

7 Define Embryogeny

8. Nematodes are acoelomates T/F

Section -B (Short Answer Type)

1. Name the three primary germ layers of a triploblastic animal.
2. Which symmetry is known as homaxial apolar symmetry? Give an example.
3. Which symmetry is known as monaxial heteropolar symmetry? Give an example.
4. Explain Biradial symmetry ; Give example.
5. What is psudocoelom?
6. How does Acoelom differ from psudocoelom?
7. What are retroperitoneal organs?
8. How is Schizocoelom formed?
9. What is enterocoelom?
10. What is Deuterostome ?

Section -C (Long Answer Type)

1. Explain what is symmetry and their types with examples
2. Write about germ layers and their derivatives
3. Describe fate of Blastopore, draw suitable diagrams.
4. What is coelom? Differentiate between enterocoelous and schizocoelous.
5. With the help of diagrams explain radial and spiral cleavage.
6. Define Embryogeny, write its use in taxonomy.

Answer Key of Section-A

1. Spongocoel
2. splitting of mesodermal band
3. Monaxial heteropolar
4. Body cavity found between the body wall and alimentary canal and is lined by mesoderm from both sides.
5. True
6. Ctenophores
7. Using embryological characters to classify animals
8. False

3.9 References

- Invertebrate by Hymen
- Invertebrate by Sedgwick
- Invertebrate by Kotpal

Unit - 4

LOCOMOTION; Amoeboid movement; ultra structure of cilia and flagella; molecular mechanisms of ciliary and flagellar movement

Structure of the unit

4.0 Objective

The objective of present unit is to understand the means of locomotion and their respective body organization present in diverse group of Invertbrate.

- Animals of protozoa phylum have locomotion through amoeboid, ciliary and flagellar movement.

4.1 Introduction

The present unit covers the type of locomotion and their respective body organisation found in various Invertebrate phyla from unicellular to multicellar organisation. Unicellular phlyum i.e Protozoa has amoeboid movement as in Sarcodina (which have temporary processes, the pseudopodia). Likewise ciliary movement is found in classification of phylum protozoa which have flagella as the locomotary organelles.

4.2 Amoeboid movements:-

It is a form of locomotion particularly characteristic of many of the sarcodine Protozoans but it is also found in a wide variety of metazoan cells, ranging from the oocytes of sponges to the white blood corpuscles of vertebrates. The discovery of amoeboid movements among plant zoospores, animal ova, in-the endoderm cells lining the digestive tract of a great variety of animals, in the nuclei of some animals -all these instances of amoeboid movement occurring in such widely different tissues inevitably place it among the most important phenomena known to occur in organisms.

4.2.1 Theories supporting amoeboid movement

Amoeboid movement is considered to be the most primitive kind of animal movement. The following theories have been presented regarding the amoeboid movement.

(1) Rosel von Rosenhof (1755) first observed locomotion in Amoeba.

(2) Schuttze (1875) proposed construction hydraulic theory.

(3) Berthold (1886) proposed surface tension theory.

(4) Jennings (1904) stated Rolling movement theory in *Amoeba verrucosa*.

(5) Dellinger (1906) proposed walking movement theory i.e., on tips of pseudopodia.

(6) Hyman (1917) first proposed sol-gel theory to explain locomotion i.e. solation at disappearance points and gelation on the side of movement.

(7) Pantin & Mast (1923-26) supported sol-gel theory proposed by Hyman (1917). Sol-gel theory was widely accepted for Locomotion in Amoeba.

(8) Goldacre & Losch Proposed Folding and unfolding of protein chain molecules.

(9) Allen (1961) proposed front or fountains zone contraction theory (Fountain theory)

(10) Yagi (1961) & Marsland (1964) again proposed and supported reversible gel-sol transformation theory.

4.2.1.1 Streaming Protoplasm theory by Rossenhof (1755).

The manner of movement common to amoeba has attracted the attention of biologists ever since the discovery of amoeba by Rosl V. Rosenhof in 1755.

The phenomenon of amoeboid movement as discovered by Rosenhof, was an isolated phenomenon. The movement in the Amoeba was always accompanied by streaming, so it came to be, generally accepted that the really fundamental feature of amoeboid movement was the streaming of the protoplasm.

4.2.1.2 Contraction hydraulic theory by Schultze (1875)

Schultze observed-that the foraminiferan pseudopods possess perfect elasticity and compared the contractility of pseudopods to the rubber bands. The contraction of the ectoplasm (plasma gel) at the posterior end causes protoplasmic flow forwards, pushing endoplasm (solplasma) in forward direction propelling the body ahead through the formation of pseudopodium.

4.2.1.3 Surface tension theory by Berthold (1886)

By means of simple experiments, with inert fluids (oils, alcohol, water, ether), Berthold concluded the locomotion in amoeboid organism is due to the physical attraction of the anterior end to the substratum. The Amoeba was supposed to behave like a drop of fluid which moved towards the point where the tension of the Amoeba's surface was decreased by contact with the substratum. Amoeba did not push out pseudopodia according the Berthold, but they were pulled out because of a difference in surface tension between them and the substratum, but pseudopods which were extended into the water and out of contact with a solid substratum, were said to be extended by a contractile effort of the posterior region of Amoeba. Rhumbler (1898), Verworn (1889, 1892), Blochmann (1894), Quincke (1888), Bernstein (1900) and Jenson (1902) agreed in a general way with Berthold's, that the surface tension changes are the cause of locomotion is amoeba.

4.2.1.4 Rolling movement theory in *Amoeba verrucosa* by Jennings (1904) (Fig. 1)

Jennings observed that in *A verrucosa*, a carbon particle on Amoeba's upper surface first passes forward and then turning downwards along the anterior tip, remains on the lower surface for a time as the body rolls forward and then passes upward at the posterior end to repeat the cycle. But Jennings found it impossible to explain for *A proteus* which moves with pseudopodia.

4.2.1.5 Walking moment theory by Dellinger (1906) (Fig. 2)

Contractile substance present in the cytoplasm is responsible for extension of pseudopodia which become attached to the substratum and then contract to pull the body forward. *Amoeba* appears to walk on its leg like pseudopodia.

4.2.1.6 Sol-gel theory by Hyman (1917) and supported by Mast and Pantin (Fig. 3)

The colloidal character of cytoplasm differentiates the properties of ectoplasm and endoplasm. The ectoplasm is a colloidal gel, the **plasmagel** and endoplasm a sol, the **plasmasol.** Amoeboid movement is interpreted as a result of coordinated gelation and solation. At the end, gel under goes solation and contraction forces the fluid sol forwards and there is transformation sol to gel (gelation) at the anterior end, so that solation is balanced by gelation. (Forcing out a pseudopodium at some point).

4.2.1.7 Reticular theory by Heitzmann

Heitzman observed a living three dimensional network of contractile fibres which was supposed to be embedded in a non living and non-contractile fluid. Thus amoeboid movement was ascribed to contraction of the reticulum, the substance of the fibres being transferred during contraction to the nodes of the reticulum, where it accumulates in the form of granules.

4.2.1.8 Folding and unfolding theory by Goldacre and Lorch (Fig. 4)

According to Goldacre and Lorch (1950) protoplasm can be thought of as a three dimensional network of protein chains linked together by cross linkages of side chains. The folding and unfolding of these protein chains caused contraction and relaxation of protein molecules. They suggested that the sol state is due to the folding of protein chains and gel state is due to their unfolding. At the posterior end the gel state (unfolded) starts folding and converted into sol state (folded) and similarly at the anterior end the sol state (folded) starts unfolding to form gel state (unfolded) which forms the pseudopodium.

4.2.1.9 Front or fountain zone contraction theory by Allen.

Allen suggested that endoplasm is not uniformly solated, so that its properties are not those of a Newtonian fluid. According to this theory, contraction of gel at the posterior end cannot by itself account for the forward flow. Instead, the contraction occurs at the anterior end in a fountain zone and this process actively pulls the axial endoplasm forwards. This frontal contraction model seems to account well for the complex details of movement of the giant Amoeba, *Chaos carotinensis.*

4.2.1.10 Reversible gel-sol transformation theory by Yagi (1961) and Marsland (1954).

This theory is most widely accepted explanation of amoeboid movement. This theory suggests that solation occurs at the anterior end in which endoplasm flows under pressure generated by contraction of the cortical plasma gel at the posterior end. This results in propulsion of amoeba.

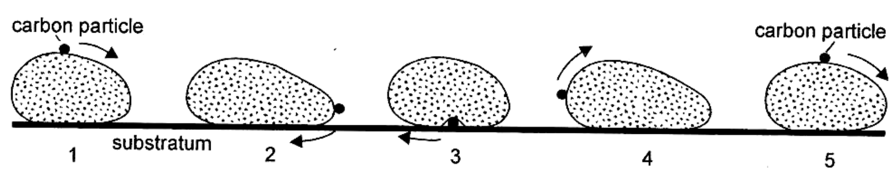


Fig. 1 Rolling movement theory (Source: Invertebrates by Kotpal)

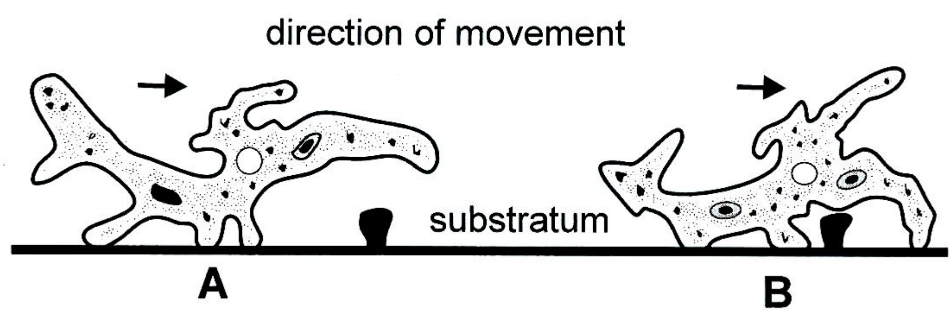


Fig. 2: Walking movement theory (Source: Invertebrates by Kotpal)

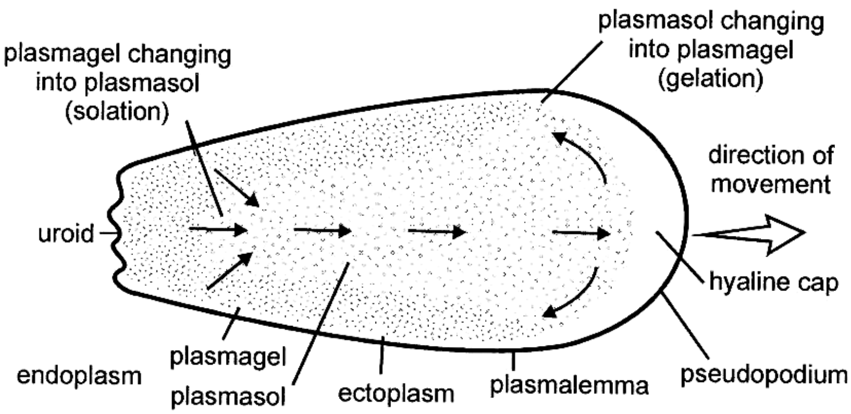


Fig. 3 Sol and gel theory (Source: Invertebrates by Kotpal)

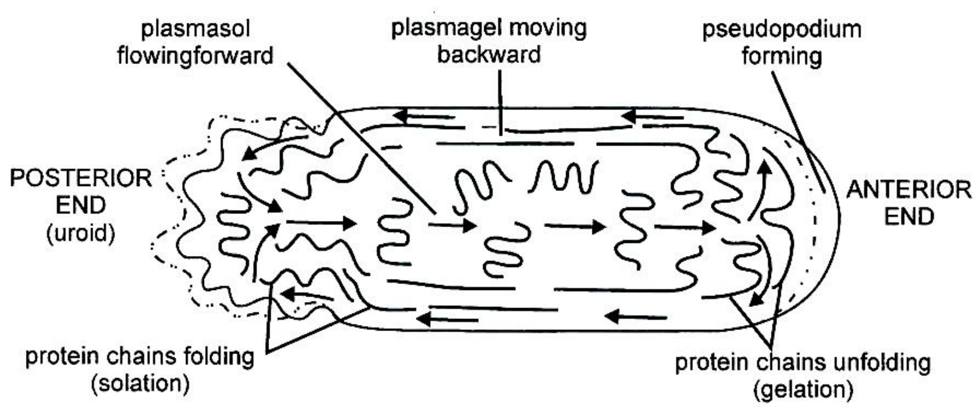


Fig. 4 Folding and unfolding theory (Source: Invertebrates by Kotpal)

4.3 Ultra structure of Flagella & Cilia

Flagella and cilia are organelles of movement for many Protozoa and which continue to function as important effector structures in most groups of animals. The exceptions are the Nematoda (absent) and the Arthropoda, in which they are only present in the excretory and reproductive systems of the Onychophora, in the sperms of some insects and in certain receptor organs as a modified form. Flagella and cilia often persist in large sized animals but only to carry out limited functions. These include not only movement, but also the sensory functions of non-motile cilia, for example in the photosensitive structures of coelenterates and echinoderms and in the rod and cone cells of vertebrates. The ultra structures of flagella and cilia are fundamentally similar in all Eucaryote organisms. The cilia and flagella are differentiated into basal body and shaft.

4.3.1. Basal body/blepharoplasts/kinetosomes

Flagella and cilia originate from basal granules or blepharoplast or kinetosomes, which resembles in structure with the centrioles that produce the spindle fibres at cell division in animals. In some species the basal body functions as a centriole in mitosis. The fine structure shows that the peripheral fibres are present in triplet pattern which is twisted and are interconnected by other fibrils two of the three being continuous with the doubles of the shaft of flagellum and arms are absent.

At the proximal part of the basal granule, the subfibrils are also connected with a central cylinder by 9 spokes, one to each triplet forming a cart wheel structure (Fig. 1, D), but at the distal part it is absent (Fig. 1, C) and is closed by basal plate. Shaft region arises from this basal plate. In case of cilium the shaft also arises from a basal body or kinetosome. The kinetosomes form a longitudinal row that is connected by means of fine, striated fibrils called kinetodesma. The kinetosomes plus the fibrils of that row make up a **kinety**. The longitudinal bundle of fibrils run to the right side of the row of kinetosomes. Each kinteosome gives rise to one kinetodesmos (fibril), which joins the longitudinal bundle and extends anteriorly. At the kinetosome, the kinetodesmos is connected to certain kinetosome triplets. The kinety system is characteristic of all ciliates (Fig. 2).

The flagella of some species of phytoflagellates such as *Ochromonas,* bear stiff lateral fibrils called mastigonemes as seen under electron microscope. The mastigonemes arise opposite two of the nine doublet fibers of the flagellum. Mastigonemes probably function to reverse water propulsion.

4.3.2. Shaft

Shaft of cilium is smaller than flagellum, it measures 5 to 10 μ in length while that of flagellum is about 150 μ. The fine structure of flagella and cilia shows a remarkable uniformity of pattern not only within the Protozoa but also throughout the Metazoa.

A flagellum or cilium (Fig. 1, A) consists of a matrix surrounded by a membrane that is continuous with the plasma membrane of the cell surface. With in the matrix is an axoneme composed of 11 micro tubular fibrils, each is formed of rows of molecular sub units of a globular protein called tubulin (molecular weight about 55,000) which resembles actin is certain respects.

Two of the 11 fibrils are single ones (diameter about 24 nm), and lie centrally. There is a sheath enclosing the central fibrils as seen in electron microscope, while the other nine are doublets each composed of an A and B subfibre and form a circle around the central pair. Some delicate strands lie between the central and peripheral ones & sometimes form spokes or radial lamellae as seen in electron microscope. One of the two subfibres of each of these peripheral doublets bear a double row of short arms which all point in the same clockwise direction and made of a protein (molecular weight about 500,000), which resemble myosin but differ in ATpase activity which is activated by magnesium as well as by calcium.

4.4 Molecular Mechanism of ciliary and flagellar movement

4.4.1 Flagellar Movement

Various theories are given for explaining the movement of flagella:

1. **Screw propellar theory:**

   According to Butschlii the movement of flagella commonly involves the generation of waves that are transmitted along it either in a single plane or in a corkscrew pattern. The waves pass to the tip of the main flagellum which beats at a rate of about 12 beats per second as in case of *Euglena* (movement of rotation). This rotation causes the tip of the organism to rotate while at the same time pushing it to one side because of this *Euglena* rotates as it swims (at a rate of about one turn per second) and it also follows a corkscrew course. The movement of its body thus is comparable with that of a propellar, as it sets up forces on the water that bring about forward displacement.

2. **Sidewise Lashing Movement: (Fig. 3, A & B)**

   Recent discoveries by Ulehla and Krijsman (1925) suggest that the flagellum beats in a side wise lash, consisting of an effective downstroke or bending and a relaxed recovery stroke or straightening. In the effective stroke the flagellum is held out rigidly with slight concavity in the direction of stroke, while in the recovery stroke the flagellum is relaxed, strongly curved and is brought forward again. This draws the body of animal forward. Usually the flagellum beats obliquely so that during forward movement the animal also rotates on its longitudinal axis.

3. **Undulating Movement:**

This type of movement is observed in uniflagellates. The movement is due to the wave-like undulations of the flagellum. The undulatory waves pass from base to tip and drive the organism in the opposite direction (Fig. 4), or the undulations pass from tip to base and pull the organisn (Fig. 4, B).

4.4.2 Ciliary Movement:

The ciliary movement is very much similar to that of flagellar movement, consisting of the same effective stroke and recovery stroke, but, the cilia bend throughout their length (Fig. 5, A & B). The water moves in the direction of beat, while the animal moves in the opposite direction. The recovery position offers less water resistance and is somewhat analogous to feathering an oar. The hydrodynamic forces impose coordination in the ciliary movement, the beating of individual cilia of a longitudinal row is in metachronal way (one after another) rather than synchronous. But cilia in transverse row beat synchronously (all together).

4.4.3 Molecular Basis of Movement

The ultra structure of flagella or cilia has been revealed by the **sliding tubule model** theory (Fig.6). According to the theory, the microtubules do not change length but adjacent doublets slide past each other, causing the entire organelle to bend, sliding involves the establishment of cross bridges and utilization of Adenosine Tri Phosphate (ATP), as in muscle contraction ATPase called dynein is present in the arms that project from one side of the A subfibrils of the flagellum and cilium. These arms point towards the B subfibrils of the next doublet, an arrangement which suggests that they connect with this, much as the ATPase of myosin muscle filament can connect them with the thin actin filaments. Thus the sliding takes place in the flagella or cilium.

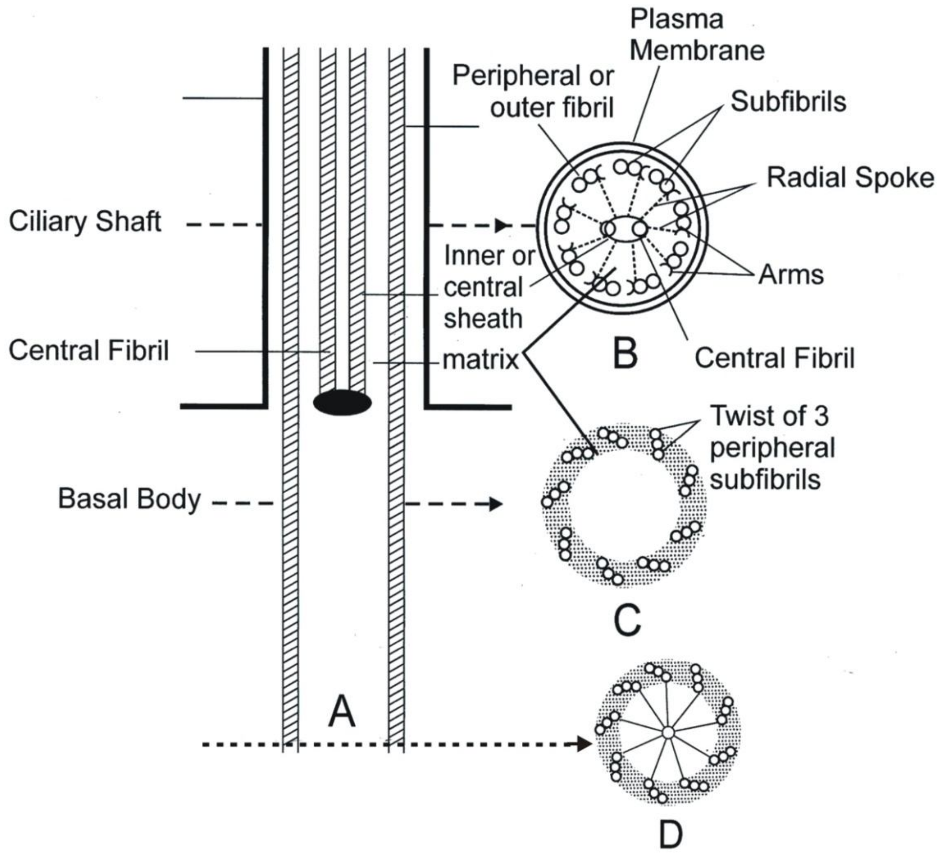


Fig. 1. Structure of a cilium and its basal body.

A-cilium in L.S.

B-Free part of cilium in T.S.

C- Basal body (Distal) in T.S.

D- Basal body (Proximal) in T.S showing cartwheel like structure with 9 spokes.

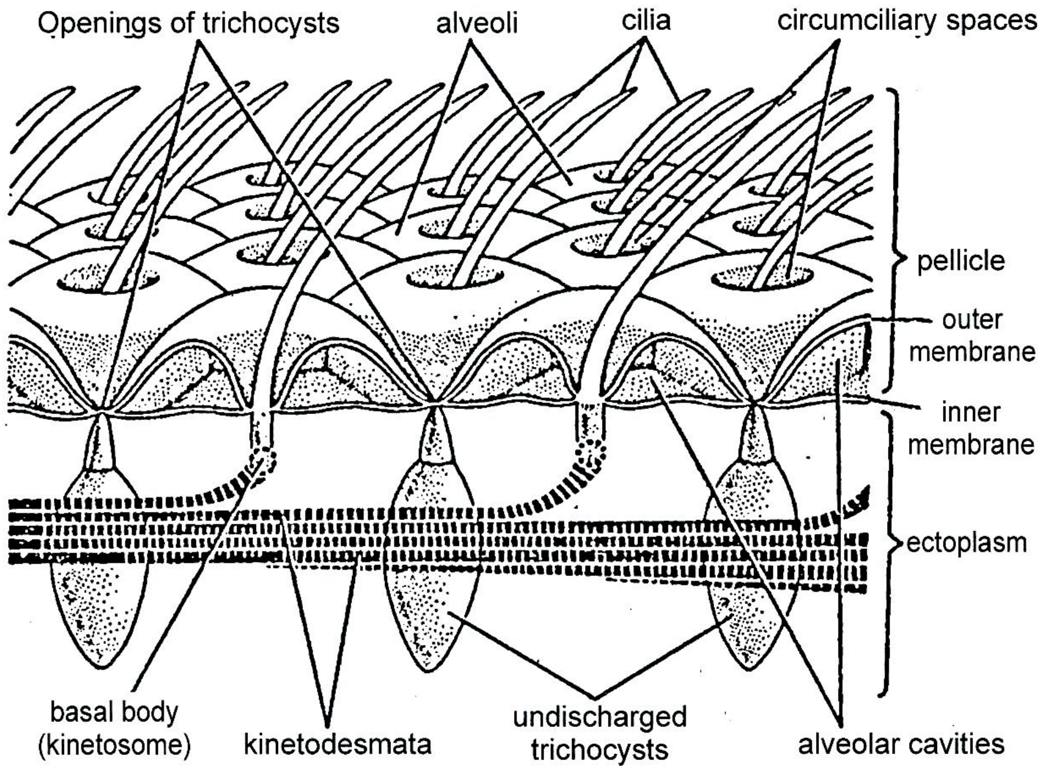


Fig.2. Paramecium: A diagrammatic three-dimensional electron microscopic representation of a portion of pellicle and infraciliary system(Source: Invertebrates by Kotpal) .

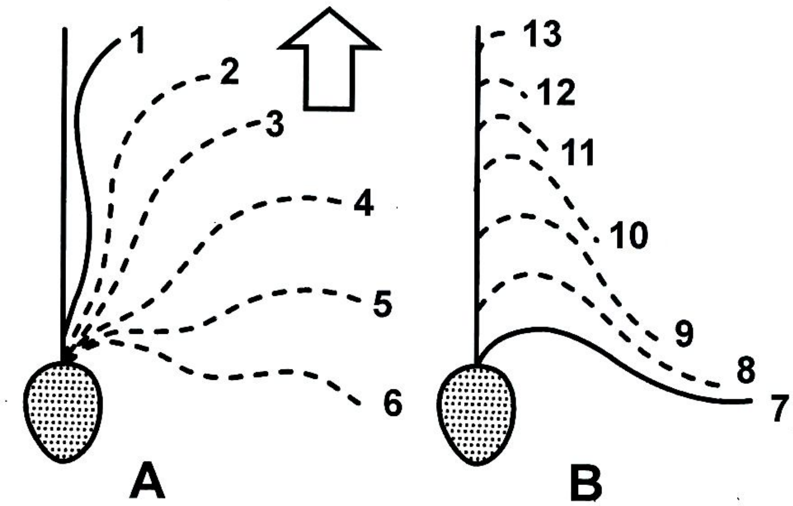


Fig. 3 Flagellar movement A-Effective stroke, B-Recovery stroke

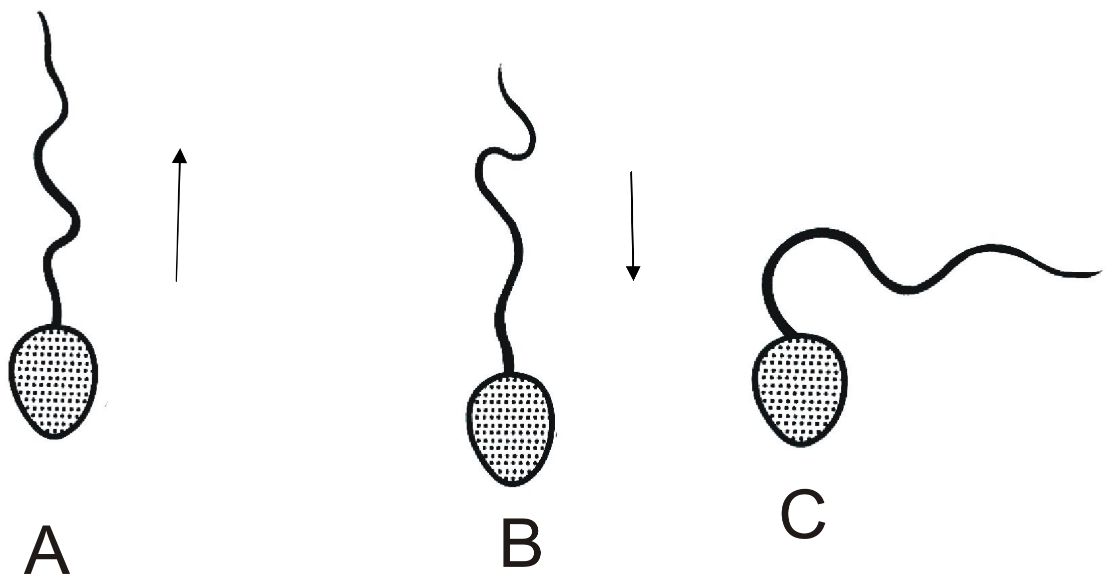


Fig.4 : Flagellar movement

(A) Pushing force generated by base to tip undulations of the flagellum

B & C : Pulling force (like an aeroplane propellar) generated by tip to base undulations of the flagellum.

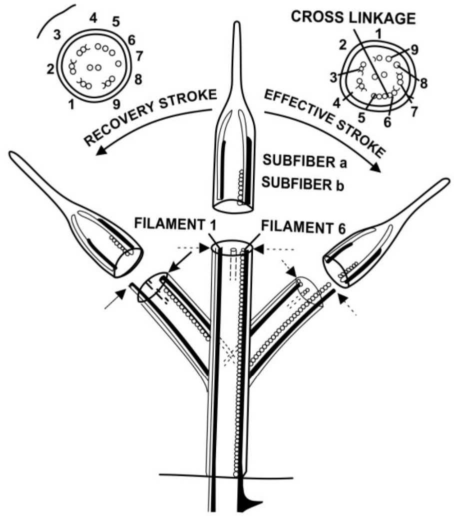


Fig. 6: Movement of subfibrils during beating of cilia and flagella

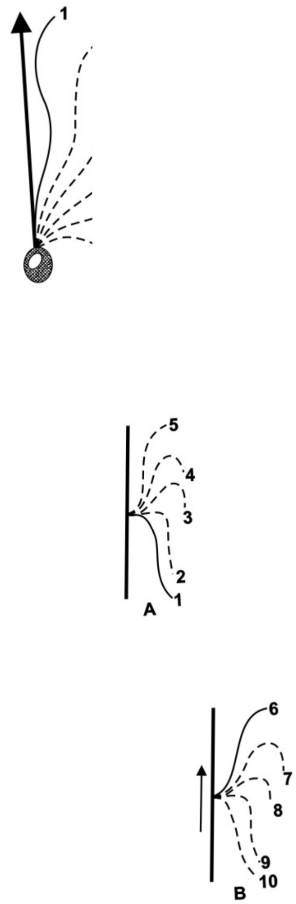


Fig. 5 Ciliary beating: Series of adjacent cilia in metachronal wave

A) Effective stroke

B) Recovery stroke

4.5 Summary

The present unit has covered the locomotion in inverebrtes in terms of amoeboid movement, various theories supporting this movement and most acceptable theory that is Sol-gel theory by Hyman and supported by Pantin and Mast. The Ultra structure of Flagella & Cilia showes that they contain 9+2 arrengement of microfibrils. The molecular basis of their movement involves the use of ATP and Tropomyosin complex. The hydrostatics mechanism for the movement is found in Coelenterata, Nematode, Echinoderms.

4.6 Glossary

- **Alar:** having wings.
- **Cilia:** Numerous small hair like projections from the cell surface that beat in coordinated fashion.
- **Diptera:** Class of Insecta in which two wings are present.
- **Ectoplasm:** The outer part of the cytoplasm.
- **Endoplasm:** the inner part of the cytoplasm.
- **Flagella:** Long whip like cytoplasmic organelle.
- **Foraminifera:** single celled protists with shells.
- **Halteres:** are small knobbed structures modified form of hind wings in Diptera.
- **Heteroptera:** Homoptera
- **Metazoa:** Multicellular organism
- **Pleura:** Lateral sclerite of thoracic segment of an insect.
- **Poikilothermic:** cold blooded animals having body temperature that varies tith the temperature of its environment.
- **Pseudopodia:** Prjection of protoplasm in Protozoa.
- **Sarcodina:** Superclass of protozoa possessing pseudopodia.
- **Sternum:** ventral sclerite of thorax in Insects.
- **Stimulus:** is something that causes a physiological or psychological response.
- **Tergum:** A dorsal sclerite of thorax in Insects
- **Trophozoites:** active, motile feeding stage of a sporozoan parasite.

4.7 Self- learning Excersise

Section -A (Very Short Answer Type)

1. Cilia in *Paramecium* arise from _________.
2. The locomotion in foraminifera occurs by ____________.
3. Blepheroplast has _______arrangement of subfibres.
4. Sol-gel theory of amoeboid movement is given by _________.

(Ans.1-Basal body; 2- Reticulopoda; 3- 9+0; 4- Mast and Pantin;

Section -B (Short Answer Type)

1. Give a short account on fountain zone or front contraction theory of amoeboid movement.
2. What do you mean by sol-gel theory of amoeboid movement?
3. Draw a labeled diagram of the ultrastructure of cilium.
4. Explain kinety found in *Paramecium*.

Section -C (Long Answer Type)

1. Discuss various theories which support amoeboid movement.

4.8 References

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Unit - 5

LOCOMOTION-2 Myonems and muscle fibres in invertebrate structure and their role in locomotion; locomotion in relation to hydrostatics; An outline of flight mechanism in insects

Structure of the unit

5.0 Objective

The objective of present unit is to understand the body organization present in diverse group of Invertbrate.

- How muscles and myonemes, hydrostatics help in locomotion?
- Flight mechanism and wing coupling found in insects.

5.1 Introduction

If we go to higher phyla such as coelentrate and echinodermata animals use hydrostatic mechanism for their movement. The muscles and myonemes are also present in higher phyla for the locomotion. The sliding of myofibrils present in muscles help in contraction and relaxation of muscles and thus in turn create locomotion. In insects which are the only invertebrates phyla known for its flight, use these muscles for their flight mechanism in addition to wings.

5.2 Myonemes and Muscle fibers

The use of muscular tissue for effective movement is a specialized element of metazoan organization, It has been evolved by sponges and is absent from protozoa. However, a fibrilar system is particularly developed within the bodies of protozoa. They consist of filaments, formed of molecular chains, which may be loosely arranged into bundles when they are contractile otherwise in resting stage they are cross-linked to form striated fibrils, example is kinetodesmata of ciliate protozoa. Similar myonemes also occur in peritrichous ciliates and sessile forms, such as *Vorticella, Carchesium* and *Zoothomnium*. They run together towards the base of the organism and continue in to the stalk as a central structure called as spasmoneme. Pellicle of ciliates and protozoan trophozoites, pseudopodia (axopodia) of Heliozoa and flagella and cilia of flagellates and ciliates also possess similar kind of fibrillar system consisting of rigid structures called microfibrils. Thus the development of powers of movement in living systems is preceeded by the evolution of muscle fibres.

The muscular tissue is characterized by the possession of myofibrils throughout the animal kingdom, which suggests that these must lave appeared early is metazoan evolution. The precise alignment, expressed as cross-striations, a characteristic of arthropods and vertebrates, are also found in certain muscle fibres of almost every phylum from the coelenterates onwards. However, sometimes in annelids, echinoderms and in some molluscs the striations have a helical pattern.

5.2.1 Structure of Muscle (Fig. 1)

Each muscle is made up of a number of fibres which are long and multinucleate, cells running the entire length of the muscle. Each fibre is bounded by the **sarcolemma** which comprises the plasma membrane of the cell and the basement membrane. The cytoplasm of the fibre is called **sarcoplasm** and the endoplasmic reticulum, which is not connected to the plasma membrane, is known as the **sarcoplasmic reticulum.**

The plasma membrane is deeply invaginated into the fibre, often as regular radial canals between the Z and the H bands (see below) and this system of invagination is called the transverse tubular or T system. It is associated with vesicles of the sarcoplasmic reticulum. The nuclei may occupy various positions in the cell.

The characteristic feature of muscle cells is the presence of myofibrils (fibrils) embedded in the sarcoplasm and extending continuously from one end of the fibre to the other. The arrangement of the fibrils varies, but they are always in close contact with the mitochondria (known as **sarcosomes**), which are giant and well developed in the flight muscle of insects)

5.2.2 Structure Of Myofibrils

The myofibrils are composed of molecular filaments consisting, mainly of two proteins: myosin and actin and rarely tropomyosin complex (Fig. 1).

Myosin filament: the myosin filaments are made up of two components, heavy meromyosin (molecular weight about 350,000) and light meromyosin (mol. about 150,000). The light meromyosin is probably structural but heavy meromyosin assists in contraction process in two ways. First it acts on ATP and provides energy for the contraction by catalyzing the breakdown of ATP to ADP. Secondly, it binds to actin.

The myosin filaments are thick (11-14 nm in diameter), stouter and are made up of numerous myosin molecules. These filaments are elongate structures with a globular head at one end and in each sarcomere (see below) all the molecules in one half are aligned in one direction, while all those in the opposite half are aligned in the opposite direction (Fig. 2).

Actin filament : These filaments are thin filaments (4 nm in diameter) and composed of two chains of actin molecules (molecular weight about 60,000) which are twisted round each other. The actin filaments are oriented in opposite directions on the two sides of a Z disc, where they are cemented together by an amorphous material. The myosin filaments are each surrounded by an array of six thin, actin filaments, each array being shared by several thick, myosin filaments.

The actin and myosin filaments are linked at intervals by cross-bridges formed from the 'head' ends of the myosin molecules.

A **Tropomyosin Complex** is also present in the contractile elements in small quantities. This complex is associated with the actin filaments, contains two proteins-Tropomyosin and troponin (complex of globulin protein). The released calcium ion during contraction bind to the troponin, which then modifies the tropomyosin molecules is such a way that myosin filament is not allowed or can not make contact with the actin filaments.

All the filaments in a myofibril tend to be aligned so that the whole fibril and fibre appears to be transversely striated or cross-striated hence each sarcomere has the regular alteration of strongly birefringent regions (the anisotropic bands or A-bands) and weakly birefringent regions (the isotropic bands or I bands). Essential features of these striations are the Z discs which run across the fibril at regular intervals cutting off series of units called **sarcomeres**. On either side of the Z discs actin filaments extend towards, but do not reach the centre of the sarcomere, while the myosin filaments do not reach the Z discs, which result in the cross-striated appearance of the muscle. In the centre of the A band, where actin filaments are absent, is the rather paler H-zone (Fig. 2).

5.2.3 Role of Muscles in locomotion

The use of muscular tissue for locomotion is solely due to contraction process found in muscle. A widely accepted theory of muscle contraction is the **sliding filament theory** given by H.E. Huxley. According to this, the contraction of a fibre is brought about by the actin filaments sliding along the myosin filaments. This sliding depends on the rapid making and breaking of cross-bridges, which contract each time they are formed and so slightly displace the actin myofilaments in relation to the myosin ones. The process depends upon the presence of calcuim ions, which are released from the sarcoplasm when the muscle fibre is stimulated and are then actively pumped back again into the reticular canals (sarcoplasmic reticulum) to bring about relaxation.

Magnesium ions are also necessary both for contraction & relaxation. However, unlike calcium ions they cannot by themselves cause fibres to contract, whereas contraction can be evoked by injecting calcium into them.

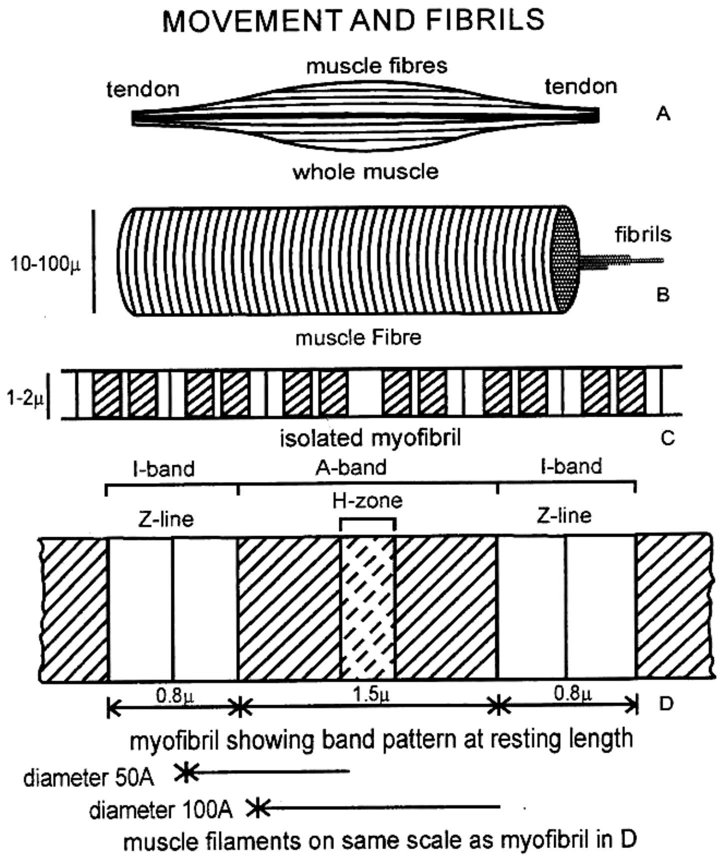

Fig. 1 Structure of muscle

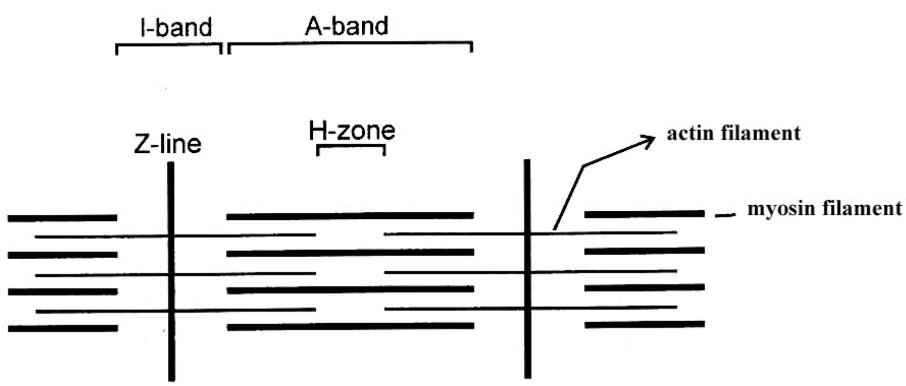

Fig. 2 Diagram of the relationships of an actin filaments (thin) and myosin filaments (thick) of striated muscle

5.3 Movement and Hydrostatics

Movement of any living organism for various activities in essential various types of movements are brought about by muscles and some other mechanisms.

Hydrostatic pressure extended by various organisms is one of such method. A type of skeletal system, known as Hydrostatic skeleton, is formed which is readily modified because of low viscosity of water. The punching of such a hydrostatic system depends upon some musculature, which surrounds an enclosed volume of fluid. When there is some contraction in any part of musculature system, a pressure is exerted on the fluid causing it to reach to rest of the body.

In the simpler organisms the muscle fibres are arranged in two main layers i.e. one circular and other longitudinal. In complex organisms the relationship of hydrostatic skeleton and associated musculature and nerves has been so organised that the localization and complexity of response is increased.

5.3.1 Organization of Coelenterates and Hydrostatic Skeletons

The phylum Coelenterata (Cnidaria) has about 9000 species. Coelenterates are diploblastic, but tissues are not grouped into organs. A single body cavity remains filled with surrounding water having mouth surrounded by tentacles, but no posterior anus. The body fluid functions as hydrostatic skeleton. (Fig 1)

Hydra is very common organism belonging to coelenterata. It shows movements in response to various stimuli. Three main regions associated with movements are tentacles and oral disc, which are mostly concerned with feeding. The second end is pedal disc, through which the animal remain attached with the substratum and slow creeping movement is affected by pedal disc. The last and third region is the column. This region is responsible for main changes in the body and movements. The central cavity known on coelenteron is closed at posterior end. The coelenteron contains the fluid, due to which the animal is able to build up a level of pressure leading to translation of muscular contraction and consequently the movements of the body. In Hydra, the coelenteric fluid along with surrounding epidermal and gastrodermal muscle fibres constitute hydrostatic skeleton.

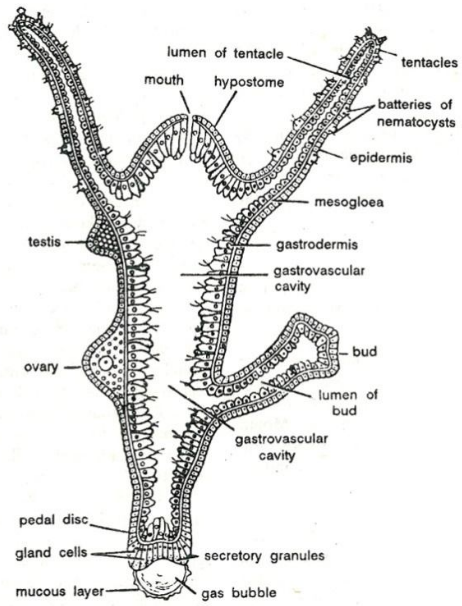

Fig.1 *Hydra.* Longitudinal section of entire animals

In Hydra, sea anemones and other animals belonging to phylum coelenterata there is considerable difference between the column, the foot and the tentacles and oral disc. It is observed that in the tentacles the longitudinal muscles are much better developed than the circular ones. The better developed longitudinal muscle fibres of tentacles are responsible for transporting food to the mouth.

5.3.2 Nematoda

In Nematode eg. Ascaris, the body wall is covered by a cuticle, secreted by non-cellular epidermis and consisting of protein, not of chitin. Underneath the epidermis is present a single layer of peculiar muscle cells, which have an outer contractile part and an inner core of unmodified and non contractile protoplasm. These muscle cells are arranged as a layer of longitudinal but not as circular layer and no muscles present in the body wall. Between these muscle layers and alimentary canal is the pseudocoel, and is filled with fluid, which froms a hydrostatic skeleton. In Ascaris, this is a unique type of hydrostatic skeletal system. The internal hydrostatic pressure of Ascaris is considerable. This pressure, acting in conjunction with the tension exercised by the body wall and with some degree of muscular tone is responsible for maintaining the constant shape, cross-section and length, characteristic of nematode body. It also provides simple undulating movements of this group of animals.

5.3.3 Echinoderms

Echinoderms or star fishes belong to a well characterized phylum in which hydrostatic principle has evolved perfectly for locomotion and feeding.

The principles involved in the use of tube feet for locomotion and prey capturing have been well studied in Asterias. A peculiar hydrostatic pressure mechanism is found in start fishes, which is known as water vascular or Ambulacral system, used for locomotion and prey capturing. (Fig 2)This system is composed of following structures.

(a) **Madreponite :** It is a rounded, thick and sieve like calcareous plate, which is situated on the aboral surface on the central disc of star fishes. It possesses numerous fine radiating furrows having more or less 250 small bones and each pore leads into a small pore canal. All the pore canals unite to from larger collecting canal within the madreporite. All the collecting canals finally lead into a sac like ampulla below the madreponite. The ampulla is continued into a stone canal.

(b) **Stone canal :** This canal is also known on madreporic canal, which is a S. shaped tube like structure which opens into ring canal on the oral side. The wall of stone canal is supported by a series of calcareous rings, to provide it strength, hence it is known as stone canal. The cells lining the stone canal are provided by cilia or flagella which create water current to draw water in it. In the beginning or in young star fishes the stone canal is a simple tube but later on, two spirally coiled lamellae develop within its lumen.

(c) **Ring canal** : Ring canal is a wide ring like canal around the oesophagus. It is pentagonal in Asterias and each angle of pentagon lies in a radial position.

(d) **Tiedmann's bodies :** Also known as racemose glands, are small, rounded and glandular sac like structures, opening into ring canal. They are nine in number and the position of 10^{th} is occupied by the stone canal, which opens into the ring canal. Each Tiedmann's body is consisted of outer peritoneum's enclosing a stroma of connective tissue and some muscle fibres along with numerous tubules. Exact role of Tildmann's bodies is still unknown, however according to some workers they are associated with filteration, while according to others these are enzyme forming bodies or as lymphatic glands, manufacturing phagocytes, which are released into the water streams.

(e) **Polian vesicles** : Polian vesicles are thin walled contractile structures. They are located at each interradius and opening on outer surface of the ring canal. It is supposed that they store water and help in regulating water pressure. Polian vesicles are absent in Asterias (Family : Asteridae).

(f) **Radial canal** : From the ring canal there arises a radial canal along each radius, which extends up to tip of corresponding arm. Each radial canal runs in the ambulaeral groove and terminates as lumen the mi terminal tentacle.

(g) **Lateral canals** : In each arm the radial canal gives out two series of lateral or podial canals along its entire length. The lateral canals of two series are short and long alternately in such a way that a short canal has a long canal on its outer and inner side, but only a short canal on its opposite side. Each lateral canal opens into a tube foot.

(h) **Tube Feet** : As each lateral canal opens into a tube foot, there are two double rows of tube feet with respect to each series of alternately present short and long lateral canal. Each tube foot consists of three regions – viz a rounded sac – like ampulla, a middle tubular podium and a cup like sucker at the terminal lower end of the podium.

Each podium in present above the ambulacral ossicle, and projecting into the coelom. The tubular podium extends through the ambulacral groove. The walls of the tube foot contains longitudinal muscles while the wall of the ampulla contains circular muscles.

The most peculiar function of this systems is locomotion by providing a hydraulic pressure mechanism. Tube feet also help in capturing prey. Thin wall of tube feet may also help in respiration by exchanging gases.

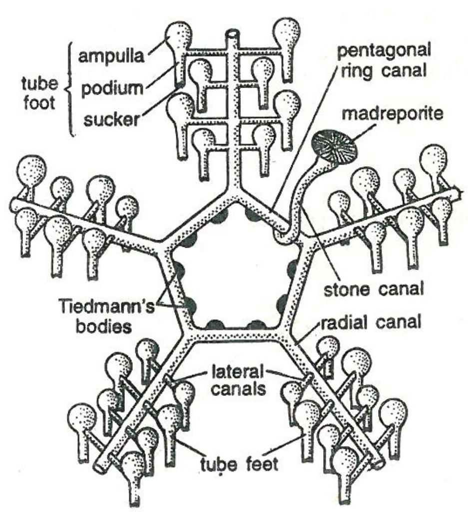

Fig.2 ***Asterias.*** **Water-vascular system**

5.4 Flight Mechanism in Insects

The Success of insects as terrestrial animal is at least partly to their ability to fly. Insects are the only poikilothermic fliers. Flight activity may be concerned with routine behavior such as feeding & reproduction or it may take the form of dispersal flight or migration from the habitat (insect fliers) and a low metabolic rate impose limitations on mobility. Insects fly by beating their wings up and down and only a few large species are known to glide for any distance between wing strokes.

5.4.1 Machinery of Insect flight

It involves mainly threecomponents.

1. Wings.
2. Muscles
   (i) Direct flight muscles
   (ii) Indirect flight muscles
3. Thorax

1. Wings:-Typically adult insects have two pairs of wings articulating with the thorax and consist of flattened lobes of the integument supported by hollow veins. At the bases of the wings, small sclerites articulate with the thorax permitting not only the movement of the wings in flight, but also enabling them to be folded back over the body when at rest. At the base of the wings are sense organs concerned with the control of wing movement and in the Diptera, the hind wings have become wholly modified as a sense organ. Wings also help in propulsion (pushing forward) of insect and during flight insect and during flight mobile wings establish a flow of air over them. Each wing articulates with the edges of the tergum, but its inner end rests on a dorsal pleural process, which acts as a fulcrum.

Insect flight muscles are very powerful. the fibrils are relatively large and the mitochondria are huge (about half the size of a human red blood cells.)

2. Muscles:- The muscles of wing fall into two classes;

(i) Direct muscles.
(ii) Indirect muscles.

Direct Muscles:- These muscles are inserted into the base of the wing-basalar and subalarsclerites which are connected to the axillarysclerites by ligaments (Fig. 1) lateral view of the thorax showing the direct wing muscles.

These are of three types.

(i) **Flexor muscle** arising on the pleuron and inserted into the third axillary sclerite (flexes the wing backward)

(ii) **Basalar Extensor/Elevator** muscles arise from episternum, sternum and coxaare inserted into the basalar.These causes extension of the wing from the flexed position.

(iii) **Subalar Depressor** arising on the meron is inserted into the subalar.These muscles extend and depress the wings.

Indirect muscles :-These are not directly associated with the wings, but move the wings as a result of the distortions which they produce in the shape of the thorax.

These are of three types (Fig. 2) :

1. Dorsolongitudinal muscles runs dorsally and longitudinally between the mesothorax and metathorax.
2. Dorsoventral/Tergosternal muscles run dorosoventrally between tergum and sternum from post phragma.
3. Oblique dorsal muscles are well developed only in Diptera and Cicadidae but absent altogether, often small in others.

3. **Thorax** : - Thorax provides base for the attachment of wings and flight muscles. It not only provides base but also during flight the shape is also changed.

5.4.2 Mechanism of Flight

There are mainly two types of flight mechanisms found in insects.

(1) Synchronous (2) Asynchronous.

Synchrous flight Mechanism:-The wing strokes are of synchronous when each contraction of the flight is produced by a nervous impulse and thus muscles are described as synchronous. Usually the wing beat frequency of insects with synchronous flight muscles is low, not more than about 25 beats/second.These insects are slow fliers and this type of mechanism is found in primitive insects like Odonata, Orthopteraand Lepidoptera.

Asynchronous flight mechanism:- The Wing strokes during the flight is asynchronous type in which several contractions of the flight muscles are produced after the arrival of each nerve impulse.The ratio of contractions to stimuli differs from the normal 1:1 ratio and these muscles are said to be asynchronous. The wing beat frequency often exceed 100 beats/sec. infast flier insects eg. Dipterans.Usually indirect muscles are involved during asynchronous type of flight mechanism.

Movements of wings:- The movement of the wings during the stroke is complex and the twisting of the wings is particularly important because this controls the production of aerodynamic forces which propel the insect through the air.

The up and down movement of the wings are produced due to :

1. Movement of flight muscles.
2. Elasticity.

1. Movement produced by the muscles.

Upward Stroke: In all insects the upward movement of the wings is produced by indirect dorso-ventral muscles inserted into the tergum of the segment bearing the wing. By contracting, they pull the tergum down and hence also move down the point of articulation of the wing with the tergum. The effect of this is to move the wing membrane up with the pleural process acting as a fulcrum.[Fig.3(A)].In some insects (Psyllidae) dorsoventral muscles are small and are replaced by the oblique dorsal muscles.

Forward & BackwardStroke: Up and down movement alone is not sufficient for flight. The wrongs at the same time must be moved forward and backward.

(a) Wings during flight, are not flat, therefore air get spilled over buckled back margin andthus gets a forward impulse.

(b) Wings are coupled together so that air gets spill over trailing edge and there forward thrust is created.

(c) A complete cycle of a single wing beat describes on eclipse (eg. grasshoppers) or a figure eight (eg. bees & flies), during which the wings are held at different angles to provide both light forward thrust. The figure eight is formed so that the tendency of air to get spilled over trail edge increases. [Fig. 4 (A & B)]

Downwards stroke :[Fig. 3 (B)] & Fig. 5(B)

Downwards stroke involving direct muscles: In Odonata andBlattaria the downward stroke is produced by direct muscles inserted into the basalar and subalarsclerites which are connected to the axillary sclerites by ligaments.

Hence contraction of these muscles exerts a pull on the wings outside the fulcrum of the pleural process and pulls the wings down.

Downward stroke involving indirect muscles: InDipteraand Hymenoptera the downward movement is produced by the dorsal longitudinal indirect muscles. The contraction of the dorsal longitudinal muscles cause the centre of the tergumto become bowed upwards (Fig.2 D), So that the tergal articulation of the wing is also moved up and the wing membrane flaps down (Fig.2 C)

Movement due to elasticity:-Contraction of the indirect flight muscles distorts the thorax so that the elastic properties of the thorax as a whole are also significant factors in wing movement. (Fig. 6) shows diagrammatically the manner in which the movement of the wings involves a lateral movement of the wall of the thorax. This movement is resisted by the elasticity of the thorax which is largely due to the sternopleural articulation and to a lesser extent, the tergopleural articulation. In thismanner much of the energy involved in the upward strokes is stored as elastic forces for use in the downward strokes. This is possible because the aerodynamic forces produced at this time act in the same direction as the wing movement, so assisting its movement.

The stable position for the wing is either to the fully up or fully down positions. Thus in flight, the wrings are moved by the muscles to the position of minimum instability and than they will swing into the up or down position as a result of the thoracic elasticity. This arrangement is called a 'Click' mechanism. At the end of each wing stroke the movement produced by the 'click' is limited by a stop. This gives greater efficiency in flight.

5.4.3 Speed and energy of flight

Flight speed is probably determined by air flow over receptors on the anterior and movement of objects from front to back across the eyes. Hinges of wings have a protein called as callesresilin. It produces energy that converts into forces which provide thrust for forward movement that can work against the air current and gravity. The fuels from which energy is derived vary in different insects. Hymenoptera and Diptera use carbohydrates. Locusts and aphids use carbohydrates at the beginning of flight, but subsequently burrn fat, which also provides the substrate in Lepidoptera.

5.4.4 Wing Coupling (Fig.7)

The wings of most insects are moved by distortions of the thorax, hence it is impossible for the fore and hind wings to beat completely independently of each other. (In Orthopera and Odonata, the wings are not linked, both pairs of wings vibrate with the same frequency and the hind wings beat consistently more advanced than the fore wings beat) such mechanical linking of the wings is known as wing coupling.

The two winged condition is apparently more efficient than the four winged and in the majority of insects the mechanical coupling of the fore and hind wings is supplemented. The wing coupling is made more precise, by an anatomical coupling of the fore and hind wings so that they move together as a single unit. Follwing are the various forms of Wing coupling :

(1) Primitive MecopteranPattern : - It is a primitive arrangement in which there is a jungal lobe at the base of the forewing and a humeral lobe at the base of the costal margin of the hind wing. Both lobes are set with setae, those on the humeral lobe being termed frenular bristles (Fig. 7(A)).

(2) Jugate wing coupling: It is not a very efficient coupling mechanism. In Trichoptera only the jugum is present on the fore wing and it just lies on top of the hind wing.But the Hepialidae have a strong jugal lobe which lies beneath the costal margin of the hind wing so that this is held between the jugum and the rest of the fore wing (Fig.7(B))

(3) JugoFrenate coupling - The jugum is folded under the fore wings and holds the frenular bristle eg. Micropterygidae.

(4) Frenate coupling –(Fig. 7 C&D) Many Lepidopterans have the frenulum well developed and engaging with a catch or retinaculum on the underside of the fore wing so that the wings are firmly coupled.

(5) Amplexiformwing coupling: - In this type of coupling the wings are coupled by virtue of an extensive area of overlap between the two. eg. Papilonoideaand Bombycoidea.

There are many more modifications for wing coupling. Few examples are : Hymenoptera have a row of hooks, the hamuli along the costal margin of the hind wing which catch into a fold of the forewing. Psocopterahave a hook at the end of cu (vein) of the fore wing, which looks on to the hind costa.Heteroptera have a short gutter edge with a brush of hairs on the underside of the clavus which holds the costal margin of the hind wing. Homoptera have modifications linking the anal margin of the fore wing to the costal margin of the hind wing.

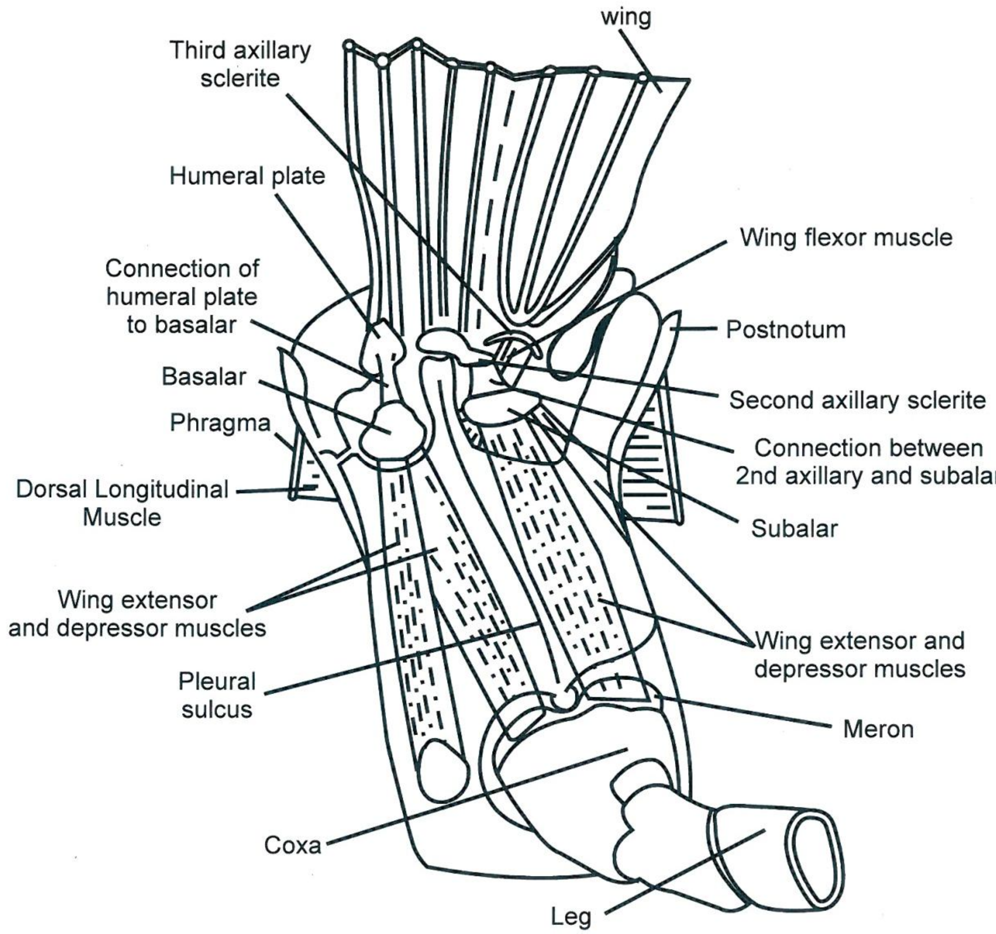

Fig. 1 : Lateral view of the thorax showing the direct wing muscles.

The pleural region is assumed to be transparent (Source: Snodgrass)

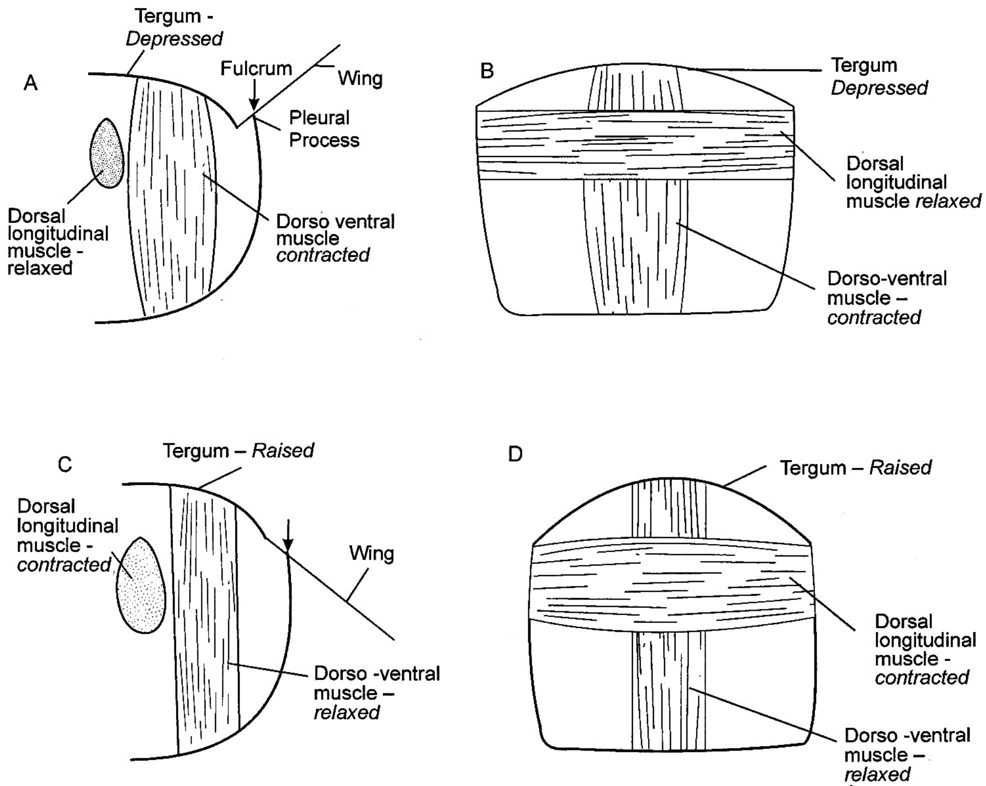

Fig. 2 : Diagrams illustrating the movement of the wings in an insect, in which both up and down movements of the wings are produced by indirect muscles.

A and C – cross section of the thorax

B and D – views the wing bearing segment from the inside

D – showing the shortening and bowing of the tergum produced by contraction of the doral longitudinal muscles.

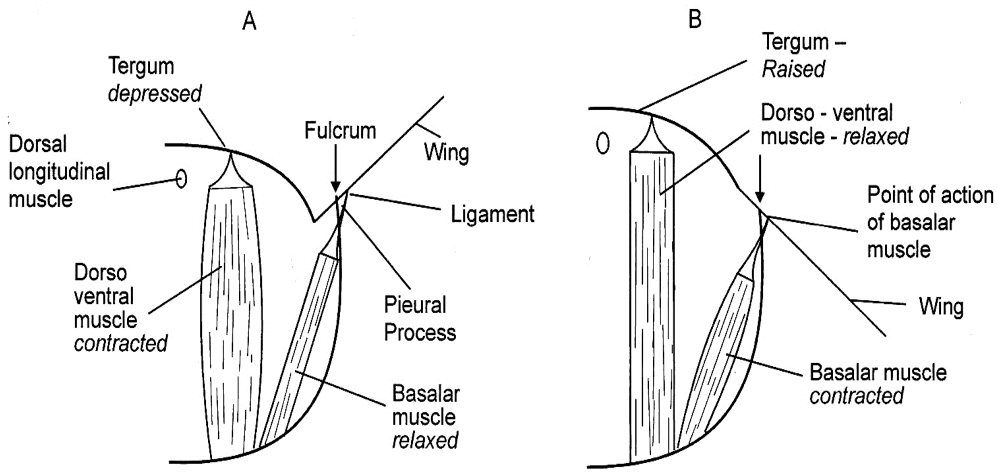

Fig. 3 : Diagrammatic cross section of the thorax illustrating the wing movements in an insect, such as a dragonfly in which he direct wing muscles cause depression of the wings

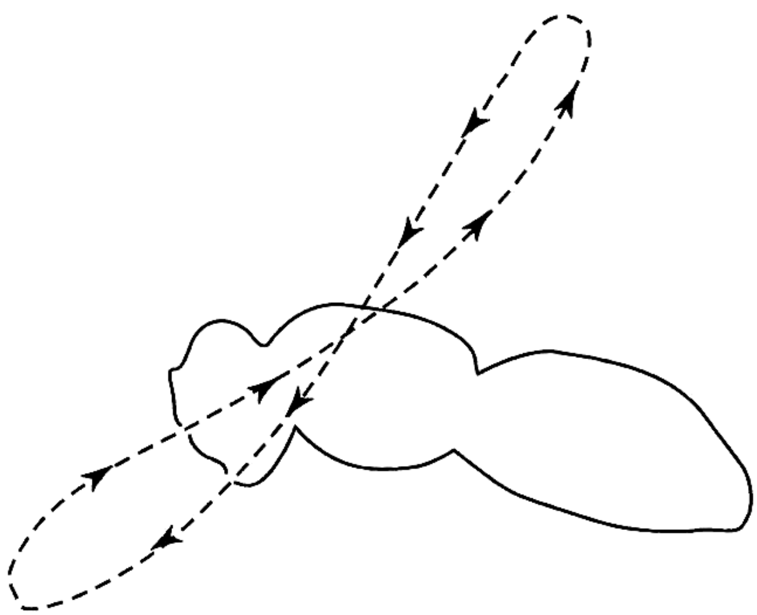

Fig. 4(a): An insect showing the figure 8 described by the wing during an upstroke and a downstroke

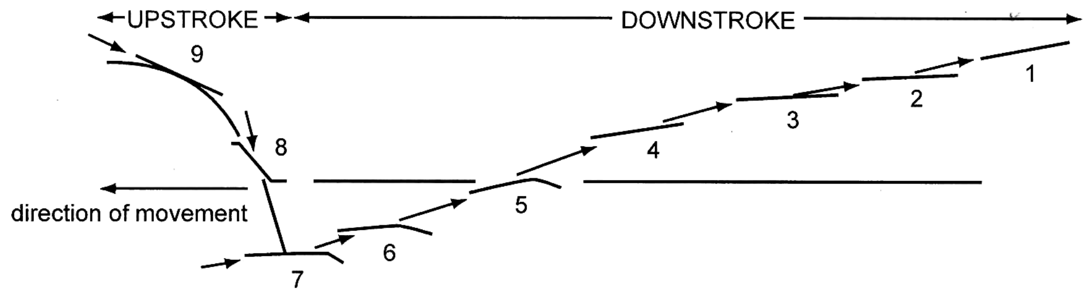

Fig. 4(b): Changes in the position of the forewing during the course of a single beat

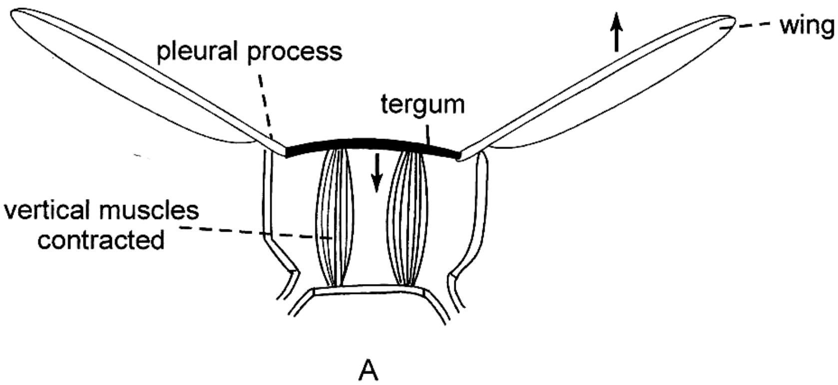

Fig. 5 (A): Upstroke resulting from the depression of the tergum through the contraction of vertical muscles

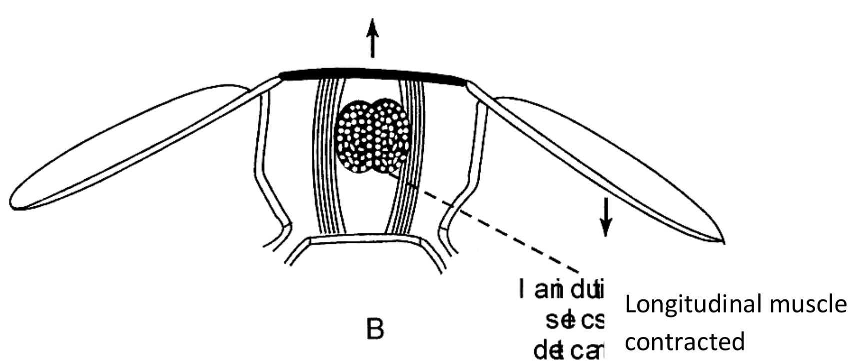

Fig. 5 (B): Downstroke resulting from the arching of tergum through the contraction of longitudinal muscles

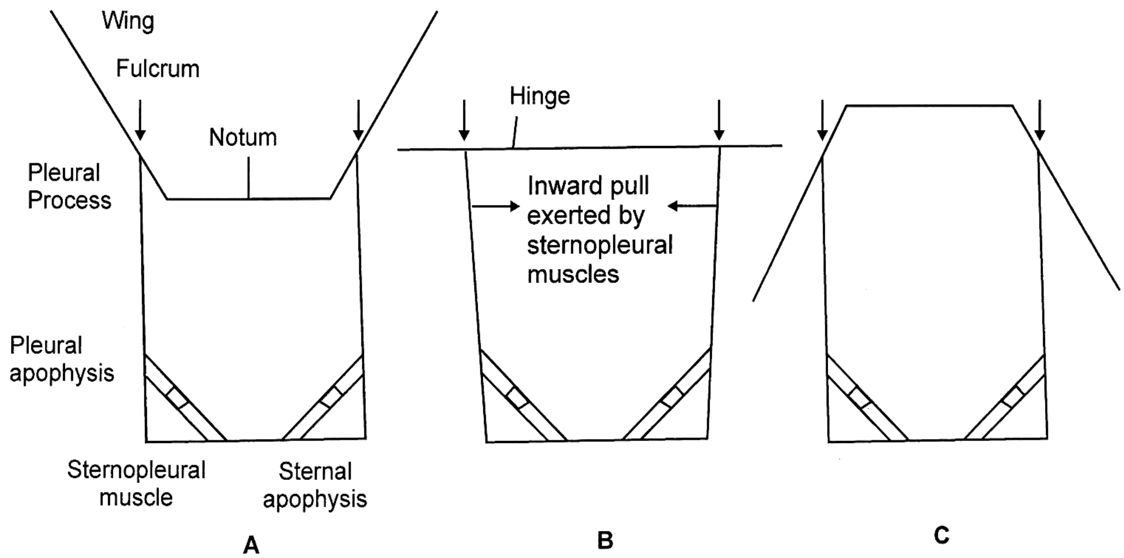

Fig. 6: Diagrammatic cross-section of the insect throax illustrating the distortion of the throax produced by wing movement

A. Wings stable in the up position.
B. Unstable position due to the inward pull of the sternopleural muscles.
C. Wings stable in the down position.

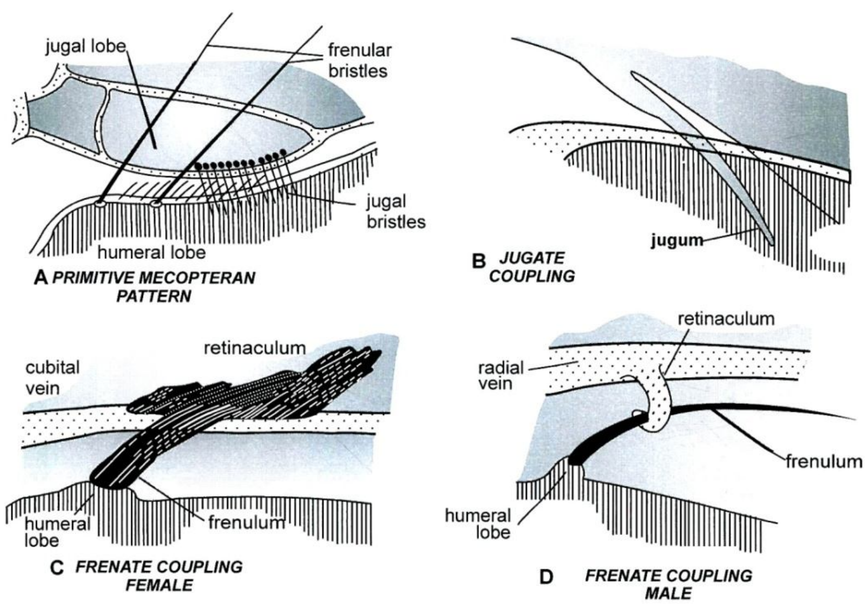

Fig. 7 : Wing coupling mechanism

5.6 Summary

Muscles and myofibriles have cross-straited structure to presence of alternate anisotropic and isotropic bands. Their movement involves sliding movement theory in which filaments acting and myosin slide in a manner that their contraction and relaxation occur.

The flight Mechanism in Insects includes the machinery i.e. Wings, Muscles and Thorax. The Direct and Indirect muscles are present in thorax attached with wings directly or indirectly, respectively. Their contraction and relaxtion brings about the synchronous, asynchronous movement upword and down stroke and forward andf backward strokes. A special features i.e. "wing coupling" is also present to support the flight mechanism in insects.

5.7 Glossary

- **Alar:** having wings.
- **Cilia**: Numerous small hair like projections from the cell surface that beat in coordinated fashion.
- **Diptera:** Class of Insecta in which two wings are present.
- **Ectoplasm:** The outer part of the cytoplasm.
- **Endoplasm:** the inner part of the cytoplasm.
- **Flagella:** Long whip like cytoplasmic organelle.
- **Foraminifera:** single celled protists with shells.
- **Halteres:** are small knobbed structures modified form of hind wings in Diptera.
- **Heteroptera:**Homoptera
- **Metazoa:** Multicellular organism
- **Pleura:** Lateral sclerite of thoracic segment of an insect.
- **Poikilothermic:** cold blooded animals having body temperature that varies tith the temperature of its environment.
- **Pseudopodia:** Prjection of protoplasm in Protozoa.
- **Sarcodina:** Superclass of protozoa possessing pseudopodia.
- **Sternum:** ventral sclerite of thorax in Insects.
- **Stimulus:** is something that causes a physiological or psychological response.

- **Tergum:** A dorsal sclerite of thorax in Insects
- **Trophozoites:** active, motile feeding stage of a sporozoan parasite.

5.8 Self- learning Excersise

Section -A (Very Short Answer Type)

1. Mitochondria present in muscles are known as ________.
2. The contraction of muscles is stimulated by ______ ions.
3. Movement in *Hydra* is due to _____________.
4. Echinoderms use _________ for locomotion.
5. Actin is present in thin filament (T/F).
6. ________ the only poikilothermic animal which can fly.

(Ans.1- Sarcosomes; 2- Calcium; 3- hydrostatic pressure; 4- Tube feet; 5- T; 6- Insects.)

Section -B (Short Answer Type)

1. Draw a diagram of a sarcomere of muscle showing different regions.
2. Define sliding filament theory of muscle contraction.
4. Give a short note on hydrostatic skeleton of *Hydra*.
5. Explain how hydrostatic pressure mechanism help in locomotion in echinoderms.
6. Differentiate between direct and indirect muscles present in insects.
7. Compare synchronous and asynchronous flight mechanism in insects.

Section -C (Long Answer Type)

1. Explain in brief the structure and role of muscles in locomotion.
2. Write an essay on movement and hydrostatics.
3. Give a detail account on machinery involved in flight mechanism of insects.
4. What do you mean by wing coupling found in Insects? Explain in brief.

5.9 References

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Unit - 6

Nutrition and Digestion

Structure of the Unit

6.0 Objectives

After going through the Unit you will be able to the processes of nutrition and digestion in lower animals, the various modes of feedings have been explained viz. ciliary feeding , filter feeding and parasitic feeding found in different phyla of invertebrats.

6.2 Introduction

All living organisms on the earth need energy to remain alive and maintain the equilibrium state of their bodies. The energy is obtained from internal or external material or chemical compounds by biological or biochemical transformation. To obtain the supply of such chemicals from external source or to synthesis by themselves using simple substances using sun's energy or chemical energy is nutrition.

Invertebrate is a group that includes a wide range of animals regardless of their organisation and phylogenetic relationship. These have no similarity in structure of function even then these are placed in a group 'Invertebrata'. These show one negative character commonly that the absence of a vertebral column. So, invertebrata is a heterogenous group of animals devided in 30 phyla out of them 11 phyla are called major and rest are minor in terms of number of species and individuals, and their contribution in ecological communities. All these are so diverse in their structural organisation and functions that it is difficult to draw some grand plan of the nutrition.

6.3 Nutrition In Invertebrates

Invertebrates obtain their nourishment in several ways. Some synthesize their own food, others obtain it from another organisms. Such organisms uses several methods to obtain their nourishment from their 'food sources'. Some invertebrates adopted parasitic mode of life and some other lead saprozoic mode.

Types of nutrition in Invertebrates

Many types of nutrition are found in invertebrates:

1. **Holophytic nutrition** : this is a autotrophic (self feeding) type of nutrition in which animals synthesize the food by photosynthesis. Energy is obtained from the sun to synthesize the food. This method is also called autotrophic phototrophy.

2. **Holozoic nutrition** : most of invertebrates obtain their food by eating fully or parts of other organisms (plants or animals). Such mode of nutrition is called holozoic. This is also named as heterotrophic (others feeding) mode of nutrition.

3. **Parasitic nutrition :** this also a type of heterotrophic nutrition but very specialized in its operation. These organisms obtain their food from other living organisms by causing non or little harm to their host organisms. There are two types of parasites: ectoparasites that live externally on the body of their host organisms to drive food, while endoparasites live inside the body of their host organisms. Invertebrates show a diversity in obtaining food from their hosts. Some absorb pre-digested food from their body surface, while others obtain pre-digested/ partially digested food from their mouth and process in their own digestive system. Some use directly the serum of their hosts blood.

4. **Saprozoic nutrition :** this heterotrophic mode of nutrition involves absorption of food by osmosis, meaning through the body surface. This

is also called osmotrophy. Food consists largely of solution of dead organic matter processed by decomposing bacteria.

5. **Myxotrophic nutrition :** in this mode of nutrition the animal adopts a combination of more than one mode of nutrition. For example, autotrophy is combined with phagotrophy or osmotrophy or parasitism.

6.4 Digestion In Invertebrates

Although, digestion of food material in the invertebrates also show a diversity in terms of types of enzymes and place of digestion, yet these follow a general plan. Infact, the process of physiology of digestion involves three basic steps – ingestion (intake of food), digestion (enzymatic breakdown of food stuff) and egestion (discarding undigested part of food). The details of the physiology differs in the invertebrates depending upon the mode of nutrition and type of food eaten. If the animal is eating big pieces or whole of the organism (as food) then it will cut and masticate the food before digestion and have apparatus for food mastication and grinding.

If the animals is feeding upon small, minute particles of food then above is not needed. Again if it is osmotroph or parasite absorbing pre digested food, then there no need of food digestion at all.

The general plan of digertion is : proteins (of food material) are digested in acidic medium (P^H 4-6) under the action of proteolytic enzymes (proteases, for example zymase). Carbohydrates are digested in alkaline medium (P^H above 7) under the action of amylolytic enzymes (amylases, ex. amylase). Lipid is digested by lipases . However, certain invertebrates only are reported to have the capacity to digest fats/lipids. It is also reported that mostly fat/lipid is egested undigested. Details of digestion differ in all the phyla and individual species.

On the basis of place of digestion, two types can be indentified : external (process of digestion occurs outside the body) and internal (process of digestion occurs inside the body). Internal digestion is again of two types : extracellular (in which food is digested outside the cell usually in the cavity of an organ surrounded by cells) and intracellular (inside the cell). Some invertebrates may show a mixture of the two, that is food is initially processed outside the cell and completed inside the cell, after the phagocytosis of partially digested food inside the cell.

6.5 Amoeboid Feeding

Amoeba is a member of phylum Protozoa. It is a carnivorous animal and adopted according to holozoic mode of nutrition. It adopts the phagotrophic type of feeding mechanism. Since amoeba is acellular (often called unicellular) therefore its feeding method is called phagocytosis. In this feeding mechanism solid food particles are engulfed by amoeba. This process is so typical that it is often called amoeboid feeding.

The solid food of amoeba consists of bacteria, diatoms, flagellates, ciliates, rotifers and desmids. A part from the fact that amoeba lacks special sense organs, it can recognize food and distinguish food from particles. In several studies amoeba is reported to show its food preferences. It shows acceptance and avoidance behaviour too.

Amoeba ingest its solid food by capturing and engulfing by phagocytosis. It uses its locomotory organs the pseudopodia for this purpose. The body surface (plasmalemma) when comes in contact with food the pseudopodia are formed. According to protozoologists amoeba and amoeboids use four well identified methods for ingestion of food, depending on the type and nature of food.

1. **Import** – As the term indicate the food e.g. algal filament is taken into the cell passively. The food comes in contact of plasmalemma and passively sinks into ectoplasm and then in endoplasm.

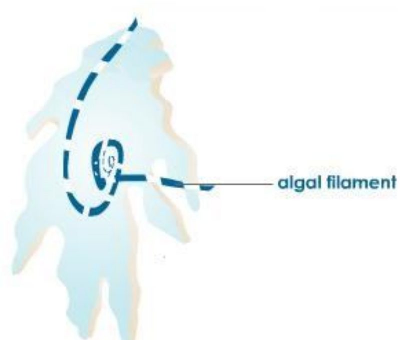

Fig1: Amoeba ingesting an alga by import

2. **Invagination** – The food sticks to plasmalemma when it comes in contact of amoeba. The ectoplasm forms a kind of tube (ectoplasmic tube) and takes the food into it. The tube is later converted into food vacuole.

3. **Phagocytosis or cicumvallation** – In this method amoeboids engulf the active prey with the help of pseudopodia. When food is near the plasmalemma the pseudopodia makes a cup like structure around the prey called 'food cup'. The opening of food cup constricts and is finally closed and envelopes the food in food vacuole or gastric vacuole. Food vacuole is a non contractile vacuole containing food and some water.

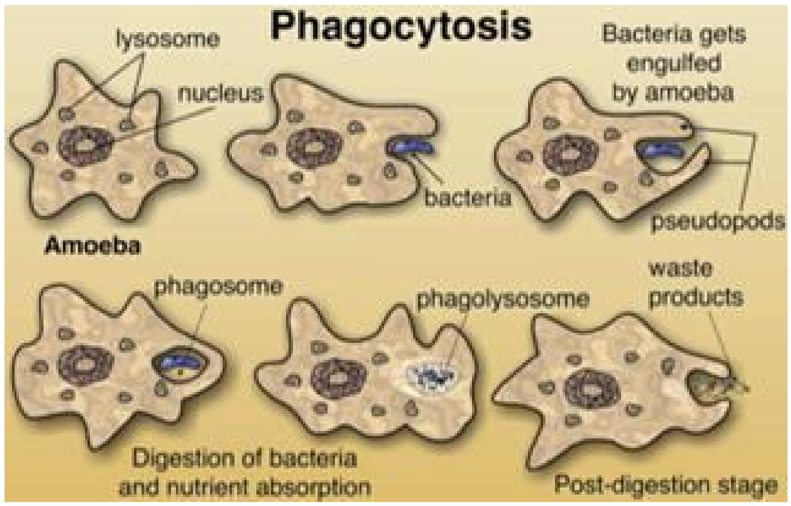

Fig2: Amoeba ingesting a bacteria by phagocytosis.

4. **Pinocytosis** – By this method liquid food is taken in the body. This method is similar to phagocytosis or cicumvallation. A food vacuole is also formed containing liquid food and surrounding water. Proteins, inorganic ions and oil droplets are taken in by pinocytosis. Like food cup the food is surrounded by pinocytosis channels through which liquid food flows into pinocytosis vesicles or pinosomes formed towards inner side of them.

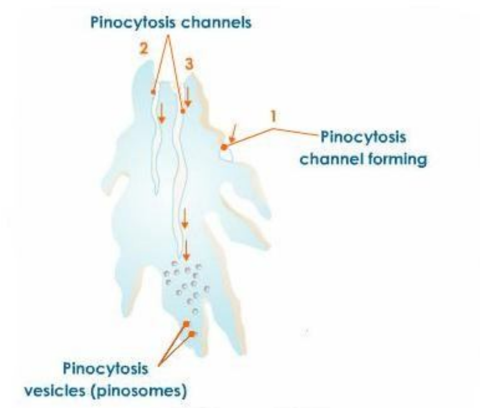

Fig3: Pinocytosis in Amoeba.

5. **Circumfluence** – When amoeboids come in contact with motionless or very slow moving food organisms (for example- bacteria), this method is used. In this method too, the pseudopodia forms food vacuole around the food and take it into the cytoplasm (endoplasm).

Digestion – the food vacuole is a temporary, non contractile vacuole contains food, some water of surrounded by membrane. After reaching to endoplasm, it fuses with lysosomes that contains a variety of enzymes. These lytic enzymes (protease, amylase and lipase) are mixed with food during cyclosis of cytoplasm. It has been shown in studies that the medium of food vacuole is initially acidic and later it is alkaline. The food is digested during cyclosis of endoplasm.

Absorption – As digestion progresses, the digested food diffuse into the surrounding endoplasm. The process of digestion is completed in roughly 30 hours. The digested food is assimilated and used in metabolic activities.

Egestion – After diffusion of digested food, the food vacuole is reduced in size. At the end of digestion it contains undigested part of food. This is emptied by reversed phagocytosis. In amoeboids there is no fixed part for the egestion.

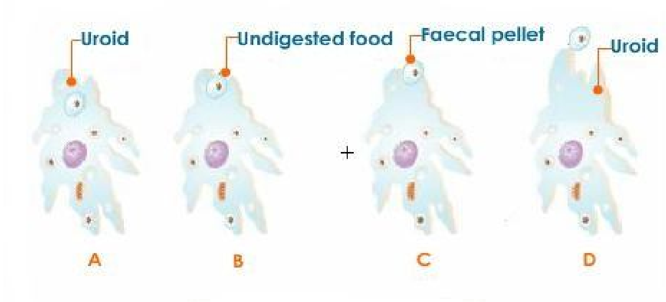

Fig4: Amoeba showing stages of egestion of undigested food.

6.6 Ciliary Feeding

The ciliates (phylum Protozoa) typically ingest their food through a mouth in two distinct ways –

a) Macrophagy and,

b) Microphagy.

In the first method some ciliates catch and ingest comparatively large organisms (often other ciliates). In second method, small organisms (e.g. bacteria) are directed towards the mouth by means of currents set up by their cilia. Another third method is also developed and evolved by holotrichous ciliates is 'feeding assisted by trichocysts'. These are oval or rod shaped bodies, lying in the pellicle at right angles to body surface. When they come in contact with food, they are extruded. Trichocyst discharge a long cylindrical shaft which bears a short spine at its free end or tip. These serve to attach to the prey organisms. There is much variation found in ciliary feeding mechanisms adopted by ciliates individually. Essentially, ciliary feeding apparatus involves three basic organelles:

1. Cytostome surrounded by cilia
2. Cytopharynx
3. Food vacuole

Ciliary feeding can by observed and described in a type animal **– Paramecium.**

Food - paramecium normally feeds mainly on bacteria, hence mode of nutrition is holozoic. Other food items are unicellular plants, pther protozoans and small parts and pieces of animals and plants. Although, it lacks specific sense organs, yet it can select and reject food particles. A single paramecium cam feed about 2 to 5 million bacteria in 24 hours.

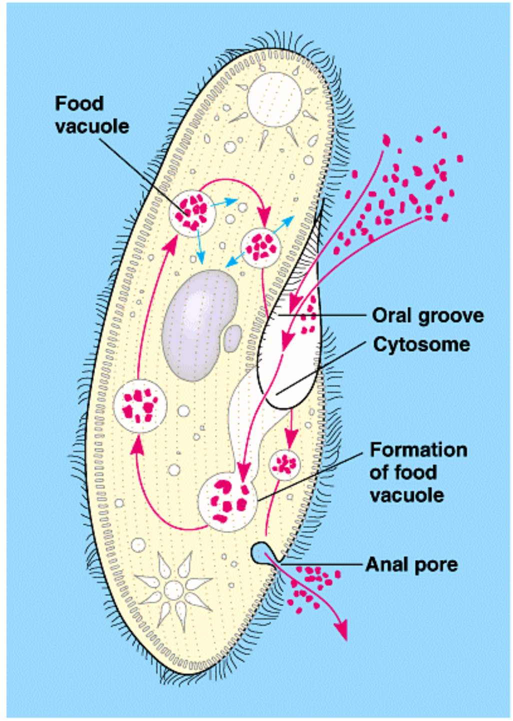

Fig5: Paramecium showing cyclosis and path of vacuoles in endoplasm

Mechanism of Ciliary Feeding- it is a common observation that this animal does not normally ingest any food while it is swimming actively. Feeding is done when it is swimming slowly or it is at rest. At the time of ingestion of food, the cilia set up a current of water down the vestibulum. Ciliary tracts of vestibule direct the current into "bucccal cavity". Small food particles are thus driven towards the buccal cavity. These particles may vary in character and they seem to be subjected to some form of selection. Therefore, Paramecium is called a selective feeder. The mechanism of selection is not well understood. Mast (1947) has reported that all kinds of particles are carried with water current into vestibule, but only selected ones enter into buccal cavity. Rest of the particles are rejected. Therefore, there are two paths of ciliary action –

1. Selection path (drives selected food particles in buccal cavity)
2. Rejection path (along which unwanted particles are driven outside the vestibule)

Cilia of cavity drives the selected particles into cytpopharynx (cell-gullet) through cytostome. The food is finally collected in food vacule at the end of cytopharynx. A food vacule os formed in 1-5 minutes depending upon the food supply.

6.7 Filter Feeding

Filter feeding is a mechanism of ingestion of food (particulate matter, planktons and minute organisms) that involves strainings of food materials from large quantity of water. It is a very popular mechanism in sessile and burrowing animals. It occurs widely across the animal kingdom. In this method the animal uses the minute organisms and particulate material that are suspended in water and therefore called suspension feeding. It requires the filtering of the water and extraction of the food particles from it. These organisms adopting the filter feeding are often described as filter feeders. Usually, filteration demands the setting up of a current in the surrounding water. This will commonly be created by flagella or cilia, with mucus aiding the trapping of food. there is a possibility that suspended material may be inedible or harmful, so a rejection mechanism is also desirable. Similarly, since size of food particle is important, a sorting mechanism is also desirable.

Filter feeders include a wide variety of animals from taxonomic groups. They are highly diversified in form, for it is distributed among many groups of the animal kingdom starting from porifera to chordates; and from larvae to adults. Clearly the possibilities here for complexities of adaptation are immense. There are simpler group where primarily filter feeding is adopted while in some macrophagous groups the secondary development of microphagy (filter feeding) is also seen. Now, we must therefore consider the more important groups individually.

Filter feeding in Sponges:

Sponges feed by filtering particulate matter from water that enters their body through minute pores (ostia). The pores, in class Calcarea, are intracellular canals in specialized cells called porocytes. Porocytes may not be present in other sponges, but pores are essentially small serving as simple and effective sorting device that allows the entry of the smallest particles only. Course of water flow may by simple or complex. Inside flagellated chambers the beating of flagella of choanocyte (collar cells) causes water to circulate through their collors of microvilli. These microvilli of collars act as strainer or sieve or filter for trapping of food particles which move towards their bases. The food particles so trapped are engulfed by pseudopodial action of choanocytes at the base of collar and are taken up in food vacuoles. Food vacuoles partially digest the food and then transfer to wandering amoebocytes of mesenchyme for completion of digestion and absorption.

The indigestible residue being discarded from the amoebocytes ans removed from sponge body in the outgoing water current. The same cells also store reserve material and transport and distribute to other cells of body of sponge. In other group of sponges, the choanocytes are smaller and are concerned more with ingestion then digestion.

Filter feeding in Polychaetes:

Many sedentary and burrowing polychaetes are filter feeders for example, Terebella, Sabella etc. The methods of filter feeding are much elaborate in polychaets than those of sponges. Feeding, as evident from examples, must have evolved stage by stage under the influence of natural selection.

A simplest form can be seen in an errant polychaet. They secrete mucous by their body surface to protect the surface and to form temporary living to burrows. In Neries diversicolor, under some conditions, the mucous secretion forms into a net within burrow, water pumped through this net particles collected in this secretion and finally, the material (secretion+ food particles) is swallowed time to time. This is perhaps the simplest form of filter feeding in Polychaets.

From this more complex methods organs and stretegies evolved along many independent lines. Such mechanism is aided by tentacles, palps, tentacular out growths (gills), branchial crowns etc. In Sabella an example of the elegance of adaptation can be seen.

Sabella is a suspension feeder of littoral zone, extracting its food from water currents created by cilia present upon branchial crown. Branchial crown consists of large number of cephalic tentacles or filaments which are stiff and pinnate. These are arranged into two rows of thirty. The branchial crown forms a wide funnel with the mouth of animal lying at its base. The cilia are used to secure the food and to direct it towards mouth. The pinnules at the distal end of filament are separated from the ones on the next adjacent filament but towards the lower part of the branchial funnel they are brought closer together and finally interlock.

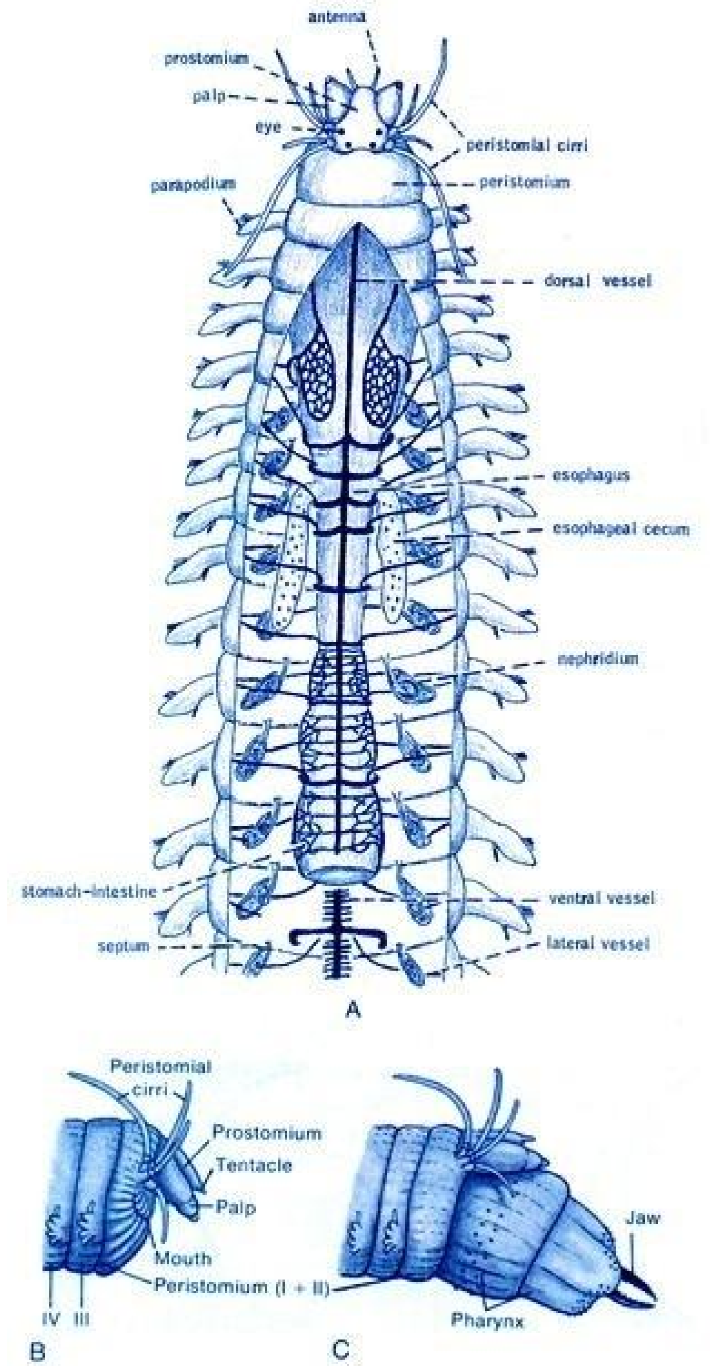

Fig6: Sabella : A. Alimentary canal B. Pharynx retracted C. Pharynx everted.

They form a filtering system upon which food particles can be trapped. Pinnule bear cilia. Towards the base of each filament two rows of pinnules pass into two continuous folds- basal folds or gill folds. Which are ciliated on both their outer and inner faces. These various structure constitute part of sorting mechanism that ensures that only suitable particles are directed into the digestive system. The large particles are removed from the animal through the action of rejection currents. The cilia of the lips and palps play an important role in this. The striking aspect of the precisious of adaptation found in this system is that mucus is extendively used in these rejection monvements. Thus ,collection and sorting processes are dependent largely upon cilia alone and upon the currents and vortices that are established by their beat.

There are other burrowing polychaets with similar in general principles to the that of Sabella, but with great variation in detail. In a small worm, Ponato ceros, common on rocky shores in its calcareous tubes, the collection and transport of food is simpler and similar in principle to that in Sabella. There is no specialized sorting mechanism, so that all particles transported by the pinnules are likely to reach the mouth. Some sorting automatically results from the small size of the animal.

One more tubicolous example, that shows the variety of feeding mechanism can be seen in chaetopterus. This is a highly specialized worm of bizarre form that lives in sand or mud with in U- shaped tube of parchment like consistency. Branchial crown is absent in this animal. Water is drawn through the tube by beating three pairs of fans that are presumably derived from parapodia. Farther forward another pair of out growths form two wings that are pressed against the wall of the tube. Mucus secreted by these is drawn backwards by cilia in a ventral groove and is formed into a conical bag. Food particles are strained out by this mucous bag. Mucous bag ends into a ciliated food cup. The food is rolled up into a ball or pellet.

At intervals the secretory process stops and the cilia in the ventral groove move in reverse, as a result the ball or pellet containing food is transported from food cup to mouth and swallowrd.

In the lugworms, Arenicola for example, the filter feeding is again specialized. These live in L- shaped burrows. They use sand as filters. They ingest this rich sand loaded with food particles by means of a simple proboscis. Periodically, the worm breaks vertical limb of L – shaped tube, amd defaecates at the surface. The digestion is completed intracellularly in wandering amoebocytes that takes food from alimentary epithelium.

6.8 Filter Feeding In Molluscs

Lemellibranch molluscs provide the best example of filter feeding. As with the polychaets (Annelida), there is a substantial element of pre adaptation has been involved. The lemellibranchs are semi sessile animals inhabitants of sandy or muddy substrata. The alimentary system is already adapted for microphagy by modifying the ciliated gill.

The water current is initiated and maintained by beating of lateral cilia of gill filament of the ctenidia. This enters through on inhalant siphon and leaves through an exhalent siphon. Ctenidia are greatly elongated with two demibranches, each of these being composed of a parallel row of filaments. In primitive protobranchs the filament is unfolded while in filibranchs and eulamellibranchs they are folded so as to form ascending ciliary junctions; in eulemellibranchs (e.g. Unio) they are joined to each other by vascular interfilamental junctions.

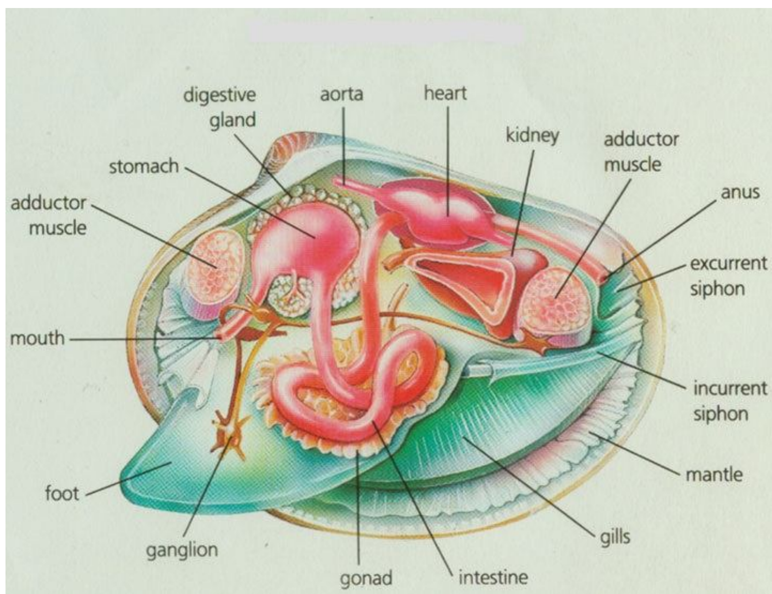

Fig7: Unio Alimentary canal and digestive gland

The beating of lateral cilia draws water into the mantle cavity through inhalent siphon. The water current enters the gill through the ostia and goes to outside through exhalent siphon. The incoming water current is loaded with food (micro-organisms and food particles). The beating of latero frontal cilia of gill filaments towards the outer surface of the lamellae throws the fine food particles over the lamellar surface. The lamellar surface secrete a mucus sheet to trap these food particles. The beating of frontal cilia moves the food loaded mucus sheet towards the food groove, downwards.

Here, ciliary beating moves the food laiden mucus sheet into the mouth. While reaching in between labial palps final sorting of food particles take place. Digestion is mostly extracellular and partly intracellular in molluscs.

In Pecten and Ostrea, the gill lamellae are folded (plicate) with ciliary beat on the crests of the folds differing from that ingrooves. The smaller food particles required are carried upwards by fine cilia to the dorsal grooves. The larger particles are carried away downwards and are rejected. In other forms, the ventro marginal groove does the sorting of fine food particles. They may have a deep channel lined by fine cilia and superficial one line by coarse cilia. Fine food particles may be carried into the bottom of the grooves, whereas closure of this may cause larger ones to its edges so that they are rejected. As another possibility, long cilia on the edges of the marginal groove permits the entry of small particles but prevent the entery of larger ones (e.g. Mya). The labial palps are ciliated structures and help in sorting of food particles. The sorting mechanism here is depend solely on the weight and not on the size of the particles. The havier ones settle down and swept away under the influence of powerful ciliary current.

Lighter ones avoid this current because they do not sink. Thus, these structures show a diversity of filtering, sorting and rejecting mechanisms in Mollusca. Indeed, as a group Mollusca provides a good illustration of adaption and evolution of ciliary feeding.

6.9 Parasitic Mode Of Feeding

The food obtaining mechanism used by parasites from their host is referred to parasitic mode of feeding. This interspecific association between host and parasites is called parasitism.

Parasitism is an association in which one partner (parasite) lives on or in the body of the other partner (the host) nourishing itself at the expense of the host, but without

Inhibiting on or in the body is the secondary. Invertebrates show a diversity in modes of parasitic feeding, guided by evolutionary forces. These show variety in selection of food, varying from tissues and body fluids of host to pre-digested one. For this these have structural adaptations. Lets have a look of this diversity of parasitic mode of feeding across the invertebrates.

If we search for parasitism we find it largely in two or three major groups : phylum Protozoa, Helminths (phylum Platyhelminthes and Aschelminthes) and phylum Arthropoda. It appeared and is adopted by unrelated animal groups.

Parasitic mode of feeding in Protozoa:

Protozoans are essentially acellular (unicellular) animals and therefore all the mechanisms to obtain food from host are showing limitations of single cell. Then general body surface and its permeability is a strong point of Protozoans. These use following methods:

1. **Phagotrophy** : Most of the intestine dwelling Protozoans ingest their food particles by phagotrophy. E.g. parasitic ciliates Nyctotherus and Sarcodine Entamoeba.
2. **Osmotrophy** : These parasites absorb simple (digested) nutrients from their body surface (plasmalemma), e.g. Zooflagellates inhibiting blood Trypanosoma.

   These may be of two types-
   a) **Coelozoic** : Absorb all food by body (cell) surface, e.g. OPalina.
   b) **Histozoic** :It feeds upon the tissues of host, e.g. young trophozoite of Monocystis feeds upon sperm substance.

On the basis of habitat adopted these are

1. **Ectoparasites** : Inhabit the external surface of their hosts.
2. **Endoparasites** :These parasites which live in side the body of their host. These are divided into four categories-
   a) Parasites of mouth : in mouth cavity of host.
   b) Parasites of Alimentary canal : in digestive tract.
   c) Parasites of body tissues : in tissues of host.
   d) Parasites of genital tract : in genital organs.
3. **Hyperparasites** : These are parasiting other species of parasites.
4. **Pathogenic parasites** : These cause disease in their hosts. These parasites use variety of methods of getting food. most common is phagotrophy and osmotrophy.

Parasitic mode of feeding in Helminthes:

In this group free living and parasitic forms can be compared. In Helminths, freeliving, ectoparasite and endoparasite are seen. Ectoparasites are characterized by attachment organs and no need of vectors. Endoparasites are specially preadapted against stress of endoparasitism e.g. powers of resistance to peristaltic movement and to enzyme actions. We encounter a transition from ectoparasitism to endoparasitism in many forms.

Parasites in Platyhelminthes and Aschelminthes feed on tissue, tissue debris, blood, bile lymph and semi or completely digested food from their hosts. Food and feeding mechanism depends on their hosts, place or part of body of host where these are living and physiological adaptations.

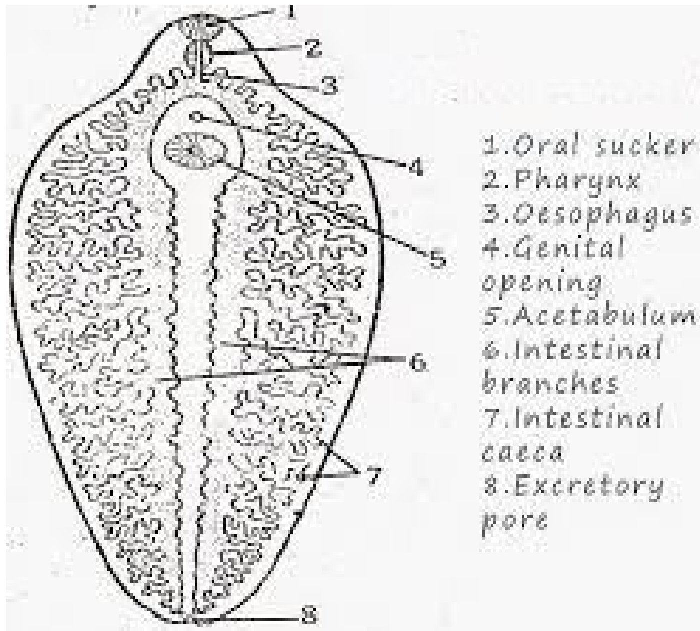

Fig 8: Fasciola Digestive system.

A simplest form can be seen in liver flukes. These endoparasites of Liver have an incomplete and simple alimentary canal. Mouth, pharynx, pharyngeal glands make feeding apparatus using which the flukes suck up food comprising of lymph, bile, blood and tissue pieces. The sucked food is lead to the branched intestine through a short, narrow muscular oesophagus.

Extracellular digestion occurs in ramified intestinal diverticula and products of digestion are directly diffused in surrounding parenchyma or mesenchyme. This is also supplemented by diffusion of glucose like monosaccharides and amino acids through its genetal body surface (tegument).

The extreme of parasitic adaptation can be seen in Tape worms where alimentary canal is altogether absent in all stages of life history. The pre-digested food is readily available to these intestine dwelling parasites. Soluble nutrients (glucose, amino acids, glycerol, salts) are either diffuse or actively absorbed through general body surface (tegument). The absorption efficiency is increased by microvilli – by increasing absorptive surface area. This is a unique mode in animal kingdom.

In parasitic Nematodes or round worms, complete alimentary canal with mouth, pharynx, intestine, rectum and anus reappears. Food and feeding mode also changes accordingly. In Ascaris lumbricoides for instance, food consists of blood and fully or partially digested food occurring in host's gut in liquid form. Food is sucked by rhythmic action of pharynx and lead to intestine. It is digested by fundamental trio of enzymes- proteases, lipases and amylases. Digestion is mostly extracellular and is aided by intracellular one by intestinal cells through phagotrophy or phagocytosis.

Concludingly, it can be said here that since semi or fully digested food is available elaborate organs and mechanisms for feeding is not needed. These are mainly osmotrophs and some are phagotrophs.

6.10 Summary

- Invertebrates is a heterogenous group and therefore mutrition is also diversified in this group.
- Brodly there is three types of nutrition found in invertebrates – Holophytic (plant like), Holozoic (animal like) and Myxotrophic (a mixture of two).
- Holozoic is again diversified into microphagous, macrophagous, parasitic (ecto and endo parasitic) and saprozoic nutrition.
- Digestion is extracellular or intracellular involving three fundamental kinds of enzymes – proteases, lipases and amylases.
- Ingestion, digestion and ejestion (defaecation) are three steps.
- Amoeboid feeding is characteristic of sarcodina (Protozoa) but is wide spread across invertebrate.
- Ciliary feeding is found in Protozoaa and many other groups of animals like sponges, polychaete worms, Molluscs and few lower chordates.
- This involves water currents, sorting and collecting food particles and rejection of unwanted ones using cilia as main organelle.
- Parasitic mode is an specialized mode of nutrition and of two types – phagotrophy and osmotrophy. It is found in many non related groups e.g. Protozoa, Helminths and Arthropods.

6.11 Self-Learning Exercise

Section -A (Very Short Answer Type)

1. What is parasite?
2. Digestion of food takes place in paramecium-
   a) Contractile vacuole
   b) Food vacuole

c) Cytopharynx
d) Cytopyge

3. Food is brought in the body through -------------------.
4. Euglena is an autotrophic animal. True/ False
5. Write one difference between microphagous and macrophagous animals?

Section -B (Short Answer Type)

1. What are differences between holozoic and holophytic nutrition?
2. Describe in short ciliary feeding in paramecium?
3. Explain saprozoic nutrition?
4. What is pinocytosis?

Section -C (Long Answer Type)

1. Discuss ciliary feeding in polychaet worms?
2. Describe parasitic mode of nutrition in Helminths? Trace the evolutionary lines too?
3. Draw well labelled diagram of paramecium and explain feeding mechanism and process of digestion?
4. Describe the mode of feeding in Molluscs? Draw suitable figures also?

6.12 References:

- Zoology Part-I by Parker and Haswell
- Invertebrates Zoology by R.D. Barnes.
- Invertebrates Zoology by S.N.Prasad
- Animal Physiology by M.P.Arora

Unit- 7

Respiration

Structure of the Unit

7.1 Objectives

After reading this unit student will be able to:

- Understand process of respiration.
- Describe the various types of respiratory organs in invertebrates.
- Describe respiratory systems in various groups of invertebrates.
- Structure and functions of Gills, Lophophores, Trachea and Lungs.
- Know, describe and understand physiology of Respiratory pigments.

7.2 Introduction

Respiration involves gaseous exchange with environment with intake of oxygen and release of carbon dioxide, followed by utilizing oxygen in oxidative process and ultimately producing ATP. This oxygen is used by somatic cells and carbon dioxide is produced. For the convenience of study and description, respiration is divided into two;

(a) External or Physical (exchange and transportation of gases)
(b) Internal or Chemical (oxidation of energy rich compounds such as carbohydrates, lipids and sometimes proteins).

To accomplish this (respiration) various kinds of respiratory organs and pigments are known to occur in animal kingdom. We are here concerned with external (Physical) respiration and oxygen transport. The structural organization and functional aspect of those are influenced by certain physical considerations. As evident from literature, availability of oxygen for animals is dependents on its concentration in the surrounding medium. If we compare aquatic habitat with terrestrial one, conditions are more favourable in air than in water. Air contains as much as 20.95% oxygen while it is 10.29 to 4.46 ml/l in water depending on temperature and salt concentration of water. As far as respiration is concerned partial pressure of oxygen & carbon dioxide is more important than their volumes.

Small and microscopic animals (e.g. protozoans, sponges) obtain their required amount of oxygen and release carbon dioxide by simple diffusion. From such simple structure and physiology, the complexities evolved. As the animal become larger and surface area available for gas exchange is reduced, more and more specialized devices evolved (e.g. gills and lungs). Since the solubility of oxygen in blood plasma is low and has limits, an effective transport system and oxygen-carrier blood pigments (protein) were evolved. Let us see the various types of respiratory systems in the invertebrates.

7.3. Respiration in invertebrates

The life originated in water and therefore primitive animals are primarily aquatic. The evolution occurred from water to land via amphibious lifestyles. As stated above, aquatic and terrestrial environment are different in their physical characteristics. Water contains less (09%) oxygen than air (21%). This result in increasing the efficiency of breathing organs.

The essential requirements for any tissues or organs to act as respiratory organs are: (a) the surface should be ultra thin (b) always be kept wet (c) should be richly vascularized (circulation) or immersed in body fluids/haemolymph. This is to facilitate easy and fast diffusion of gases (O_2 and CO_2). Gills are the best example for aquatic and the lung is the best example of a successful solution for air breathing. Now we shall see many ways in which the form and organization of the animal body have been influenced by above factors.

7.4. Respiration in lower invertebrates

Lower invertebrates are generally smaller in size and simple in body organization. They are near the base of phylogenetic tree of animal kingdom. These lack true coelom in their body. Phylum protozoa to helminthes are included in this category. These animals have adopted a simple and effective method of respiration, i.e. diffusion through outer covering of body.

Starting from Protozoa, Amoeba for example, it has no special respiratory organelle and respiratory pigment. Plasmalemma is permeable to gases dissolved in water. Oxygen easily diffuses from water into the cytoplasm because concentration of oxygen is greater than what is in cytoplasm. The oxygen is used in cytoplasm for oxidation of carbohydrates and fats results in CO_2 and water. CO_2 diffuses out in the water easily as its concentration in water is lower. Some CO_2 also given out with water discharged by contractile vacuoles. In Euglena and Paramecium the plasmalemma is covered with semi permeable pellicle. Simple diffusion across general body surface is again used as mode of gaseous exchange.

Same is repeated in small sized sponges (porifera), Coelentrata and free living Helminthes. The size of Helminthes is bigger than earlier three phyla but it is compensated by increasing surface area by flattening or supplemented by fluid filled pseudocoel.

In parasitic (endoparasites) Helminthes, anaerobic or anoxybiotic respiration mechanism is adopted. Resultant CO_2 diffuses out through general body surface. So concluding, diffusion is the main mechanism of gaseous exchanges. In first three phyla of lower invertebrates (Protozoa, Porifera & Coelentrata) plenty of free O_2 is available and consumed in aerobic or oxybiotic respiration. In last two (Platyhelminthes ans Nematoda/Aschelminthes) free living kept on aerobic mode but endoparasites adopted and shifted towards anaerobic mode because oxygen content inside the body of host is very low. These adopted to slow metabolism rate also.

7.4.1. Respiration in Protozoa

Respiration is oxybiotic or aerobic type, although some endoparasites have adopted anaerobic mode too (e.g. Entamoeba). Gaseous exchange takes [lace through diffusion from general body surface. Body surface is composed of permeable plasmalemma, with or without semi-permeable pellicle.

7.4.2. Respiration in Porifera

Respiration in porifera is oxybiotic or aerobic. These are bigger animals in comparison to protozoans. Therefore, this supplemented by canal system. Body of sponges is perforated by dermal ostia. The water is drawn into canal system through those ostia (porocyte). Passing through the body, gaseous exchange takes place between the flowing water and body cells of sponges. Oxygen dissolved in water diffuses into cells and CO_2 diffuses out from the cell into the water. The poriferans also lack special respiratory organs, respiratory pigments and circulatory system.

7.4.3. Respiration in Coelenterata

Coelenterates exhibit aerobic mode of respiration almost all members of this phylum are aquatic. These do not posses specialized organs for respiration, respiratory pigement, blood or blood vessels. Therefore, respiration is carried out individually by each cell. Body wall is thin and water circulates through body cavity (coelenteron) mostly cells are in contact with oxygen loaded water. Hence, gaseous exchange takes place by diffusion. In case of jelly fishes (e.g. Aurelia) some works pointed out that sub genital pits facilitate gaseous exchange.

7.4.4. Respiration in Helminthes

Helminthes are warms both free living and endoparasites in relation to their habit and habitat. It includes two major phyla, Platyhelminthes and Ascehelminthes. In free living forms, e.g. Dugesia (Planeria), aerobic mode of respiration is found. Gaseous exchange takes place through general body surface. Like earlier three phyla, helminthes also lack specialized organs and pigments for respirations and circulatory system. Transportation of gaseous within body is performed by mesenchyma or parenchyma.

In the endoparasites, the situation is different. Oxygen contents in host's tissues and body is low. Therefore, these animals have shifted from aerobic to anaerobic or anoxybiotic mode respiration. The glycogen (reserve food) is broken into CO_2 and fatty acids. End product of this anaerobic glycolysis is lactic acid. CO_2 diffuses out through general body surface and lactic acid is eliminated through excretory system.

In Nematodes and other Ascehelminthes, endoparasites adopt the above anaerobic method is used. Transportation of gases within body is carried out by pseudocoelomic fluid filled in body cavity (pseudocoel). Some workers pointed out the pressure of small amount of haemoglobin in psudocoelomic fluid, which serves to transport oxygen.

7.5 Organs of Respiration

The organs of animal's body which are needed for exchange of gases (O_2 & CO_2) between surrounding medium and body are known as respiratory organs. Depending upon the habitat, two types of respiration are seen; (1) aquatic and (2) Terrestrial, where water and air respectively supply oxygen. Invertebrates have developed two main types of respiratory organs, accordingly. For aquatic respiration there are gills and lophophores and for terrestrial (aerial) respiration there exist trachea and lungs. All these respiratory structures consist of a common plan: a moist semi permeable and highly vascularized membrane always exposed to external oxygen rich surrounding medium.

7.5.1. Gills

Gills or bronchial are respiratory organs of aquatic animals. These vary greatly as regards their position in body, shape and size. The origin and evolution of gills can be traced along with the complexity of body organization. First gill like structure can be seen in tubicolus/burrowing annelids and members of minor phyla. They had tentacles or branchial crowns at the oral end. Before their function of filter feeding was known, and understood the tentacles were generally termed gills or branchae or branchial crown. Along with filtering food they perform respiratory exchange of gases also.

Well organized and well formed gills are better found in two phyla; Arthropoda and Mollusca. On the basis of their form and shape these are two types:

(1) Pectinate: Consisting of longitudinal axis from which filaments (lamellae) are given off on its one side (uni or mono pectinate) or both sides (bipectinate).

(2) Plate gills: These are flat or plate like gills and acquire various forms.

Gills in Mollusca:

Mostly molluscs are aquatic and respire by means of gills which are called Ctenidia (singular- ctenium). These are situated in mantle cavity. The gills of mollusca are a homologous organ.

Structure of gill in molluscs: ctenidia are projections of body surface or mantle. These show fundamentally same basic structural plan. It consists of a main axis or stem placed horizontally bearing on one or both sides a row of alternately arranged filaments or lamellae. These are delicate, flexible and numerous structures covered by cila. The movement of cilia is responsible for maintaining water current in mantle cavity. Ctenidium receives blood from alternate branchial vein and it is returned to heart by efferent branchial vein.

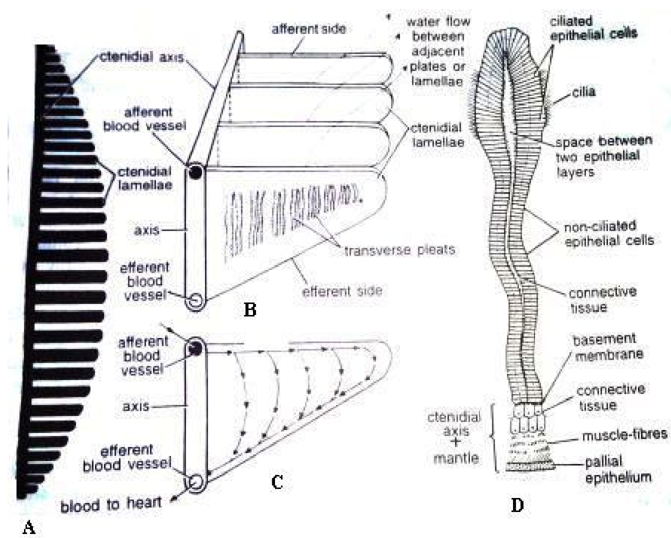

Fig. 1 Gills in Pila; A-a monopectinate ctenidium. B-stereogram to show water current through gill lamellae. C- single lamellae to show flow of blood within it. D- A lamella in T.S.

Types of ctenidia in mollusca: gills or ctenidia vary so much in number, form and position in mollusca that classification of this phylum is based mainly on gills. In class monoplacophora there are 5 pairs of unipectinate (monopectinate) gills composed of finger like lamellae. In class Amphineura gills are true ctenidium. In Placophora, these are 6-80 in number and are arranged in two rows. In aplacophora gills are either absent or two large plume-like ctenidia were found one on either side of anus. In class Gastropoda, as a result of torsion gills are shifted to the front of the body. In prosobranchs single pair gills is seen. In mesogastropoda and neogastropoda a single gill is present on left side which is monopectinate. In opistnobranchia gills become shorter and posterior. Single ctenidium is present on right side.

In pelecypoda, the gills are most complex, these serve for nutrition (filter feeding) and brood pouches. In sub class protobranchia gills are smaller and situated at the back of mantle cavity. In filobranchia, gill filaments become elongated and thread like. In pseudolamellibranchia gills have more cohesion then in filibranchia. In eulemellibranchia vascular cross-connection with ostia are found in inter lamellar junction.

Finally, in class septibranchia, gills degenerate and replaced by horizontal, muscular and perforated septum. Septa moves up and down to maintain water current and respiratory gas exchange is entirely done by mantle.

In class Cephalopoda, gills are simple and bipectinate. Lamellae are leaf like, delicate and arranged in a row on the axis or stem. Important point to be noted here is that cilia are absent. Water current is produced and maintained by co-ordinate action of muscular mantle, funnel and inlet valves. This is an advanced feature of evolutionary importance.

In certain members of phylum mollusca, true gills or ctenidia are absent and respiratory functions is taken over by other morphological structures. These are popularly called secondary or adaptive gills. These are of mainly three types;

(1) Anal gills: These are a rosette of delicate and retractile gills around anus at the posterior end of body. e.g. Doris.
(2) Pallial gills: these are present in the form of a row in the pellial groove on each lateral side of it. e.g. Patella.
(3) Cerata: These are many simple or branched structures situated on dorsal surface of body. These are richly vascularized and have regulative capacity. e.g. Aeolis.

Gills in Arthropoda: Gills or branchiae in arthropoda are evident in class Crustacea. These may vary in number, position and details of anatomical structure, but made on a similar fundamental plan. On the basis of their origin and attachment are of three types:

(a) Podobranch or foot gill- It is found attached to the coxa of appendage.
(b) Arthrobranch or joint gill- It is found attached to the arthrodial memberane joining an appendage to body.
(c) Pleurobranch or side gill- It is found attached to the lateral wall of the body segment having the limb.

For example, in Palaemon (Prown) one podobranch, two arthrobranchs and five Pleurobranchs are present.

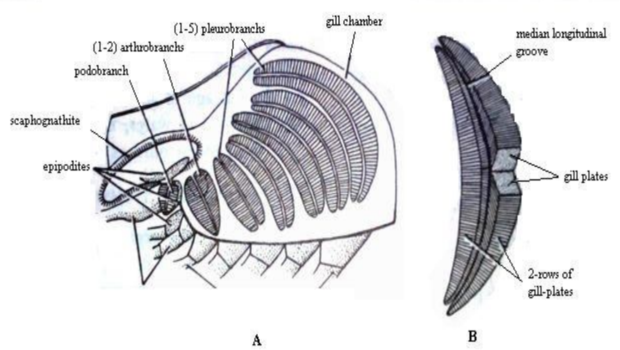

Fig. 2 Palaemon. A- gill chamber exposed to show the gills. B- A phyllobranch

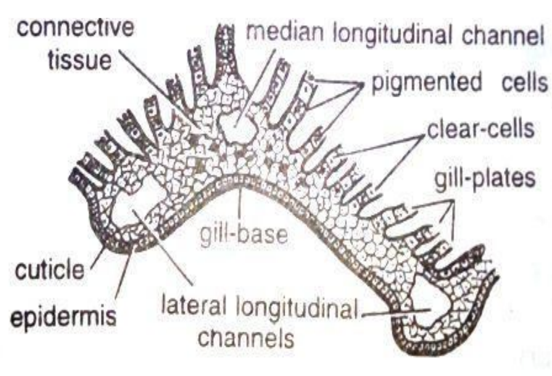

Fig. 3 Palaemon: Gills in oblique T.S.

Structure of a typical gill: Each gill is curved structure and is connected to the thorax by small root like structure- gill root. A. gill consists of two rows of thin leaf like gill plates. If these are arranged like the leaves of book, the gills are called Phylobranch. Gill plates are arranged at right angles to the longitudinal axis or base of the gill. Gill plates are largest in middle and gradually become smaller towards the two ends.

Histology of gill revealed that each gill is made of double layer of cuticle enclosing a single layer of cells within itself.

There are two types of cells in it;

> (a) Pigmented cells and (b) transparent cells. The gills are supplied with three longitudinal blood channels running in the base or axis of gill. Blood brought by afferent branchial channel and taken away by efferent branchial channel.
>
> Water current is brought in by vibrating movement of appendage or part of it. e.g. in prawn, it is scaphognathite of each important evolutionary features as cilia are totally absent in adult arthropods. Gaseous exchange takes place by simple diffusion on thin & delicate gill plates, between water and underlying blood.

7.5.2. Lophophores

Lophophore is a hollow tentacle like structure, function of which is later understood as food-catching organ also, serves as respiratory organ. This is characterstic feature of three minor phyla; the Phoronida, the Bryozoa and the Brachiopoda.

In these phyla, it is a circular or horse shoe shaped fold of the body wall that encircles the mouth and bears numerous ciliated, hollow tentacles. Each contains extension of coelom. The ciliary tracts of tentacles drive a current of water through the lophophore.

This water current serves two functions; collection and sorting of food particles and planktons; and gaseous exchange for respiration by providing a large surface area.

In the Phoronida and Brachiopoda there is additional advantage of blood-vascular system. In Phoronida a ring vessel running in the coelom at the base of the lophophore and giving off a single vessel in to each tentacle. The efficiency is increased by presence of haemoglobin.

7.5.3. Trachea

Trachea is ectodermal structures, formed by invegination (ingrowth) from the surface. As a result, these are lined by cuticle (and not by cellular layer) called intima. The intima is thickened and forms spinal or ring shaped ridges. These thickening are called the taenidia that serve to maintain an open lumen to ensure the passage of air (gases). It opens outside by means of opening called spiracles. Typically, these are found in thorax and abdomen, situated on pleura. Trachea is primarily air-breathing organs.

The trachea is found in *Paripatus*, *myriapods* and insect which form a natural group of terrestrial arthropods. The essential features of well developed tracheal system are that it transports oxygen to the tissue by tracheal tubes, that branch to reach all parts of body. The tracheal branches form fine terminations called tracheoles, possess thin wall and are permeable to water and possess taenidia. Tracheoles, because of their minute size these are surrounded by cells and end blindly within them.

Trachea perform pulmonary and tracheal functions. In the former they do not convey oxygen to the tissues but simply aerate the “blood” or “haemolymph” (as the case may be) in theadjcent “blood” sinus. In the later one, they convey oxygen to cells of body tissue.

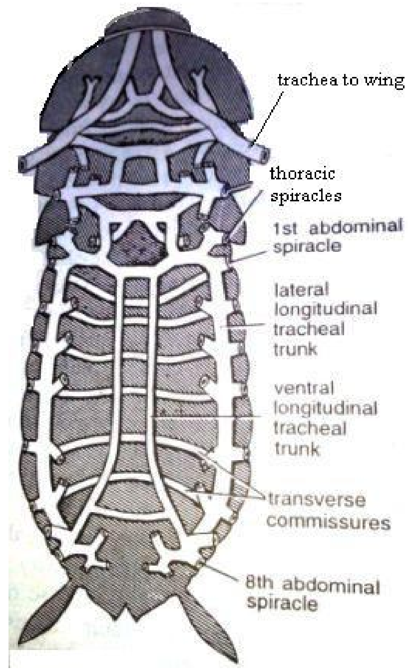

Fig. 4 Tracheal system in Insect.

With tracheae there is some loss of water vapours. This problem is overcome by developing the devices for closing the spiracles, for successful operation, these closing mechanisms must be regulated to meet the respiratory needs. e.g. in locust the respiratory movements are under control of a ventilation centre in the meta thoracic ganglion.

In aquatic insects, trachea act in two ways, firstly the animal (insect) may return to the surface of water to breathe through its spiracles and may supplement this by carrying down under the water a store of air on its body surface. Secondly, as in fully aquatic insects, by developing tracheal gills, which make it possible to obtain O_2 from surrounding water by diffusion.

7.5.4. Lung

Lungs are hollow structures possessed by air breathing animals. Theoretically, these are hollow structures, elastic having fine branches of air pipes or tubules ending into a space when vascular element can exchange gases (O_2 & CO_2) by simple diffusion.

We are accustomed to regard ‘lungs’ as being organs that require ventilation to function satisfactorily. Secondly we suppose pulmonate lung was a purely a terrestrial respiratory organ or that it was confined in aquatic animals to aerial respiration. Thirdly, we cannot expect a fully efficient, terrestrial lung (like vertebrates) at this stage of evolution.

The lung is encountered in amphibious gastropod mollusks. This is developed as an adaptation to aquatic or amphibious habits. Some examples may be discussed here. *Lymnaea truncatula* has a lung filled with air lives an aerial life in marshy habitats. *Planorbis*, living in water returns to the surface to refill its lung with air. The efficiency is increased in this mollusc by the presence of haemoglobin dissolved in blood.

In terrestrial forms (e.g. limax) mantle cavity is transformed into a pulmonary sac or lung. This organ is used as an organ for aerial respiration. Pulmonary sac’s roof is richly supplied with ‘blood vessels’. The ‘breathing’ (air intake and release) is done by alternate contraction and relaxation of muscles of mantle floor. Gaseous exchange takes place through semi permeable wall of mantle.

In Pila which is the amphibious form, mantle cavity is divided by incomplete septum called epitaenia, into a left pulmonary chamber and a right branchial or ctenidial chamber. The pulmonary chamber is used to breath in air while the ctenidial chamber for breathing in water.

Lung or pulmonary chamber of Pila opens outside through a large and oblique pulmonary aperture. The left nuchal lobe acts as siphon through which air enters into pulmonary sac. After gas exchange, air returns through the same path. Alternate contraction and relaxation of pulmonary sac muscles ensure flow of air in and out of mantle cavity. Epitaenia is raised and the air is not allowed to enter the branchial chamber.

7.6 Physiology of Respiratory Pigments in The Invertebrates

The respiratory pigments found in invertebrate animals serve as oxygen carriers. If we study distribution or occurrence in the animal kingdom we find that these have been evolved independently in many lines. The most common compounds are haemoglobin. It depends on the capacity of animal to synthesize “porphyrin”. They are derivatives of a parent compound called porphin (see fig.).

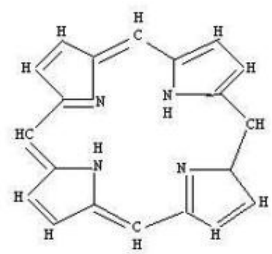

Fig: Porphin

An important property of porphyrin is their ability to associate with metals and form metallo porphyrins. Thus, iron porphyrin acts as prosthetic groups of the peroxidases. Protoporphyrin is derived from porphin, which produce ‘haem’ (ferrous protoporphyrin) on addition of one ferrous ion atom. When this is joined with a molecule of globin the result is haemoglobin. This is the best known of all the oxygen carrier molecules.

Among invertebrates haemoglobin is characteristic of annelid and entomostracan crustacean. It is present in dissolved state in blood and in the tissues. In mollusca its occurrence is sporadic (e.g. planorbis). Invertebrates haemoglobin is red when bound with O_2 and purple in deoxy state.

Another pigment is chlorocruosin, a type of green respiratory pigment present only in four families of Polychaeta (phylum Annelida): (1) Ampharetidae (2) Chlorhaemidae (3) Sabellidae and (4) Serpulidae. It is close to haemoglobin. Protein and one functional group are different.

There is one more pigment haemerythrin. It is reddish violet iron containing respiratory pigment. It is found in Sipunculids, some Polychaete, like magelona and brachiopod (e.g. lingula). It is rare pigment.

A very peculiar pigment haemocyanin that is found in some molluscs (e.g. Helix) malacostracan crustacean, some chelicerata (e.g. Limulus) and spiders. It is unique in having copper in place of Iron (haem).

In general, these respiratory pigments function as oxygen carriers or as oxygen stores, providing O_2 at times of shortage. Pigment in blood works as carriers and in tissue (e. g. muscles) they serve as oxygen storage. Most important property of these pigments relevant to the physiology is their oxygen affinity. Partial pressure of O_2 is important for the saturation of these pigments.

7.7 Summary

- Respiration is exchange of oxygen and carbon dioxide in living organisms.
- Body surface serves the best and fundamental respiratory device.
- Gills, lophophores, trachea and lungs are important respiratory organs of invertebrates.
- Gills and lophophores present in aquatic animals.
- Lungs and trachea serve as respiratory organ in terrestrial forms for air breathing.
- Many types of respiratory pigments are found in invertebrates but these have no phylogenetic relationship.
- Haemoglobin is widespread respiratory pigment in animal kingdom. Chlolrocruorin, haemerythrin and haemcyanin are other pigment occurring sporadically.

- Respiratory pigments function as oxygen carriers and oxygen storage.

7.8 References

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Unit - 8

Excretion: excretory systems in various invertebrates, osmoregulation and ionic regulation

Structure of the Unit

8.0 Objectives

This unit gives an account of various type of excretory organs present among annelid, arthropoda, mollusca and echinodermata. By the end of this unit you will understand:-

Diversity of excretory organs that are present in various invertebrate major phyla and their role in excretion.

8.1 Introduction

a. Excretion :

The end products of metabolism such as CO_2, water and nitrogenous waste substances removal is very essential in an organism. Respiration helps in the removal of CO_2 and to some extent the water. Certain other substances like salt, water and fat derivatives etc are excreted through skin by an organism. However, elimination of nitrogenous substances from the body is a major problem. Ammonia, Urea and Uric acid are the major nitrogenous waste products that are highly toxic to the body. Removal of these nitrogenous waste products is commonly known as Excretion, even though, excretion includes the removal of all the waste materials from the body. Thus, the definition of excretion is restricted to the elimination of nitrogenous waste products in all the contexts. The specialized organs that help the excretory function are known as Excretory Organs. As there is no development of excretory system in invertebrates, the excretory organs will function for the excretion of waste products from the body.

b. **Excretory organs :**

There is a great diversity noticed with reference to the excretory organs along with the diversity in organisms in the animal kingdom. It is more so in invertebrates. The diversity of excretory organs is based on the environment, habitat, mode of life. The structural diversity of excretory organs is noticed among the same order or class or phylum but not restricted to different phyla. In Protozoa, Porifera and Coelenterata, no special organelles are present for excretion, nitrogenous wastes (mainly ammonia) is excreted by diffusion from the general body surface in the surrounding water. The excretory organs in some important invertebrates Phyla such as Platyhelminthes, Aschelminthes, Annelida, Arthropoda, Mollusca and Echinodermata are described in this chapter.

The structure of various excretory organs was described in different groups of animals in the animal kingdom, before their functions were indentified due to variations in the progress of contemporary fields of science. Hence, sometimes, there may be different names for the same organ or vice versa.

8.2 Excretory Organs in Platyhelminthes

In Fasciola hepatica, excretory system comprises a large number of flame cells or flame bulbs or protonephridia, connected with an intricate system of excretory ducts of various orders.

A. **Flame cells :** Flame cells or protonephridia, which themselves are modified mesenchymal cells, are distributed throughout mesenchyme in a specific pattern, called the flame cell pattern by Faust(1919). They are usually of irregular shape and send out pseudopodial processes into the surrounding tissue. Each flame cell has an intracellular lumen or cavity, in which hang a few long cilia, each arising from a basal granule situated in cytoplasm. In the living fluke cilia vibrate like the flickering of a flame; hence the name “flame cell”.

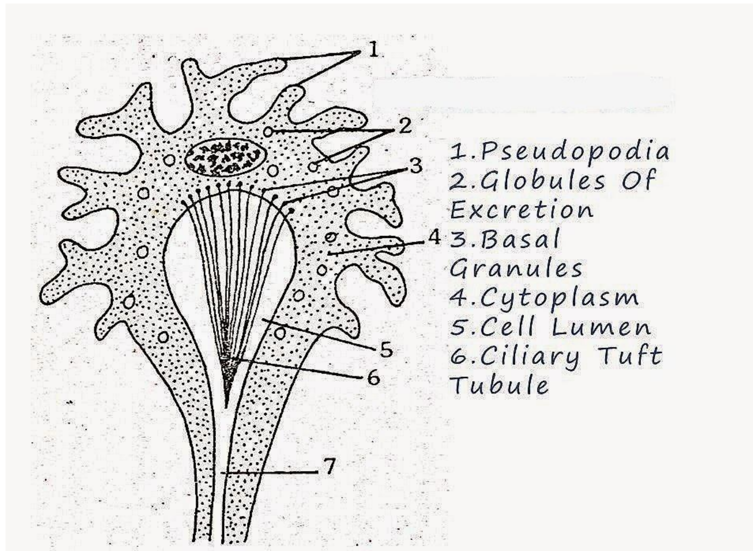


Fig : Fasciola. A flame cell

B. **Excretory ducts :** Lumen of flame cell is continuous with a microscopic capillary duct. Capillary ducts from a few protonephridia open into a narrow collecting tubule. Several such tubules open into larger twigs, which in turn open into vessels. Excretory vessels of anterior part of body open into four trunks, two dorsal and two ventral, which unite posteriorly to form a single median longitudinal excretory canal. It extends upto the posterior end of body where it opens out through the single excretory pore situated somewhat ventrally. Excretory vessels of posterior part of body open directly in the longitudinal excretory canal. All the ducts except the single median longitudinal canal are lined with cilia.

C. **Physiology of excretion :** Main excretory products of fluke are fatty acids, carbon dioxide and ammonia. These substances diffuse into protonephridia from the surrounding mesenchyme. Excretory fluids are kept moving through tubules by the action of cilia and finally squeezed out through the excretory pore by contractions of the body. The enzyme alkaline phosphatase, found in flame cells and collecting tubules serves in the selective transfer of chemical substances. Some nitrogenous wastes are also passed to the exterior through the surface tegument.

Protonephridial system is excretory as well as osmoregulatory, since it controls the amount of fluid (water) in the body.

8.3 Excretory Organs In Aschelminthes

In Ascaris lumbricoides, excretory system is quite simple due to absence of flame cells or protonephridia. There is a H-shaped tubular excretory system. It is supposed to be formed by a huge excretory renette cell at the juvenile stage. Into its cytoplasm tunnel like structures form canals of the excretory system. It consists of two lateral longitudinal excretory canals, right and left, connected anteriorly below pharynx, by a transverse canalicular network. Each longitudinal canal extends posteriorly along the entire body length through a lateral epidermal chord and is closed at both ends. Externally their location is marked by the two lateral lines. Left canal is slightly wider than the right. Anterior limbs of H are reduced. Lumen of canals is devoid of cilia. A short terminal excretory duct extends from left side of transverse canalicular network to the excretory pore situated mid- ventrally, a little behind the anterior tip. The nucleus of the excretory cell lies anteriorly on the left longitudinal canal, two more smaller nuclei have also been located, one on the terminal duct and one on the transverse canalicular network, indicating that the canal system is evolved probably by more than one cell.

Physiology :

Available data suggests that excretory products of Ascaris is mainly urea, thus it is a ureotelic animal. Excretory canals collect the excretory products from different parts of body. Pressure of pseudocoelomic fluid helps in ultrafiltration. Excretory products are eliminated through the excretory pore. Some ammonia and urea are also passed out with faeces through anus.

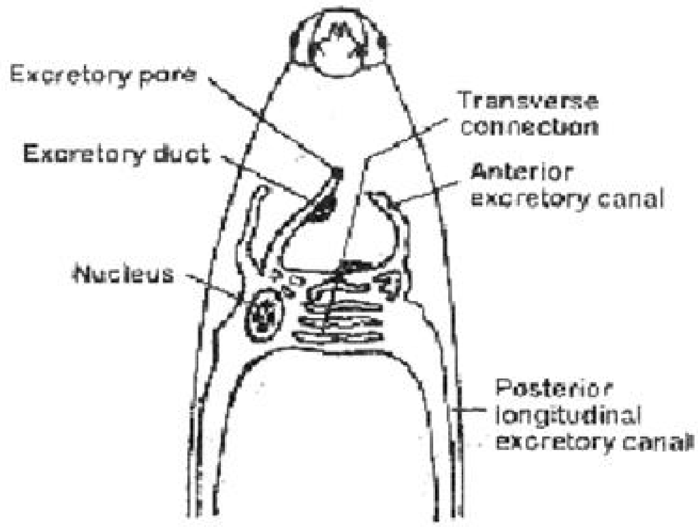


Fig 2: Ascaris 'H' type excretory system

8.4 Excretory Organs In Annelida

The excretory organs of annelida are as follows:

1. Nephridia
2. Coelomduct
3. Nephromyxia
4. Chloragogen Cells
5. Botryoidal tissue
6. Ciliated Organs.

1. Nephridia: Nephridia originate from ectoderm. They are segmentally arranged coiled ciliated tubes. Nephridia developed internally as inpushings or invaginations from the ectoderm. Thus, they are projected into coelom as nephridia.

Types of Nephridia: Following are the important types of nephridia found in annelids:

i. **Protonephridia** : Protonephridium is a primitive type of nephridium. It is found in Alciopa, Phylodoce and Glycera etc. It terminates into coelom as a blind tube. Hence it is known as a closed type nephridium. It opens exteriorly by nephridiopore. These tubes branches and each branch end into a tubular cell known as solenocyte. Solenocytes resemble the flame cells. They have a cavity internally and are surrounded by a mass of cytoplasm with a nucleus in it. From the mass of cytoplasm a flagellum arises. It is vibratile.

ii. **Metanephridium** : It has two openings. One of the end of Metanephridium opens into coelom by a funnel like opening known as Nephrostome. The other end of metanephridium opens outside the body through nephridiopore. Metanephridium is found in Dravida, Nereis etc.

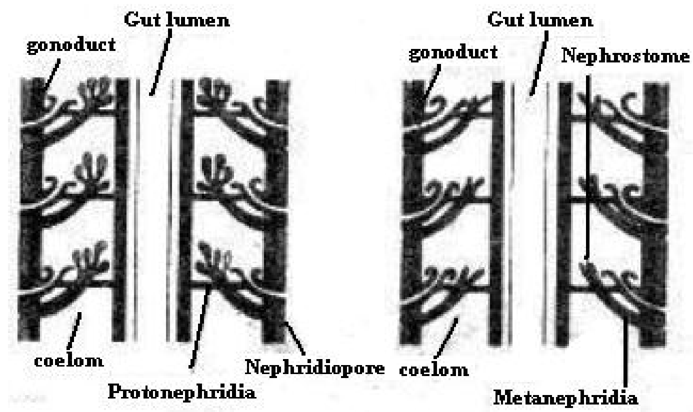


Figure showing Protonephridia and metanephridia

In Neries, typical structure of metanephridium can be seen. A pair of metanephridia is arranged in each segment. In the mass of syncytial cytoplasm, coiled tube like metanephridia is embedded. One of the end of the nephridial tube opens into coelom through a ciliated funnel known as nephrostome. Below the nephrostome, the short neck is present and it leads into coiled nephridial tube. It opens outside the body through nephridiopore just before this, a swollen and broad terminal duct is present. The coiled nephridial tube is having 3 distinct regions:

i. Anterior ciliated region near the neck,
ii. Middle glandular region,
iii. Posterior muscular region.

The nephridium in leech is a modified metanephridium. Nephrostome is totally absent. Between 6-22 segments, there are in total 12 pairs of nephridia . Each nephridium is having a horse shoe-shape. This part is known as main lobe and it has two limbs. i) Anterior limb and ii) Posterior limb. Inner lobe is present between anterior and posterior limb.

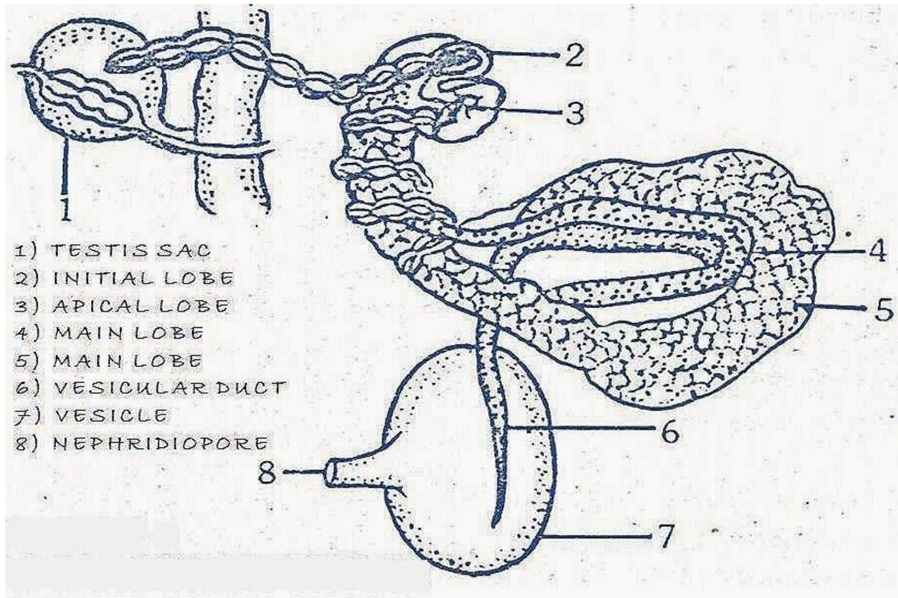


Fig 3 : Nephridium of a Leech

The posterior limb continue forward as a apical lobe which looks like walking stick . A hollow long tube that coils around the apical lobe is known as initial lobe. One of the initial lobe ends into main lobe and the other end ends blindly into testis sac in case of testicular nephridia. From the inner end of the anterior limb arises a duct known as vesicle duct, which leads into a bad called vesicle or bladder. A short excretory duct arises from this bladder and opens outside by a nephridiopore.

In Pheretima, nephridia are small sized or micronephridia, as compared to large sized meganephridia of Neries and Leech. They occur in all segment of body except the first three segment. According to their location in body, these are distinguished into 3 types : A. Pharyngeal, B. Integumentary and C. Septal.

A. Pharyngeal nephridia : These nephridia occur as paired tufts on either side of pharynx and oesophagus in the 4th, 5th and 6th segments. Each tuft consists of hundreds of coiled branched tubules without nephrostomes. In each tuft, the terminal ducts of all tubules join to form a single thick walled common duct. Thus there are 3 pairs of common pharyngeal nephridial ducts, which run anteriorly parallel to the ventral nerve cord. Ducts of 4th and 5th segment open into pharynx, while those of 6th segment open into buccal chamber. Pharyngeal nephridia are thus enteronephric.

B. Integumentary nephridia : These nephridia lie scattered on the entire inner or parietal surface of body wall in each segment except the first two. There are 200-250 nephridia in each segment but in the segment of clitellum (segments 14 or 16) their number increase to more than 2000 constituting the 'forests of nephridia'. Integumentary nephridia are microscopic V-like in shape and lack nephrostomes. Their terminal ducts open on body surface independently through minute openings known as nephridiopores. Integumentary nephridia are thus exonephric.

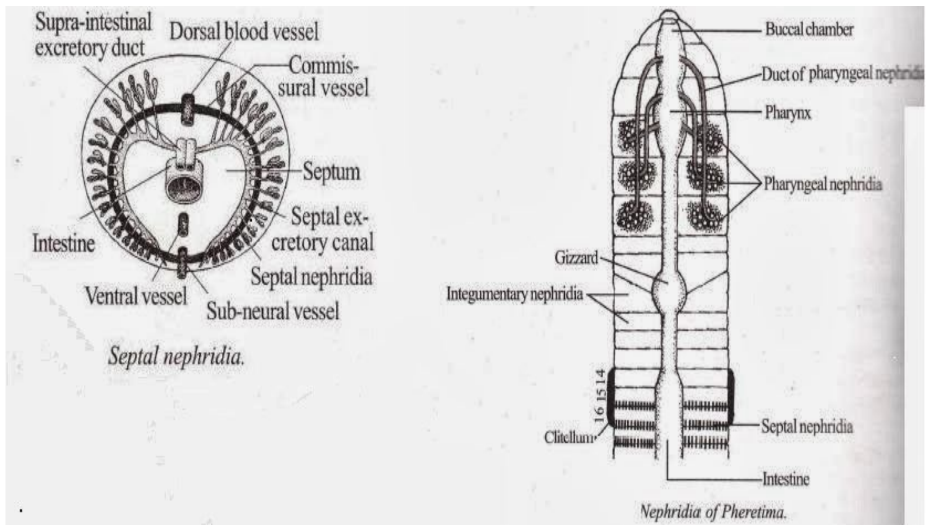


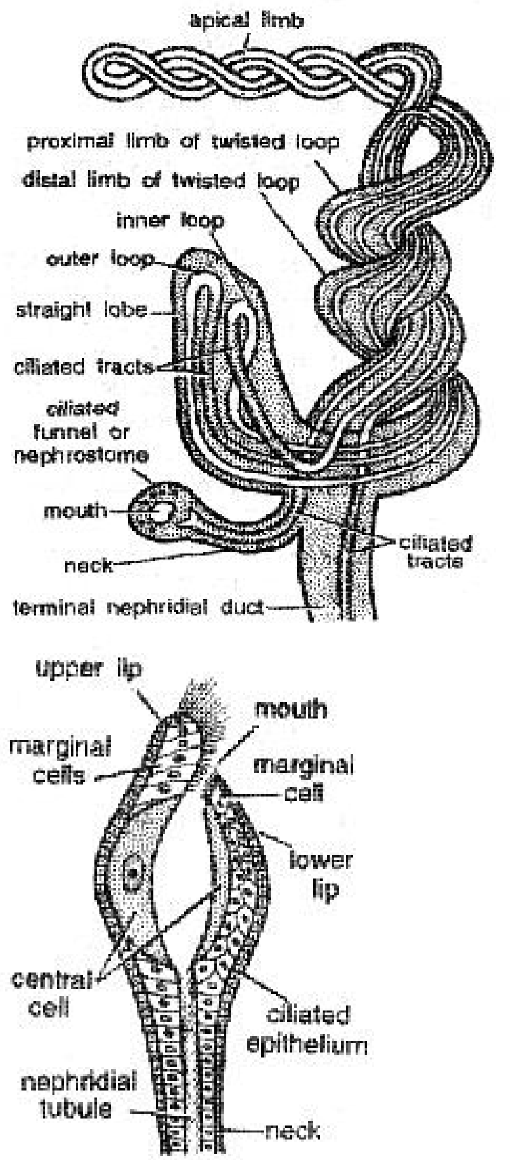
Fig. 4

C. Septal nephridia : These are the largest nephridia of Pheretima. They are attached to both the faces of each intersegmental septum behind 15th segment.

a) **Structure :** A typical septal nephridium consists of three main parts : 1. Nephrostome, 2. Body, and 3. Terminal duct.

1. **Nephrostome :** Nephrostome is a ciliated funnel communicating with the coelom. It consists of an elliptical pore bounded by the so- called upper and lower lips. Upper lip is formed of a large central cell and 8 or 9 marginal cells, whereas lower lip is formed of 4 or 5 compact cells. All the cells are ciliated.
2. **Body of nephridium :** Nephrostome leads into the main body of nephridium through a short, narrow and ciliated tube like neck. Body consists of two parts, a short straight lobe and a

long twisted lobe with a narrow apical part. Straight lobe is one half of the twisted lobe's length. Twisted lobe consists of a proximal limb and a distal limb, which are spirally twisted upon each other. Proximal limb is joined to the neck.



A B

Fig 5: Pheretima. Septal nephridium A. Entire nephridium B. Nephrostome in L.S.

3. **Terminal duct :** distal limb of body of nephridium ends in a short and narrow duct, called terminal duct.

Nephridial tubule : nephridium consists of a syncitial glandular mass traversed by a coiled tubule, having four ciliated tracts in its course, one in neck, two in body and one in terminal duct. There are four parallel tubules in the straight lobe, 3 in the basal part and 2 in the apical part of each limb of twisted loop, and a single tubule in each of the neck and terminal duct.

b) **Arrangement :** Each septum, behind 15^{th} segment bears 4 rows of septal nephridia, 2 on its anterior face and 2 on posterior face. Each row may contain 20 to 25 nephridia, so that there are 80 to 100 nephridia on each septum or in each coelomic compartment. Nephridia remain suspended freely in coelom of each segment while their terminal ducts open into a pair of septal excretory canals, which run inwards along the posterior face of septum, one on each side, parallel to the commissural vessel of their own side. These canals discharge their contents dorsally into a pair of supra intestinal excretory ducts, situated side by side mid dorsally just above the intestine, but beneath the dorsal blood vessel and extending from 15^{th} to the last body segment. These ducts open into intestine in each segment through narrow ductules, each having a sphinctered opening. Septal nephridia are thus also enteronephric.

D. Exo and Enteronephridia : If nephridia opens directly into the exterior through nephridiopore, then they are known Exonephric or ectonephric nephridia. Ex. Meganephridia of Nereis, Hirudinaria and Lumbricus and integumentaly microhephridia of Pheretima.

If nephridiopores are absent and the nephridia open directly into excretory canals or alimentary canal, such nephridia are called as Enteronephric nephridia. Ex. Pharyngeal or septal nephridia of Pheretima.

2. Coelomoducts:

These originated from mesoderm and arranged segmentally. Coelmoducts are wide tubes and they developed as out-pushings or evaginations from the coelom into the exterior. Coelmoducts open on one side into coelom by a relatively large ciliated funnel known as Coelomostome. It can be easily distinguished from the small sized ciliated funnel called as Nephrostome of nephridia. The second end of coelomoduct opens into the exterior by genital pore.

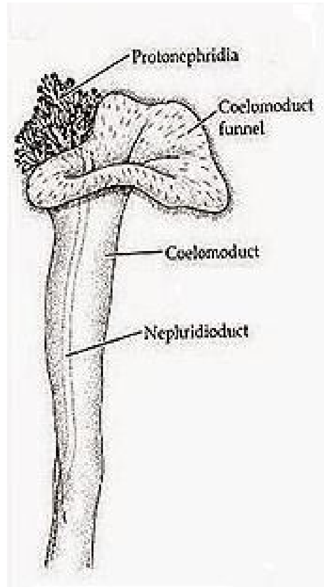


Fig. Coelomoduct

Coelomoducts primarily acts as gonoducts. The genital products developed on the wall of coelom are conveyed to the outside of the body by these coelomoducts. Hence, coelomoducts are confined only to few segments in which reproductive organs are present. However , in certain cases, coelomoducts as secondary function act as excretory ducts. In earthworms (Oligochaeta), both male and female reproductive funnels and ducts are coelomoducts only. Even, the uriniferous tubules forming the vertebrate kidney are nothing but coelomoducts.

3. Nephromixia:

In more primitive Poltchaeta and Hirudinea, Oligocaeta, the coelomoducts and nephridia are separate.

However, in some Polychaeta, the coelomoducts donot remain independent but fused partially or wholly with the nephridium and results in the formation of a compound segmental organs called as Nephromixia. Thus, they originate both from ectoderm and mesoderm. Similarly, they serve for both the purposes of excretion and the function of reproductive system in carrying out of the body, the gamets.

Different types of nephromixia are identified based on the degree of fusion of both nephridia and coelomoducts in the formation Nephromixia. Even, they may share only one external opening or their fusion may be very intimate, so that they share most of part the same duct.

Basically, four types of nephromixia are found in annelid.

a. **Protonephromixium:** It is formed due to fusion of a coelomoduct with a protonephridium. It conveys both excretory abd reproductive products to the outside of the body. Protonephromixium are found in Phyllodoce.
b. **Metanephromixium:** It is formed by the union of coelomoduct with Metanephridium. It is found in Capitellids, Hesione etc.
c. **Myxonephridium:** Nephridium and coelomoduct are very intimately fused to form a single composite organ. Funnel is formed from coelomoduct and myxonephridial ducts are formed from nephridia. They are found in Arenicola.

4. **Chloragogen Cells:**

Buchsbaum reported that nephridia are not only the means of excretion in earthworm ex. Pheretima posthuma. A large number of yellow cells called as Chlorogogue or Chlorogogen Cells are present around the intestine and dorsal blood vessel in Pheretima. They are originated from coelomic epithelium or peritoneum of alimentary canal. Few scientists report that they have excretory function. They collect nitrogenous waste products from blood capillaries of the gut. Later, these nitrogeneous wastes are deposited as yellow granules i.e. guanine in their cytoplasm. When nitrogenous waste products are fully deposited in cytoplasm, the chlorogogen cells detach from gut wall and drop into the coelomic fluid. Finally, they are eliminated through septal nephridia or dorsal pores in Pheretima. These chlorogogen cells released freely into the coelom are called as Eleocytes. Semal-van Gensen said these degeneratives chlorogogen cells are eliminated by phagocytic coelomocytes.

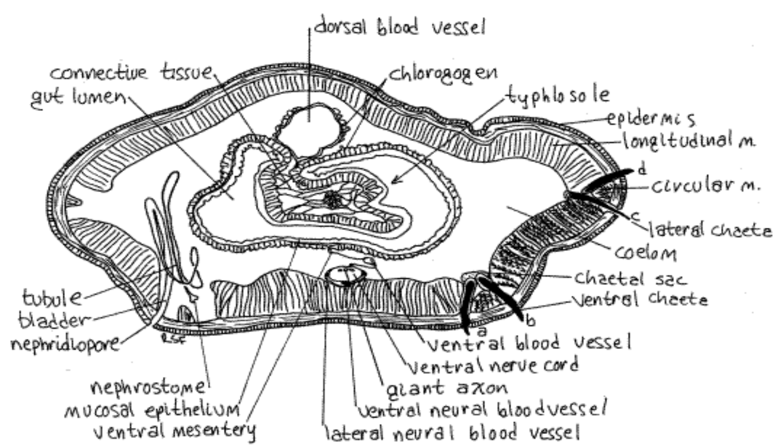


Fig. showing Chloragogen cells

Another opinion is that, the detached and degenerating chlorogogen cells serves as storehouse of reserve food materials in the form of glycogen and fat. Liebman (1946) said that eleocytes migrate to different parts of the body and to various tissues and even including developing eggs. Thus, they supply the reserve food. Chlorogogen cells are found with deamination of proteins, formation of ammonia and synthesis of urea. Thus chlorogogen cells are vital in the organization of intermediary metabolism in earthworm. Thus, they are comparable with the liver of vertebrates.

5. **Botryoidal tissue:**

   It is found in Leech. The entire coelom is filled with botryoidal tissue. From the beneath the longitudinal muscles of body wall to until the surrounding of the alimentary canal, the botryoidal tissue is occupying the space in the coelom. Botryoidal tissue is composed of a network of large branching tubular cells arranged end to end. It fills entire coelom except few spances such as haemocoelomic spances. The walls of the Botryoidal cells are loaded with dark brown pigment. Their intracellular canals are filled with red haemocoelomic fluid. It has excretory function like that of Chlorogogen cells.

6. **Ciliated Organs:**

   In some annelids, coeomoducts are reduced to maximum size as simple Ciliated Organs. In nereis Ciliated Organs are attached to the dorso-lateral longitudinal muscles. They open directly outside the body.

   In Leech, a paired peculiar ciliated organ is present. They have a central reservoir and a large number of funnels. Each funnel is a ciliated organ has a distinct connection with the nephridium. However, this connection is lost in case of adult. At the same time, excretory function is also lost and it becomes a part of haemocoelic system and produces coelomic corpuscles or coelomocytes.

8.5 Excretory Organs In Arthropoda

The main excretory products in Arthropods are ammonia and uric acid. Hence, the organisms which excrete ammonia are called ammonotelic organisms. Ex. Most of the crustaceans. The organisms which excrete uric acid are called Uricotelic organisms. Ex. Insects.

The Arthropod excretory system is as complex as other aspects of organization of this phylum. In these arthropods, the characteristic excretory organ is basically a tubular structure. However, due to earlier misnomer is still prevailing and in use, they may call them as nephridia. As a detailed discussion is not required for this title, we are presenting the different varieties of excretory organs present in this phylum, Arthropoda as follows:-

1. Nephridia
2. Green Glands
3. Coxal Glands
4. Hepatopancreas
5. Nephrocytes
6. Crural Gland
7. Malphigian Tubules
8. Miscellaneous Organs:
   i. Ectodermal Gland
   ii. Integument
   iii. Midgut Epithelium
   iv. Intestinal Caeca
   v. Lymphatic Organs
   vi. Fat Body Cells
   vii. Uricose glands

1. **Nephridia:**

   They are paired structures arranged segmentally in each organism often corresponding to the pairs of legs. They are present at the base of each pair of legs. Nephridia open at the inner base of each leg. Cilia are present in the excretory ducts. Each nephridium has an endsac, a ciliated funnel, a coiled tube, a bladder and an ectodermal duct, which opens to outside by an excretory pore, called as nephridiopore, Ex: Peripatus. The nephridium in this organism is a modified coelomoduct.
2. **Green Gland:**

   These glands are green in colour. Hence, they are called as Green gland. They are also known as Antennary glands as they are located at the basal segment of antenna. They are the excretory organs of Crustacea. In each animal only a pair of green glands are present. Green glands have different structures in different organisms.

   Antennary glands in fresh water Prawn(Palaemon **):** Each gland is enclosed in the coxal segment of each antennae. It is pea seed or gram seedd in size with opaque white in colour. Each gland consist of three parts i. End sac ii. Labyrinth or glandular plexus and iii. The bladder, which opens outside by renal pore.

The labyrinth is larger than end sac and formed of greatly coiled large number of excretory tubules. These tubules are embedded in a mass of connective tissue and lined with single large layer of excretory epithelial cells. The labyrinth opens by many apertures into the bladder and single aperture into the end sac.

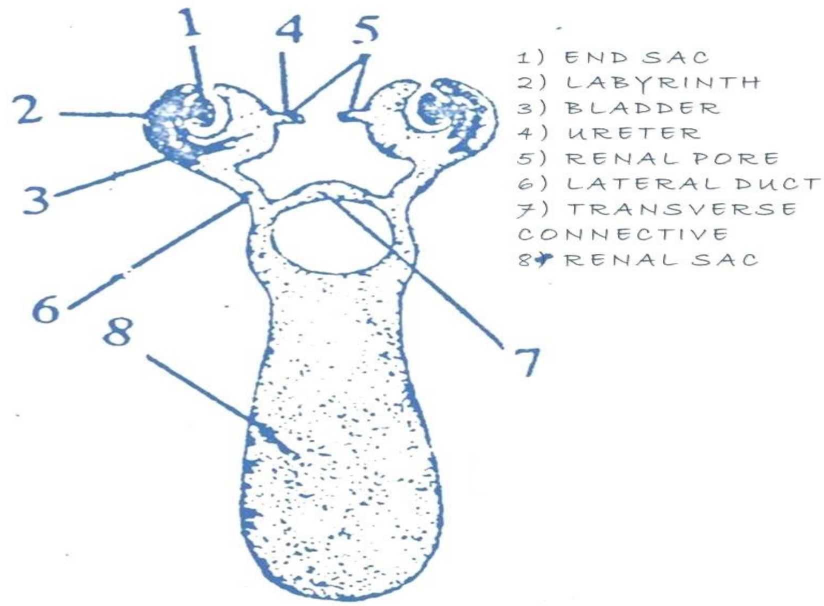


Fig: Palaemon Excretory organ in dorsal view

The end sac is been shaped. It is the smallest part lying in between the bladder and labyrinth. Internally, its cavity contains large blood lacuna. The end sac has two wall layers. Outer thick layer consists of connective tissue containing numerous small blood lacunae. The inner layer has large excretory epithelial cells.

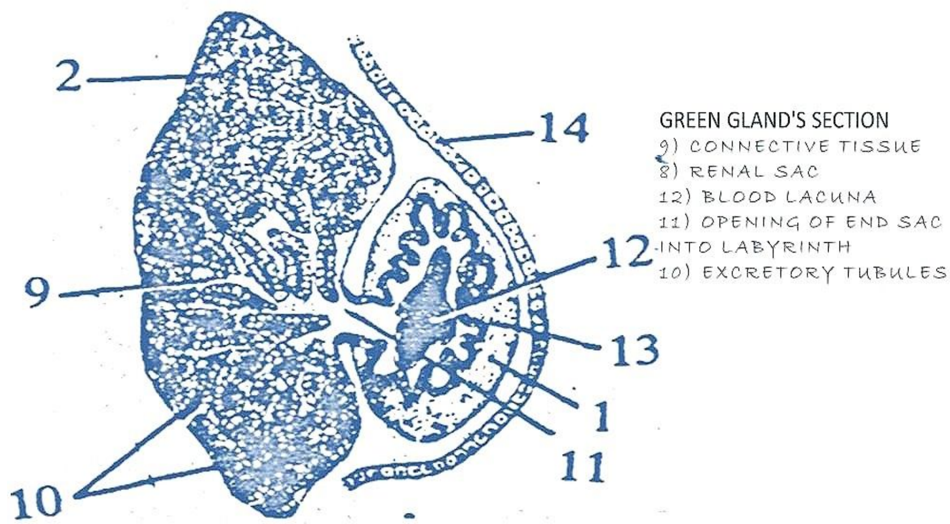


Fig : Palaemon Antennary gland in section

Largest part of antennary gland is bladder. It is located on the inner part of the end sac. It is thin-walled sac made up of a single layer of excretory epithelial cells. This bladder's middle wall is extended as a short and narrow excretory duct or ureter. It opens outside as renal pore which located on a papilla on the inner side of coax of the antenna.

From the bladder of each green gland, a narrow lateral duct arises. Lateral ducts of both sides are connected through a transverse connective. Later, the two lateral ducts run backwards to open into a median sac known as renal sac. It is located just above the cardiac stomach and just beneath the carapace and extends upto gonads. Renal sac is a large, thin-walled sac made up of a single layer of flattened excretory epithelial cells.

Physiology of excretion:

Like a vertebrate kidney, antennary glands has dual function i.e. excretion and osmoregulation. By ultra filtration, water and dissolved substances are separated from the blood and later passed into end sac. Ammonia is excreted by end sac. Uric acid and other nitrogenous compounds are excreted by other parts of the antennary glands. Labyrinth collects useful substances by selectively reabsorption and returns it in to the blood. The excretory fluid or urine flows into bladder. After collecting excretory fluid from renal sac into the bladders, the entire excretory products are thrown out through renal pore.

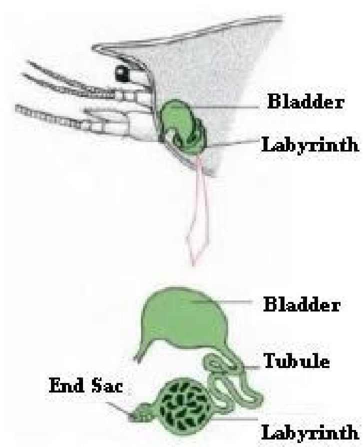
Green glands on Penaeus: It is a simple structure. The green glands have a round bulbous end sac, a long coiled tube like labyrinth and a bulbous bladder opening outside by excretory pore.

Green gland of cry fish (Astacus) : It has also simple structure like the green gland of Penaeus. The green gland of cray fish starts with end sac, which is demarcated as sacculus and cortex. The cortex is connected with labyrinth. Labyrinth is like a long tububle and is connected with a big sac known as bladder, which opens outside by excretory pore.

3. **Coxal glands:**

They are found in Scorpion an arachnid. They are homologous with the green glands.

A pair of shining white coxal glands is attached to the coax of the third pair of walking legs. Coxal glands are derived from coelomoducts and in adult coelomoducts of fifth segment persist in the form of coxal gland. Each coxal gland has three parts i. Large excretory sacculate or end sac ii. A coiled tube or labyrinth and iii. A swollen reservoir or bladder. This bladder opens exteriorly by a small orifice. Urate crystals were found in coxal glands when carmine injected into the body cavity.

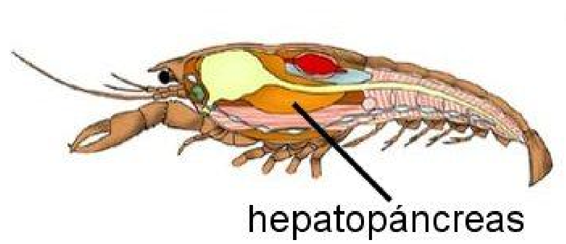


Coxal Gland

In Limulus coxal glands are known as brick-red glands as they are brick red in colour. In spiders, coxal glands are degenerated structures.

4. **Hepatopancreas :**

Generally Hepatopancreas is associated with digestive system. However, in Scorpion, it also acts as an excretory organ. Hepatopancreas is a massive structure present in the cavity of mesosoma. It opens into mid gut through five pairs of ducts. Pavlovsky, a scientist, injected ammonia carmine into body cavity of scorpion. Later he found bright red granules inside the cells of Hepatopancreas. Thus, he proved the excretory function of hepatopancreas in scorpion.



5. Nephrocytes :

These are found in insects and arachinids as specialized excretory cells found in the body cavity in groups. They have excretory and phagocytic functions.

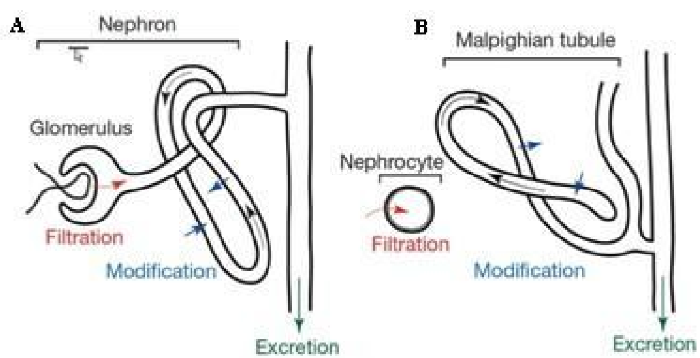


Fig. Shows Naphrocyte

6. Crural glands:

They are seen in peripatus and supposed to have excretory function. A series of paired, grandular thin wall vasicular structures are known as Crural glands that lie laterally in the body cavity of males only. They open to external at the bases of the legs. These are also called as coxal glands by some of the authors. The external opening of crural glands, lie just outside the nephridiopore.

7. Malphigian tubules :

Malphigian tubules are the excretory organs in Chelicerata, Mandibulata sub-phyla of Arthropoda. In 1969, Malphighi, discovered the tubules and they are named after him as malphighian tubules(Fig.7.14). Commonly they are seen as excretory organs in class Insecta, Arachnida and Myriapoda. Only one pair of malphighian tubules is present in centipedes, 2 pairs in millipedes and scorpion, 60-150 in cockroach. Thus, their number varies in different organisms.

In cockroach malphighian tubules are extremely fine, yellow or cream coloured unbranched blind tubes. They open into the anterior end of the hind gut or proctodaeum. Basically they are the outgrowths and around 60-150 malphighian tubules are arranged in 6-8 bundles.

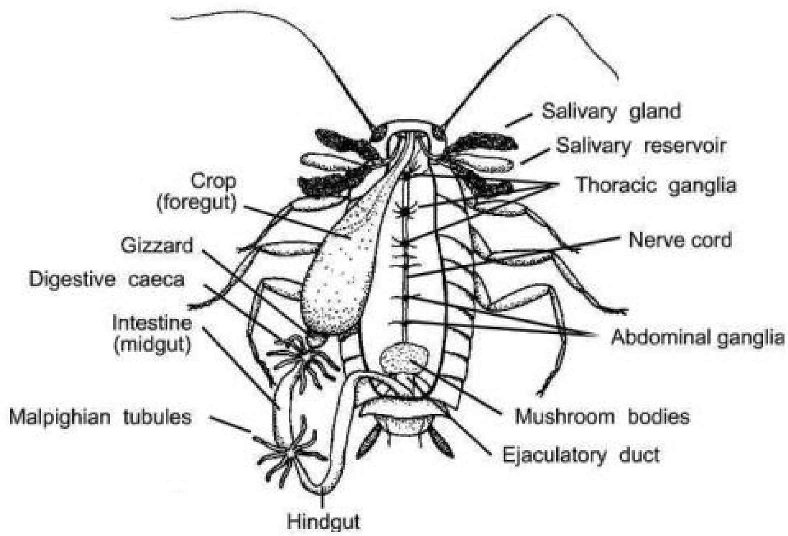
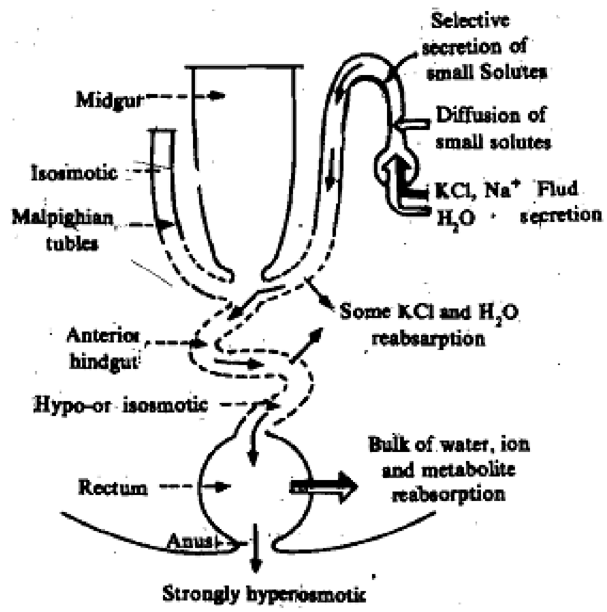


Fig. shows Malpighian tubules

Each malphighian tubules is 25mm long and 0.05 mm in diameter. They are lined by a granular epithelium with brush border towards internal lumen. They float in the haemolymph. A malphighian tubules has two functional parts. Glandular cells of distal secretory part extract nitrogenous wastes (mostly in the form of salts of uric acid, e.g. potassium urate) and water from haemolymph forming a solution called urine. The urine flows towards the proximal absorptive part of tubule which reabsorbs certain salts, such as potassium bicarbonates, and some water



resulting in precipitation of uric acid. Uric acid already present in haemolymph combines with reabsorbed potassium bicarbonate and water to form the relatively soluble potassium urate which again becomes available to be actively transported from haemolumph into the lumen of distal portion of malphighian tubules. From malphighian tubules uric acid moves into ileum by gentle peristaltic waves. More water is reabsorbed in colon and rectum so that more or less solid uric acid is eliminated with faeces through anus. Generally uric acid and urates have a very low solubility in water. Hence, the excretory product is in paste form rather than as excretory fluid or crystalline form.

8. Miscellaneous Organs:

In Arthropods, there are few other Miscellaneous Organs that carry out excretory function. Sometimes they may have excretory function as a secondary adaptation. Few of such structures are described below.

i. **Ectodermal Gland:**

In Nebalia, eight pairs of ectofermal glands present between the folds of the shell in the antennal region. They are considered as excretory organs.

ii. **Integument:**

Thick , hard, non- living and horny chitinous exoskeleton is present in all the Arthropods. In various organisms, the excretory products are deposited on the inner surface of the integument. These excretory products are eliminated along with the integument during moulting or ecdysis in all the Arthropods. Thus, integument has excretory function.

iii. Midgut Epithelium

Mid gut epithelium cells have excretory function in few arthropods. Ex- Belanus and Lepas.

iv. Intestinal Caeca

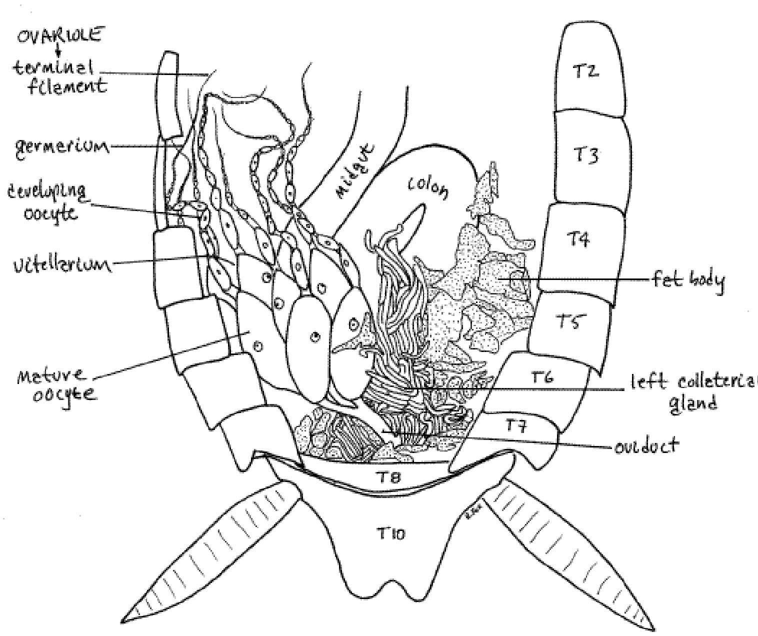
In Squilla (Class : Crustacea) the rectum bears a pair of intestinal caeca. A comb like internal wall is present in these intestinal caeca. They do excretory function.

v. Lymphatic Organs

Lymphatic tissue and organs are found in Scorpion as specialized structures. Lymphatic tissue is found beneath the body wall especially in the area of mesosoma. A pair of Lymphatic organs is connected with the coxal glands. They are internally filled with lymphatic tissue, phagocytic cells and connective tissue. Hence, Lymphatic organs and tissues are considered to have phagocytic and excretory function in Scorpion.

vi. Fat Body Cells

Fat body cell are found in insects, ex. Cockroach. They have originated from the walls of embryonic coelomic cavities. In adults, they fill up most of the area of haemocoelom. Fat body is irregularly lobed, white tissue consists of i) Rounded or polyhedral vacuolated cells containing glycogen, fat and protein as reserve food. ii) Excretory products such as uric acid and urates deposited in urate cells through out life. This type of excretion is called as storage excretion.



vii. Uricose glands

They are also found in insects ex. Cockroach. The mushroom gland of male cockroach possesses long, blind, peripheral tubules known as Uricose gland or Urriviuli majors. It stores uric acid as a part of storage excretion method. This excretory product is discharged over spermatophore during copulation.

8.6 Execretory Organs In Mollusca

Even though diversity is present among various organisms in the phylum Mollusca, the group preserves a good deal of uniformity in excretory system, despite the variety of forms shown by other organs such as ctenidium and foot. The important excretory organs are listed below:

1. Nephridia or sac like kidney
2. Organs of Bojanus
3. Kebers Organs

Nephridia or sac like kidney

They are also known as renal organs. On each side of the body six pairs of nephridia are present in Neopilina belonged to class Monoplacophora. Each nephridium has a central sac giving out several srcretor lobules and diverticula. Nephridia have short ducts that open laterally by nephridiopores into pallial groove. The last five pairs are located near the gills. Except the first pair of nephridia the remaining five open internally into coelom i.e. three pairs into the body coelom and two pairs into pericardial coelom.

In Chiton, belonged to class Amphineura ther are two selender and symmetrical kidneys or nephridia are present. Each has an elongated Y- shaped canal. The unpaired limb of Y- runs longitudinally on each side of the body terminating blindly in anterior. The ventral or external branch of paired limb of Y, opens to exterior through nephridiopore. This opens inturn into posterior part of the mantle cavity. The dorsal or internal branch of paired limb of Y – opens into pericardium through a ciliated renopericardial aperture or funnel. Thus, both pericardial and external apertures of the kidney in this way lie near one another at hinder end. The excretory area or surface is increased due to numerous branched caeca or lobed canals. These caeca open into all the 3 limbs of kidney especially in anterior region. Cubical or ciliated epithelium is present in the three limbs.

Kidney or Renal sac : In Sepia the excretory system has a kidney as excretory organ. It includes a kidney or renal sac consisting of three thin walled chambers, two ventral and one mid dorsal, which communicate with one another. Two ventral chambers open at one end, to the exterior by renal apertures placed on renal papillae, lying one on either side of the rectum, and at the other, communicate with the pericardium by renopreicardial apertures. Through each ventral chamber passes the corresponding branchial vein, formed by the bifurcation of the venacava. Vein is covered by excretory glandular epithelium which extracts the nitrogenous waste products from the blood. Dorsal chamber encloses the pancreatic follicles covering end opening into the ducts of the digestive gland. They are richly vascular and are said to serve an excretory function. Nitrogenous excretory substance has been detected in the cavities of the renal sac in the form ofGuanine which is discharged into the mental cavity.

Renal Organ or Kidney:

In Pila globosa the excretory organ is a large kidney or renal organ like the gill it is the organ of the left side, that of the right side having disappeared or modified into the gonoduct. It communicates with the exterior on one hand and with the pericardial cavity representing coelom on the other, it is thus of the nature of the coelomoduct. It consists of two chambers a right anterior and a left posterior.

i. **Enterior Renal chamber:** It is more or less an oval organ, reddish in colour and lies enterior to the pericardium. It opens into the branchial chamber of the mental cavity through a slip like opening near the epitaenia. At the other end, it communicates with the posterior renal chamber through an internal opening. Internal cavity of the anterior chamber is very much reduced due to the presence of many triangular leaf like processes or lamellae, those arising from the roof alternating with those from the floor. Dorsal surface of the chamber is marked by numerous transverse grooves, corresponding to these internal lamellae.

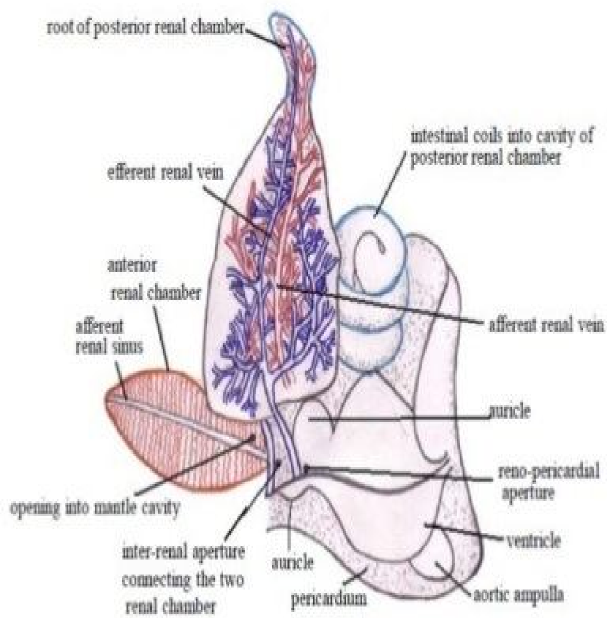


Fig: Pila Excretory organ

Lamellae on the roof are arranged on either side of a median longitudinal axis, or the efferent renal sinus. Lamellae on the floor are arranged on either side of a similar median axis, the afferent renal sinus, which is the right branch of the peri- intestinal sinus. It breaks up into numerous branches to supply the lamellae on both the sides.

ii. **Posterior renal chamber:** It is a broad, brownish to grey and hook- shaped chamber, situated behind the anterior renal chamber, in between the rectum on the right and the pericardium and the digestive gland on the left. Its large internal cavity encloses a part of the genital duct and a few coils of the intestine. At one end, it communicates with the anterior renal chamber through an aperture, and at the other with the pericardium through an elongated slit like reno- pericardial aperture, perforating a thin vertical reno-pericardial septum, separating the two afferent and efferent renal vessels profusely branch in the roof of this chamber.

Physiology of Excretion

Two renal chambers are richly supplied with blood from which the nitrogenous waste products are separated. Excretory fluid from the posterior chamber is also transferred to the anterior chamber, from where it is discharged through the external renal aperture into the mantle cavity and finally passed out of the body through the right nichal lobe along with the outflowing water. Excretory fluid contains mostly ammonia and some ammonium compounds, urea and uric acid. Pila shows an adaptation for water conservation during terrestrial phase by converting ammonia into the insoluble uric acid. During aquatic phase, Pila excretes ammonia, but during terrestrial phase, it excretes uric acid. So it is both ammonotelic as well as uricotelic.

Digestive gland of most gastropods also forms an organ of excretion. It contains some excretory cells which engulf and store the excretory wastes and later pass out through the stomach and intestine.

1. **Organs of Bojanus**

   Excretory organs in Unio are (i) a pair of kidneys or organs of Bojanus, and (ii) Keber's organ or Pericardial gland.

   The two kidneys or nephridia are often termed the organ of Bojanus after the name of their discoverer. They are situated beneath the floor of the pericardial cavity, one on each side of the vena cava. They are derived from the true coelom (urocoels).

   Each kidney is a long, dark and glandular tube open at both ends. It is bent upon itself like a broad U- shaped tube, with the loop posterior, the two ends anterior and the two limbs lying parallel and one above the other. The lower arm is brown, spongy, glandular and thick walled, forming the kidney proper, which opens anteriorly into the fluid filled pericardial cavity by a small ciliated renopericardial aperture. The dorsal arm is small, non glandular, lined by ciliated epithelium and thin walled known as the ureter or urinary bladder, which opens anteriorly into the supra branchial chamber of the inner gill lamina by a small renal aperture. The bladders of both the kidneys intercommunicate by an oval apertute.

Physiology of excretion: The ventral glandular portion of the kidney extracts guanin and other nitrogenous waste products of metabolism from the coelomic pericardial fluid as well as the blood supplied to the kidneys. The walls of the pericardial sinus are also glandular, and supposed to secrete waste materials from the blood into the coelomic cavity.

The ciliated epithelium lining of the bladder produces an outgoing current, thus coveying excretory fluid from the glandular part of the kidney to the supra branchial chamber which leads to the excurrent siphon. There is reabsorption of salts in the two kidneys which also serves for maintaining the blood concentration level by removing excessive water from it.

2. Kebers Organs

It is also known as pericardial gland. It is placed infront of the pericardium as a large, reddish brown, glandular mass. Keber's organ discharges nitrogenous waste products into pericardial fluid through reno- pericardial aperture, nitrogenous wastes enter the kidneys proper from keber's organ. The glandular part of the kidney proper also filters nitrogenous waste products from the blood. Then form kidneys proper excretory fluid enters the urinary bladder and then supra branchial chamber. The outgoing water, takes away the nitrogenous wastes from the supra branchial chamber along with its out flow. In addition to excretrion, the excretory organs also help in osmoregulation.

8.7 Excretory Organs in Echinodermata

In phylum Echinodermata, definite excretory organs are absent. The nephridia the primary excretory organs in invertebrates is totally absent in both larval and adult stages of all the Echinoderms. This applies to even other groups such as Hemichordata and Urochordata which are in other context probably related to Echinodermata. However, recent morphological studies suggest that axial organs in Asteroids and Echinoids may have excretory function. The other structure that play an important role in serving excretory function in the entire phylum of Echinodermata are Coelomocytes.

1. Axial Gland :

Earlier, the axial gland was also known as axial organ or ovoid gland, or dorsal organ or septal organ or brown gland etc. It is a part of the axial complex. It has three parts:

a) Axial sinus, a thin walled tubular coelomic cavity containing,
b) A stone canal and
c) An axial gland or organ.

Stone canal and axial gland are very closely attached to its walls by mesenteries.

Axial gland is an elongated fusiform spongy body. Mostly it is brownish or purplish in colour. Axial organ is externally clothed by coelomic epithelium and internally with several strands of lacunar tissue i.e. irregular spaces containing coelomocytes and bounded by connective tissue. Histologically the axial organ or gland is closely associated with haemal channals. The axial organ forms the center of the entire haemal system in Echinoderms. Hence, it was earlier described as Heart.

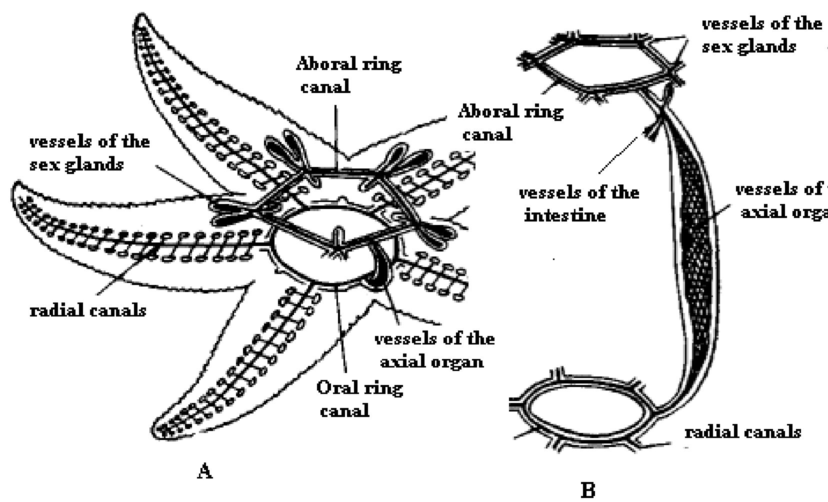


Fig: Shows (A) General diagram starfish; (B) Axial organ (gland)

The oral end of axial gland terminates in the septum dividing the hyponeural ring sinus. Axial gland aboral end give out a head process surrounded by terminal sac or dorsal sac or madreporic vesicle.

2. Coelomocytes :

In all the Echinoderms, the coelom is filled with coelomic fluid. It is like sea water in composition with less alkalinity. The coelomocytes are present in the coelomic fluid. These coelomocytes are produced by axial gland. Coelomocytes are also known as amoeboid coelomocytes or amoebocytes. They are two types:

a) Amoebocytes with slender pseudopodia,
b) Amoebocytes with petaloid pseudopodia.

These are generally regarded to be two phases of the same cell.

These coelomocytes recognize and highly phagocytic on the foreign substances including bacteria, pigments and collagen etc. Thus, they act like leucocytes or white blood corpuscles of blood and serve to ingest and remove foreign bodies from coelom and the other parts of the organism. Thus, they help in excretion as they ingest the waste matter and send them out of the body through the walls of dermal papulae or branchiae. Coelomocytes also help in transporting oxygen as some of the coelomocytes are containing haemoglobin.

Physiology of Excretion:

Generally, ammonia is the principal nitrogenous waste material in all the Echinoderms. The excretory products, ammonia is removal occurs by general diffusion process through thin areas of the body surface such as rectal caeca or dermal papulae or tube feet etc. It was noticed that when dye was injected into coelom, the coelomocytes engulfed the waste and when the dye was laden in the coelomocytes, the migrate to the papulae where the collect at the distal end. Then, the tip of papulae constricts and pinches off. Thus coelomocytes are discharged outside the body. Other coelomocytes containing excretory products passes to outside the body through the epithelium of suckers present in the podia or at other sites. Remaining waste may be excreted by the cells of pyloric caeca. In addition to ammonia, Echinoderms may excreted ammonia compounds, urea and creatine but not the urates.

8.8 Summary

- Removal of Ammonia, Urea and Uric acid nitrogenous waste products from the body is commonly known as Excretion. The specialized organs that help the excretory function are known as Excretory Organs.
- In Protozoa, Porifera and Coelenterata, no special organelles are present for excretion, nitrogenous wastes (mainly ammonia) is

excreted by diffusion from the general body surface in the surrounding water.

- Flame cells are major excretory organ in Phylum Platyhemminthes. 'H' shaped excretory system is characteristic of Ascaris (Aschelminthes).
- Different type of excretory organs are present in Phylum Annelida i.e. Nephridia, Coelomoduct, Nephromyxia, Chloragogen Cells, Botryoidal tissue, Ciliated Organs.
- In Pheretima, nephridia are small sized or micronephridia these are distinguished into 3 types : A. Pharyngeal, B. Integumentary and C. Septal.
- Green gland or Antennary glands are the excretory organs of Crustacea. They are located at the basal segment of antenna.
- Coxal glands are found in Scorpion an arachnid. They are homologous with the green glands. They are attached to the coax of the third pair of walking legs.
- Malphighian tubules are seen as excretory organs in class Insecta, Arachnida and Myriapoda. In cockroach malphighian tubules are extremely fine, yellow or cream coloured unbranched blind tubes. They open into the anterior end of the hind gut or proctodaeum.
- Nephridia or sac like kidney, Organs of Bojanus and Kebers Organs are important excretory organs that present in Phylum Mollusca.
- In phylum Echinodermata, definite excretory organs are absent. The nephridia the primary excretory organs in invertebrates is totally absent in both larval and adult stages of all the Echinoderms. Axial gland and Coelomocytes are playing a role of excretory organs in echinoderms.

8.9 Glossary

- **Ammonotelic** Producing ammonia as the end product of nitrogen metabolism.

- **Excretion** Removal of metabolic wastes by an organism.
- **Integument** The outer layers of the body wall. Usually comprising the epidermis and underlying connective tissue (dermis) plus any secreted cuticle or exoskeleton.
- **Metanephridium** (pl. Metanephridia) An excretory tubule that opens into the coelom by a ciliated funnel and to the exterior by a nephridiopore.
- **Nephridium** (pl. Nephridia) An excretory tubule usually opening to the exterior via a nephridiopore.
- **Nephrostome** An open ciliated funnel at the inner, coelomic, end of a metanephridium.
- **Pseudocoel** Body cavity not lined by the mesoderm.
- **Ureotelic** Producing urea as the end product of nitrogen metabolism.
- **Uricotelic** Producing uric acid as the end product of nitrogen metabolism.

8.10 Self-Learning Exercise

Section A : Very short answer type

1 In which Phylum 'H' shaped excretory system present :

a) Annelid

b) Mollusc

c) Platyhelminthes

d) Aschelminthes

2 Write the name of excretory organs of unio?

3 Green gland are located at the basal segment of -----------------.

4 What is Enteronephridia?

Section B : Short answer type

1. Write short notes on:
    a) Organs of Bojanus and
    b) Kebers Organs
2. Draw a labelled diagram of Septal nephridium.
3. Write short notes on :
    a) Green gland
    b) Coelomocytes
4. Explain excretory system in Platyhelminthes in short.

Section C : Long answer type

1. Describe excretory organs in Phylum Arthropoda with suitable diagrams.
2. Explain excretory system in Phylum Mollusca.
3. Write short notes on :
    a) Coxal gland
    b) Axial gland
    c) Nephridia in Annelida

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Unit 9

Nervous System: Coelentrate, Annelida, Arthropoda, Mollusca and Echinodermata

Structure of the Unit

9.0 Objectives

After going through this unit you will be able to understand :

- How nervous system has evolved in animals.
- Simple Nerve cells to complex nervous system evolution in animals.
- Role of nervous system in animals
- Complexity of nervous system from Coelentrates to Echinodermates.

9.1 Introduction

Nervous system plays an important role in animals as most of organ systems are controlled by this system. This system is the part of an animal's body that coordinates the animal's voluntary and involuntary functions. It is also responsible for transmission of signals between different parts of the body. The nervous system has evolved from primitive form to an advance form in animals as there is diffuse nerve net in Coelentrates and there is an advance central nervous system in Arthropoda.

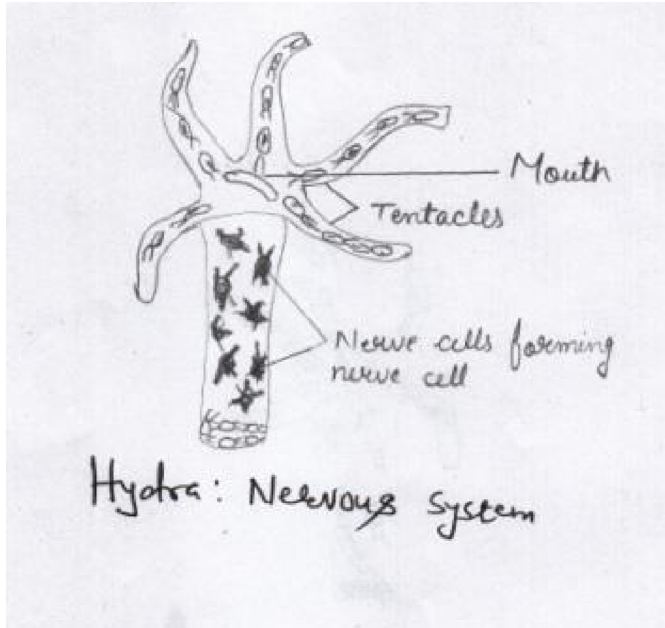
9.2 Coelentrate Nervous System

9.2.1 General Account:

There is primitive nervous system in coelentrates. It consists a diffuse nerve net and central nervous system is absent. Ocelli and statocyst are part of Sensory organs.

9.2.2 Nervous system in Hydra

This animal has a very simple and primitive type of nervous system. Bipolar and multipolar nerve cells (neurons) are present in body wall. They form 'nerve net ' or nerve plexus which one is irregular as well as discontinuous also. Two nearby neurons are not connected but their end or neurites are responsible for synaptic junction. The net of such neurons forming synaptic junction is called as 'synaptic nerve net'. There are as many neurons are present on pedal disk as we around mouth but there is no groupings is seen as well. The impulses by nerve net in hydra can be passed in all direction which may be also called as 'diffuse unpolarized transmission'.



There are two types of nerve nets are present in epidermis and gastrodermis. The nerve cells of both the nets are interconnected. The process of neurons is attached to the sensory cells and act as receptor for outer stimuli. The epithelial and endothelial muscle cells are also controlled by nerve nets and also act in response of external stimuli via neurons. This is also called as 'neuro-muscular system'. It is believed that nervous system has evolved in animals from coelentrata.

9.3 Nervous system in Annelids

9.3.1 General account

As described earlier, the advancement in nervous system is seen in annelids with compare to coelenterates. The well developed nervous system can be seen here in form of a pair of cerebral ganglia (brain) and a double ventral nerve cord. This ventral nerve cord bears ganglia and lateral nerve in each segment as annelids are true segmented animals.

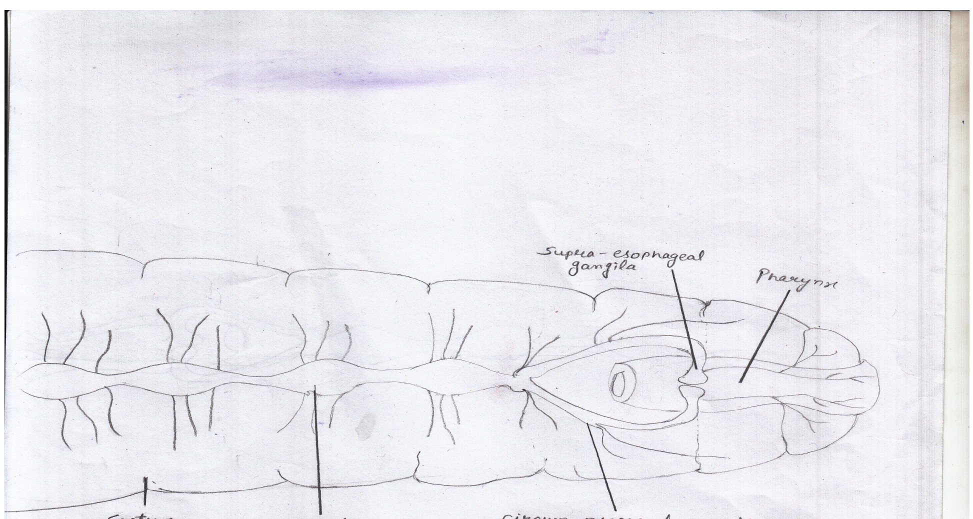
9.3.2 Nervous system in Indian Earthworm

In Indian Earthworm (*Pheretima posthuma*), the nervous system is advanced and developed. There are three part of nervous system in Earthworm. 1. Central, 2.Peripferal and, 3.Sympathic nervous system.

1. Central Nervous System: This system consists a front nerve ring and posterior ventral nerve cord.

(i) Nerve ring: it is composed of two cerebral ganglia, circumpharyngeal connectives and sub pharyngeal ganglia. These two cerebral ganglia are pear shaped and form brain in earthworm. The brain is dorsally present in third segment between buccal cavity and pharynx. Again a pair of thread like connective emerge from brain in both sides around pharynx and fuse to sub-pharyngeal ganglia present in forth segment below pharynx. This connective is called peri- or circum-pharyngeal connective. Cerebral ganglia, circum-pharyngeal connective and sub-pharyngeal ganglion form the “nerve ring” around pharynx.

(ii) Ventral nerve cord: It arises from sub-pharyngeal ganglia situated on mid and ventral position till end of the body. There is a ganglion in each segment on ventral nerve chord in form of enlargement. Ventral nerve cord is internally double in nature but it looks like single one. The two types of neuron, motor neurons and associated neurons are present in the ventral nerve cord, are responsible for contraction of body/ segments.



Earthworm : Nerve System

2. Peripherae nervous system: 8 to 10 lateral nerves are emerged from cerebral ganglion which pass through buccal cavity and prostomium. Also there are nerves from circum-pharyngeal connectives witch runs in buccual chamber and peristomium; whereas nerves from sub-

pharyngeal ganglia are supplied to organs present from 2 to 4 segments. Three pairs of lateral nerves are also supplied by each segment ganglion.

3. Sympathetic nerve system: an enlarged nerve plexus is present under epidermis, on elementary canal and within muscles of body wall. The plexuses are joined to peri-pharngeal connectives.

Functioning of nerve system:

Most of activities in earthworm are controlled by nervous system. The nerves are in connecting to muscles of body and are responsible for different actions.

9.4 Nervous system in Arthropoda

9.4.1 General account

Nervous system in Arthropoda is as advance as in Annelida. There is dorsal brain again connected with nerve ring to ventrae nerve cord.

9.4.2 Nervous system in common cockroach

As already mentioned the nervous system in cockroach carries (I) The Central (II) Peripheral and (III) Sympathetic nervous system.

(I) Central nervous system: this system comprises brain along with ventral nerve cord and the ganglia.

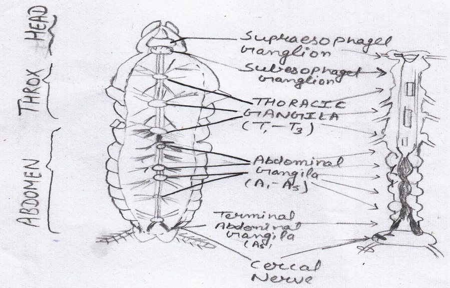
  (i) Brain: is in form of supra-oesophageal ganglion (bilobed) situated in the head above esophagus. Three pair of ganglia are fused alltogether in head region. The brain is divided in to three subparts.

  (a) Protocerebrum (b) Deuterocerebrum and (c) Tritocerebrum

  There is present a ventral sub-oesophageal ganglion which is contacted to brain by circum-oesophageal commissure.

  (ii) Ventrae nerve cord: the ventral nerve cord is double cord and situated on mid- ventral location. This starts from sub-oesophageal ganglion and ends at the last abdominal ganglion. There are nine ganglia in ventral nerve cord out of which three are present in thorax and six are abdomen.

(II) Peripheral nervous system: by this system nerves are distributed to all body parts from ganglia. Paired optic nerves to eyes are supplied from protocerebrum where as paired antennary nerves to antennae are supplied from deuteron-cerebrum in the same manner thoracic ganglia



Cockroach : Nerve System

supply nerves to wing, leg/muscles and other thoracic and abdominal organs.

(III) Sympathetic nervous system: some authors have also mentioned this system as stomogastric nervous system. There are total four ganglia namely (i) frontal ganglion (ii) hypocerebral ganglion (iii) ingluvial ganglion and (iv) proventriculuas ganglion.

The nerves are supplied to pharyx, labrum and clypeus. Esophagus is supplied nerves from hypo-cerebral ganglion. Crop is supplied nerves from ingluvial ganglion.The proventricular gangalion is present on the surface of proventriculus.

A retro-cerebral complex is also present above hyprocerebral ganglion. Two lobes called corpora cardiac and corpora allata are important part of this complex. Corpora cardiac is responsible for regulation of heart beats and peristalsis of foregut as well. Corpora allata is responsible for metamorphosis and also helps in reproduction through hormone secretion.

9.5 Nervous system in Mollusca

9.5.1 General account

This phylum again has a well developed nervous system. It also bears paired

ganglia, nerves and connectives. One important aspect is there that a Circumentric ring is formed by ganglia.

9.5.2 Nervous system in Pila

As described above the nervous system of Pila bears paired ganglia, commissures and the connectives connects them. Nerves in form of branches are supplied to all body organs.

(I) The ganglia: there are paired ganglia which are the mass of nerve cells as well.

The following type of ganglia are present in Pila:

(i) Cerebral ganglia: It is present on dorso-lateral side of buccal cavity. Two (right & left) cerebral ganglia are present, which are triangular in shape.

(ii) Ganglionic mass: this is composed of pedal ganglion, pleural ganglion and other nerves. There are to pleural-pedal (right & left) are Present in Pila.

(iii) Buccal ganglia: It is present dorso-laterally near the joint of esophagus and buccal mass.

(iv) Supra instinal ganglion: this is present near pleura-pedal gangionic mass.

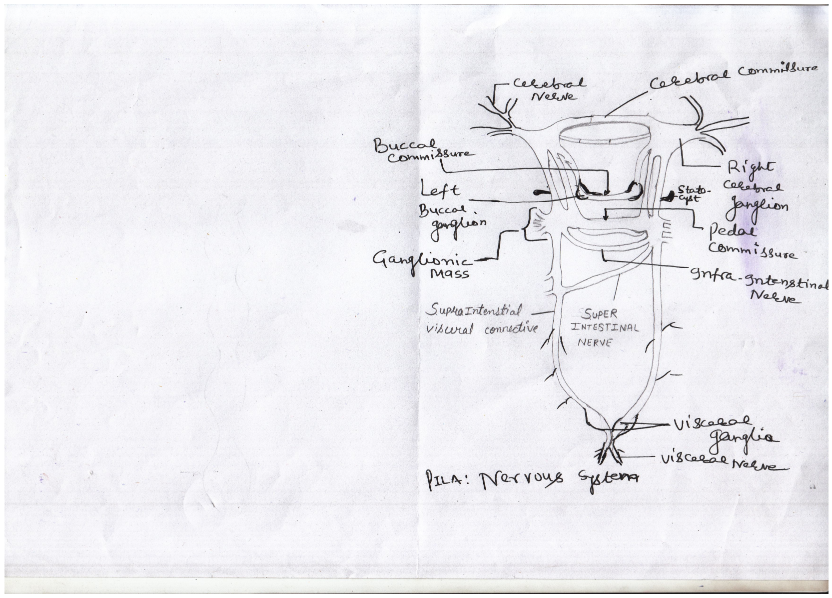
(v) Viceral ganglia: present at the end of visceral mass; two fused ganglia are there.

(II) Commissures: the commissures always connects similar ganglia. There are three commissures are present in pila.

(i) Cerebral Commissure; connects cerebral ganglia.

(ii) Pedal commissure; connects pedal ganglia.

(iii) Buccal commissure; connects buccal ganglia.



(III) Connectives: the connectives always connect two different ganglia. Following conectives are present in pila.

(i) Two cerebral-buccal connective

(ii) Two cerebral-pedal connective

(iii) Two cerebral-pleural connective

(iv) Pleuro-infra intestinal connective

(v) Supra-intestinal visceral connective

(vi) Infra-intestinal visceral connective

(vii) Supra-intestinal pleural connective

(viii) Zygoneury

Various nerves are supplied to different part of body from the different ganglia.

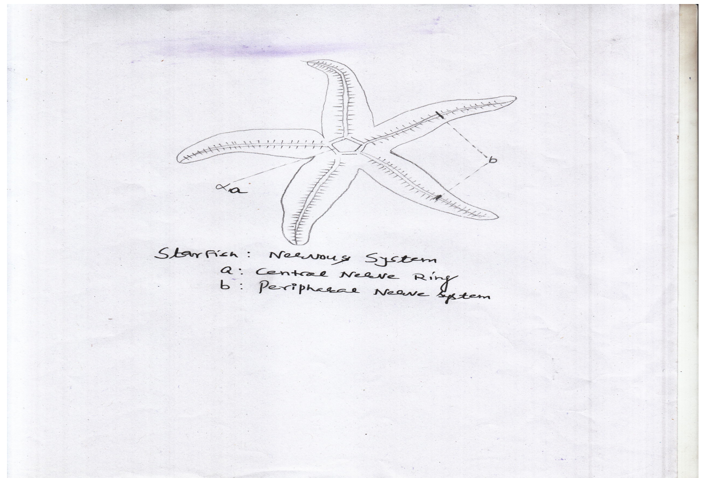
9.6. Nervous system in Echinodermata

9.6.1 General account

The nervous system in echinodermata is simple as there is no brain is seen in the animals of groups. The circumoral ring and radial nerves are main part of nervous system in the echinodermata.

9.6.2 Nervous system in starfish

As mentioned earlier, the nervous system in starfish is simple. It only consists a nerve ring net which is formed of some ganglion cells and nerve fibers. The nerve system is confined to body wall only except the visceral nerve plexus situated in the gut region.



(I) Central nerve ring or circumoral nerve ring which is associated with readial nerve rings and subepidermal plexus.

(II) Pheripheral nerve system: the five branches are distributed to the arms from central nerve ring.

Along with above coelomic and visceral system is seen to supply in organs.

9.7 Summary

The nervous system is the part of an animal's body that coordinates the animal's voluntary and involuntary functions. It is also responsible for transmission of signals between different parts of the body. The nervous system has evolved from primitive form to an advance form in animals as there is diffuse nerve net in Coelentrates and there is an advance central nervous system in Arthropoda. Ventral nerve system is present in Invertebrates; ganglia play an important role in the group.

9.8 Glossary

- **Commissures:** connects similar ganglia
- **Connectives:** connect two different ganglia
- **Ganglia:** Mass of nerve cells

9.9 Self Learning Exercises

Section A (Very short answer type)

1. Which one has simplest type of nervous system

(A) Cockroach (B) Hydra (c) Camel (D) Starfish

2. Nerve plexus is present in…………………..
3. Stomogastric nerve system is present in………………
4. Corpora allata is present in Cockroach. (True/False)

Section B (Short answer type)

1. Name any two ganglion present in Earthworm ?
2. Draw well labeled diagram of Nerve system in Starfish.
3. What is Corpora allata?
4. What is Connective?

Section C (Long answer type)

1. Write a note on complexity of nerve system in Invertebrates.
2. Write a note on nerve system in Earthworm.
3. Write a note on nerve system in Pila.
4. Write a note on nerve system in Cockroach.

Answers of Section A Questions

1. B 2. Hydra 3. Cockroach 4. True

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Unit - 10

Receptors: Structural and functional organization of the mechanoreceptors, chemoreceptors and photoreceptors

Structure of the Unit

10.0 Objectives

After going through this unit you will be able to understand the structure and functions of various receptors(mechanoreceptors,chemoreceptors and photoreceptors)found in different groups of the invertebrates

10.1 Receptors In Coelenterata

Sense organ of Aurelia are eight rhopalia, situated one in each of the per and interadial marginal notches. Each rhopalium comprises tentaculocyst or statocyst, two ocelli and two olfactory pits.

a) **Tentaculocyst or statocyst :** it is a hollow club shaped structure situated in the marginal notch between two marginal lappets. It is covered on the outer side by a process of bell margin, termed hood, which also connects the bases of two marginal lappets. Just below the club is a pad of tall ciliated sensory epithelial cells which are connected with the subumbrellar nerve net lying below epidermis. Tentaculocyst is a specialized hollow tentacle. Projecting into tentaculocyst is an extension of circular canal lined by gastrodermis. Lying in the distal part of tentaculocyst is a mass of polygonal statolith cells of gastrodermal origin. Each statolith cell contains a self secreted particle, the statolith composed of calcium sulphate and calcium phosphate. Statoliths act as weight, causing the club of tentaculocyst to bend up and down at its base, whenever the animal tilts to one side or other during swimming.

   Tentaculocyst control the equilibrium of umbrella during swimming. If umbrella is tilted, the clubs of tentaculocysts press against their sensory pads beneath, the sensory cells which become stimulated. Higher the tilt, the greater is the stimulation. The impulse is conducted through subumbrellar nerve net to the muscle fibres which react accordingly. In response the upper half of umbrella drives less water than lower half at each beat, so that the umbrella automatically rights itself.

b) **Ocelli :** There are two ocelli, one of ectodermal and other of endodermal origin. The former, known as pigment spot ocellus, consists of a patch of pigmented and sensory epidermal cells on the outer side of the club of tentaculocyst. The latter, known as pigment cup ocellus, consists of a cup shaped cavity lined by pigmented and sensory gastrodermal cells and is situated on the inner side of tentaculocyst in association with statoliths. Sensory cells of both the ocelli are connected with their respective underlying nerve nets. Ocelli are photoreceptors.

c) **Olfactory pits :** These are in the form of depressions of thickened epidermis containing sensory cells. One such depression lies at the base of hood. It is termed the outer or aboral olfactory pit. The other, known as inner or adoral olfactory pit, is situated on the inner side of tentaculocyst at the base of pad of ciliated sensory epithelial cells. These olfactory pits are probably chemoreceptor.

10.2 Receptors In Platyhelminthes

Sense organs or receptors occurring in Planaria are : (i) a pair of eyes (photoreceptors), (ii) ciliated pits, grooves and auricular organs (chemoreceptor), (iii) some scattered tangoreceptors and rheoreceptors.

a) **Eyes :**

Eyes or ocelli are a pair of conspicuous, black, rounded spots situated dorsally on head. Each eye has a cup-like form with its opening directed antero-laterally.

The cup is lined by a layer of pigment cells. Projecting into its hollow are numerous bipolar neuro- sensory light receptive photosensitive or retinal cells. In this type of eye, known as inverse eye, the light has first to pass through photo sensitive cells before reaching the pigmented cells. Expended distal end of each photo sensitive cell, projecting into cup longitudinally striated forming a striated border of uncertain function. Proximal ends of these cells run side by side forming the so called nerve fibers which communicate with the brain. Eye of Planaria lacks a lens. It cannot form an image but can perceive the

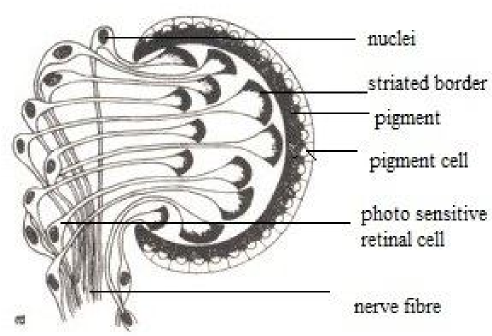
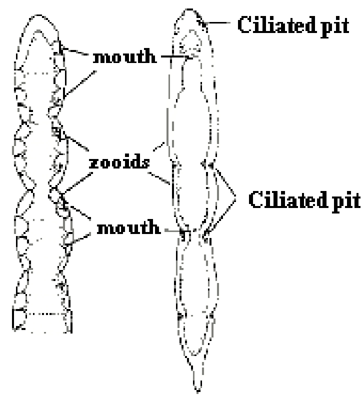


Fig: Planaria. V.S. of eye

difference between light and dark. Planarians with eyes removed can react to light but slower and less accurately.

b) **Ciliated pits, grooves and auricular organs** :

Anterior end of body bears several grooves and pitlike depressions. A pair of whitish grooves situated on auricles, are known as auricular organs. Ciliated pits, grooves and auricular organs are devoid of gland cells and rhabdites and the sensory cells lining them are chemoreceptors, i.e. sensitive to chemicals. Their sensory processes project just a little above the epidermis. These receptors help in detecting food and orienting the body towards it, hence are called tast receptors. If auricals are removed the animal cannot locate food.



Ciliated pits

c) **Tangoreceptors :**

These are touch sensitive or tactile cells found all over the body. They are distributed abundantly on ventral surface, specially around mouth, on lateral margins and at enterior end. Their sensory processes project beyond the epidermis so that their tips lie slightly beyond the level of cilia.

d) **Rheoreceptors :**

These are sensory cells sensitive to water currents. The sensory processes of rheoreceptors project much beyond the level of cilia.

10.3 Receptors In Aschelminthes

The sense organs of Ascaris are simple elevations supplied by nerves. They include various papillae, amphids and phasmids.

A. **Papillae:** Papillae are in the form of small villi situated on different body parts.

   a) **Labial Papillae:** These are formed by sensory cells surrounded by many supporting cells. These are gustatoreceptors and present on three lips surrounding mouth.

   b) **Cervical Papillae:** Dorsally, about 2mm behind lips, are present a pair of cervical papillae. These are tactile organs.

   c) **Anal papillae :** Present ventrally below the posterior end of male are 5 pairs of post anal papillae and 50 pairs of pre anal papillae. They help in copulation.

B. **Amphids** : On each latero ventral lip, a single amphid is present near a single papilla. These are gustatory sensory or chemo receptors.

C. **Phasmids :** These are chemo- receptors unicellular glands, openings one on either side of tail.

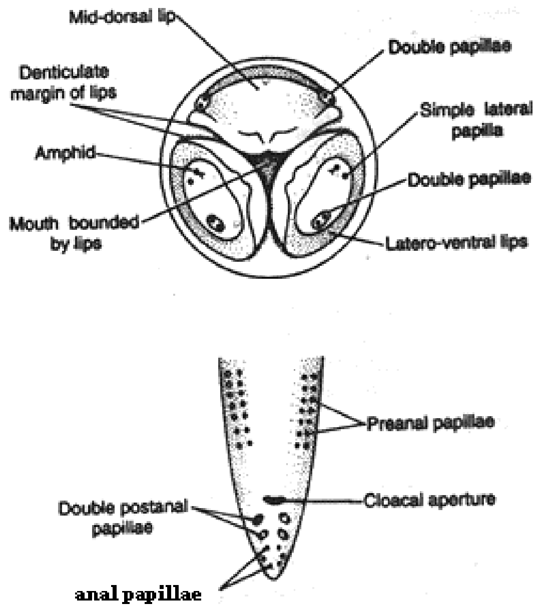


Fig: Papillae and amphid in Ascaris

10.4 Receptors in Annelida

A. **Prostomial tentacles :**

These are a pair of small, cylindrical projections from anterior border of prostomium. They are probably tactile. Surface of tentacles bears numerous sensory spiral organs, each consisting of about 100 photoreceptor cells, spirally arranged within a cuticular pit.

B. **Prostomial palps :**

These are a pair of stout highly muscular, two jointed structures arising one from each ventro-lateral aspects of prostomium. Proxima or basal joint is large, while distal one is small and can be retracted into the former. In addition to serving as lateral lips, the palps probably serve as organs of touch, taste and smell.

C. **Nuchal organs :**

These are a pair of small pits on the posterior dorsal surface of prostomium behind eyes. Pits are lined by ciliated epithelium with gland cells and connected by nerves to the hind part of brain. They serve as organs of smell and chemoreception and help the worm in detecting prey.

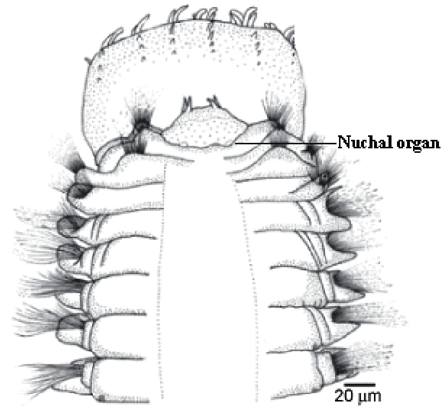


Fig: Nuchal organ in polychaete

D. **Peristomial cirri :**

These are elongated, slender, unjointed structures, two pairs on each side of peristomium, serving as tactile organs.

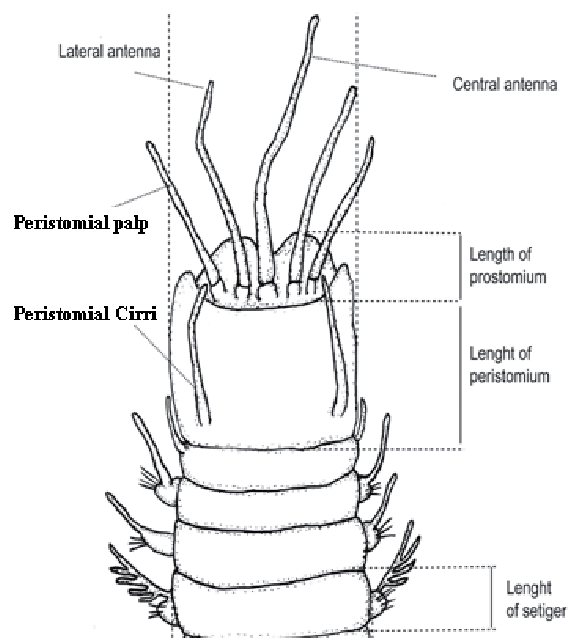


Figure showing peristomial palp and peristomial cirri

E. **Eyes :**

Dorsal surface of prostomium bears 4 simple black eyes. Each eye is a cup like structure with a pigmented wall consisting of radially arranged tall, narrow and light receptive retinal cells. Each retinal cell is differentiated into three distinct parts :

a) An outer nucleated part drawn out into a nerve fibre of the optic nerve,
b) A highly pigmented middle part or main body,
c) An inner part forming a clear hyaline rod projecting towards lens.

Cup is filled with a gelatinous substance forming the lens which, according to Andrews, is secreted by the retinal cells. Outer exposed surface of eye is covered by a layer of flattened epidermal cells and a transparent protective cuticular layer, together forming the cornea. Retinal cells are modified ectodermal cells and become continuous with epidermis at the edges, so that the small opening of cup towards cornea functions as a pupil. Eyes are not image forming but enable the worm to detect changes in light intensity. Clamworms are photonegative.

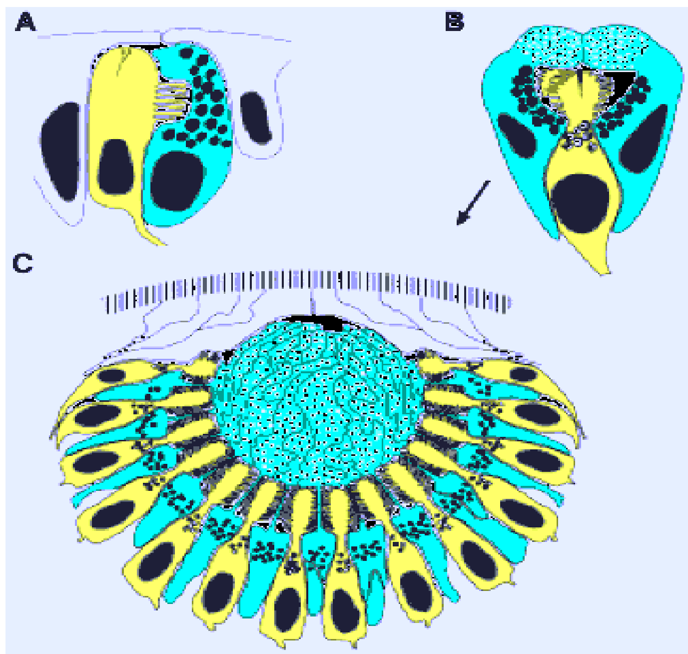


Fig: Eyes in annelida; (A) Larval, (B) adult and (C) fully grown eyes

Earthworms have well developed sense organs or receptor organs which are quite simple in structure, consisting of a single cell or a group of specialized ectodermal cells. Pheretima has three types of sense organs : (i) epidermal receptors, (ii) buccal receptors and (iii) photo- receptors.

1. **Epidermal receptors :**

   These are distributed all over epidermis but are more abundant on the lateral sides and ventral surface of body. Each receptor has an elevated cuticle covering a group of tall, slender and columnar receptor cells, bearing small hair like processes at their outer ends and connected with nerve fibres at their inner ends. They are surrounded on all sides by ordinary supporting epidermal cells, are separated from each other by spaces, have nuclei at different levels and possess internally a few basal cells. They are tactile (relating to touch) in function and according to some, they also respond to chemical stimuli and changes in temperature.

2. B**uccal receptors** :

   These are confined to the epithelium of buccal chamber. They are similar to epidermal receptor except that they possess broder outer ends, better developed sensory hairs, and more deeply situated nuclei. They are gustatory and olfactory (relating to taste and smell) and probably also respond to chemical stimuli.

3. **Photo-receptors :**

   Photosensitive organs, restricted only to dorsal surface, are more numerous on prostomium and peristomium and gradually reduce in number towards posterior end of body. They are totally absent in clitellum. Each photoreceptor consists of a single ovoid cell, with a nucleus and clear cytoplasm containing a network of neurofibrillae and a small transparent L- shaped lens or optic oraganelle or phaosome, made up of a hyaline substance. Lens focuses light rays from all directions on neurofibrils. A neurofibrils converse to an afferent nerve fiber which leaves the cell at its base to join the central nerves system. Photoreceptors enable worms to judge the intensity and duration of light.

Sense organs or receptors of Leech consist of modified epidermal cells. These of 4 types :

a) Nerve endings
b) Annular receptors
c) Segmental receptors
d) Eyes.

a) **Nerve endings :**

Free nerve endings occur all over the body, between epidermal cells, with there ganglion cells lying beneath the epidermis. These are probably chemoreceptors detecting chemical changes in the surrounding water.

b) **Annular receptors :**

Each annulus of body bears 36 very minute annular receptors, 18 on dorsal and 18 on ventral side, arranged in a trasverse row. Each receptors projects as a minute papilla and consists of many flattened overlapping cells that receives their nerve supply from the lateral branches. They function as tango receptors or tactile organs.

c) **Segmental receptors :**

These are small whitish elliptical papillae born upon the first annulus of each body segment, four pairs dorsally and three pairs ventrally. Each receptor consists of two types of cells, i. tactile cells or tango receptors and ii. Light sensitive or phtotoreceptors. There are 5-10 long, cylinder tactile cells, separated from one another and provided with hair like processes at their outer free ends. The light perceiving or photoreceptors cells, found only in the dorsal receptors, contain a cresentic hyaline substance in their cytoplasm, the optic organelle or lens. Each receptor receives a nerve branch and functions both as tangoreceptors and photoreceptors.

d) **Eyes :**

There are 5 pairs of eyes, arranged as a semicircle of black spots, along the dorsal margin of the anterior sucker, 1 pair in the first annulus of each of the first 5 segments. Each eye is in the form of a cylinder or cup with its long axis perpendicular to body surface. Wall of cylinder is formed of black pigmented tissue, enclosing a large number of clear, refractile, photoreceptors cells arranged in longitudinal rows. Each cell has a small rounded nucleus embedded in a thin peripheral layer of cytoplasm, surrounding a crescentic hyaline lens or optic organelle. Outer reconvex surface of eye is covered by transparent epidermal cells and cuticle forming a short of cornea. An optic nerve enters each eye basally and runs along its median axis distributing branches to all the photoreceptors cells.

All the eyes are not of equal size. They become smaller posteriorly so that the 5^{th} pair is the smallest. Eyes are differently directed and each can receive light only from one directions. It is not known whether the eyes form any image. Probably they only enable the leech to distinguish light from darkness and to locate the direction of source of light.

10.5 Receptors in Arthropoda

1. **Compound eye**

a) **Structure :**

Prawn has one pair of black and hemispherical eyes. Each eye is mounted on a short, movable and two-jointed stalk, which is lodged in an orbital notch at the base of rostrum. Each eye is made of a large number of independent visual elements or units, called ommatidia (Gr., ommation, little eye). Such eyes are called the compound eyes. These are characteristic of Arthropoda and do not occur elsewhere in the animal kingdom. All the ommatidia (about 2500) are arranged radially and are similar in structure, each consisting of many cells arranged along its central axis. Their description is as follows :

i.**Cornea :**

The outermost convex layer of eye forming cornea is the transparent cuticle. In surface view, cornea exhibit a large number of squares or facets by clearly visible lines, thus giving the appearance of a graph paper. In insect eyes, the facets are not squares but hexagons. Below each facets lies one ommatidium.

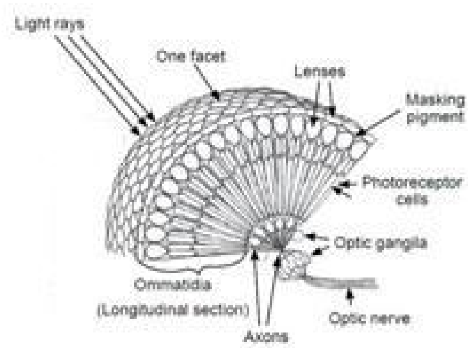
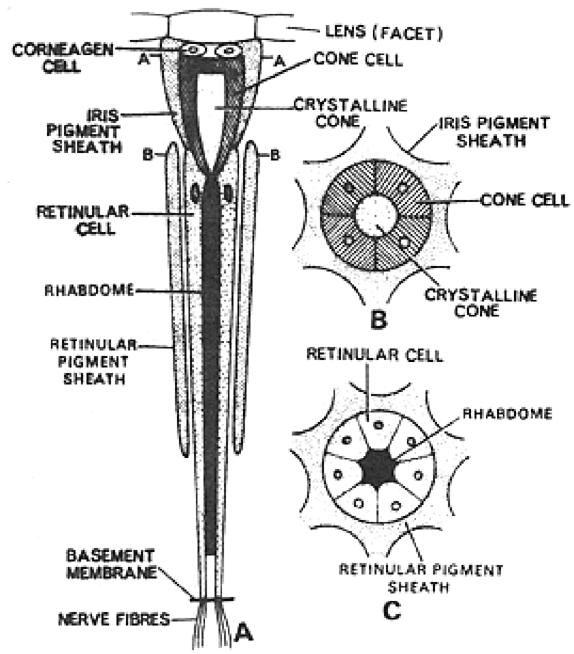


Fig: Palaemon. L.S. of compound eye showing arrangement of ommatidia ii.**Corneagen cells :**

Each corneal facet thickens in the centre to form a biconvex corneal lens. Beneath the lens lie two corneagen cells which are modified epidermal cells and secrete a new cornea as soon as the old is cast off in moulting.



V.S. of an ommatidium

iii.**Cone cells :**

Beneath the corneagen cells lie four elongated cone cells or vitrellae which constitute a transparent, homogenous crystalline cone. Inner ends of cone cells are long and tapering. The part of eye, from cornea up to extreme ends of cone cells, is known as the dioptrical region, which focuses light upon the inner sensitive part or receptor region of eye.

iv.**Rhabdome and retinal cells :**

Inner ends of cone cells lie upon an elongated, spindle shaped rod, the Rhabdome. It has a transversely striated appearance. Rhabdome is secreted and surrounded by receptor region of eye. Inner ends of retinal cells rest upon a basal membrane beyond which they are continuous with sensory nerve fibres of optic ganglia which are connected with brain by the optic nerve.

v. **Chromatophores :**

Each ommatidium is cut off from its neighbours by a sheath of movable, amoeboid, dark pigment cells or chromatophores which are arranged in two series. Outer series lying along the cone cells is called iris pigment and inner series separating the rhabdomes is called retinal pigment. Amoeboid pigment cells take up different positions according to the variations in the intensity of light.

b) **Mosaic vision** :

Working of compound eye is very complex. It is deficient in focusing ability and clarity of image. But such an eye is efficient for picking up motion and for peripheral vision. It functions as a very efficient organ for photoreception. Mounted on a movable stalk, it can move on the head in much the same manner as the antenna of radar, and gives the animal almost 360 degree vision. Each ommatidium is capable of producing a separate image of a small part of the object seen. Therefore, in prawns and other arthropods possessing compound eyes, the image of the object viewed consists of several dark and light tiny pieces or spots, so that the total image of an object formed is a sort of a flat mosaic. Moving objects can thus be detected. The vision effected is said to be mosaic vision because of its similarity to mosaic art work.

The nature of composite image formed varies according to different intensities of light. Thus two types of images are formed. This is made possible by the movement of pigment cells:

a. **Apposition image :**

In bright light (during daytime) the pigment cells spread in such a way that they completely isolate optically the adjacent ommatidia. No light can pass through from one visual unit to the other. In this condition the rays of light which strike the cornea obliquely, are absorbed by the pigment cells without producing a visual effect.

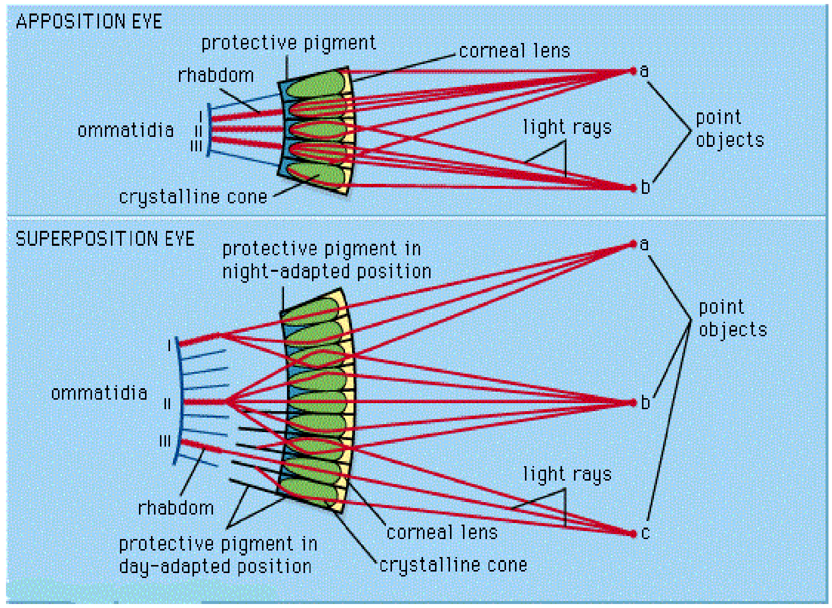


Fig : Palaemon. Digrammatic representation of image formation by a compound eye

Only those rays of light which fall perpendicularly upon the cornea can travel through the ommatidium and reach the Rhabdome to form a point of image. As a result the complete image formed is a mosaic of several components placed in juxtraposition in which the slightest movement is readily detected. In other words, each ommatidium respond to a fragment of the total field of vision and then these fragmentary images are fitted together into a single general picture. It is known as a mosaic or apposition image. Its sharpness depends upon the number of ommatidia involved and the degree of their isolation from one another. In butterflies which are night blind, the eyes are permanently set in this condition and are suited to see only in bright light. The image formed by this type of eye is never very good. It functions best at short distances only. Thus, most Arthropods are always short sighted.

b. **Superposition image :**

In dim light (during night) the pigment cells migrate and become separated into distal and proximal pigments, so that the neighbouring ommatidia no longer remain optically isolated but work in unison. In this condition even oblique rays of light are capable of forming a point of image after passing through a number of ommatidia in their way. As a result, an overlapping of the adjacent points of image occurs so that a continuous or superimposition image is obtained. It is not sharp but the animal gets some short of idea of the objects moving about in the surrounding. In some insects, like moths and fireflies, the eyes are well adapted to see at night but are day blind.

The Prawns, like most Arthropods seem to adjust their eyes to form both types of images according to the prevailing intensity of light. The optic nerve carries impulses (electro chemical waves of energy) to the brain, where they are interpreted and registered as an upright mental image.

2. Statocysts :

I. **Structure of Statocyst :**

Statocysts are a pair of small, white, bead- like cuticular and hollow spherical sacs. A statocyst lies inside the basal segment or precoxa of each antennules, attached to its dorsal wall. It opens dorsally on the concave surface or depression of precoxa through a minute statocytic aperture, which remains covered by a small fold of integument. A small statocystic branch of antennular nerve supplies the statocyst. Cavity of statocyst is oval, filled with minute sand particles, and lined by a number of elongated delicate sensory hairs or receptor setae. Each receptor seta is innervated by a small branch of the statocytic nerve. It consists of a swollen base and a long tapering shaft, which points towards the centre. The shaft is bent in the middle and bears fine bristles beyond the bend.

II. **Function of statocyst :**

Statocysts perceive the direction of the force of gravity and function as the organs of orientation and equilibrium. The sand particles function as statoliths. Any change in the position of the swimming prawn causes a corresponding displacement of sand particles, which press against some of the sensory setae and stimulate them. Stimulated setae convey the information to brain through nerves, so that the animal corrects its position. At each moulting statoliths are also shed along with the chitinous lining of statocyst, so that freshly moulted individuals lose much of the power of orientation. However, the animal acquires new sand particles through the dorsal pore when the statocyst lining is renewed.

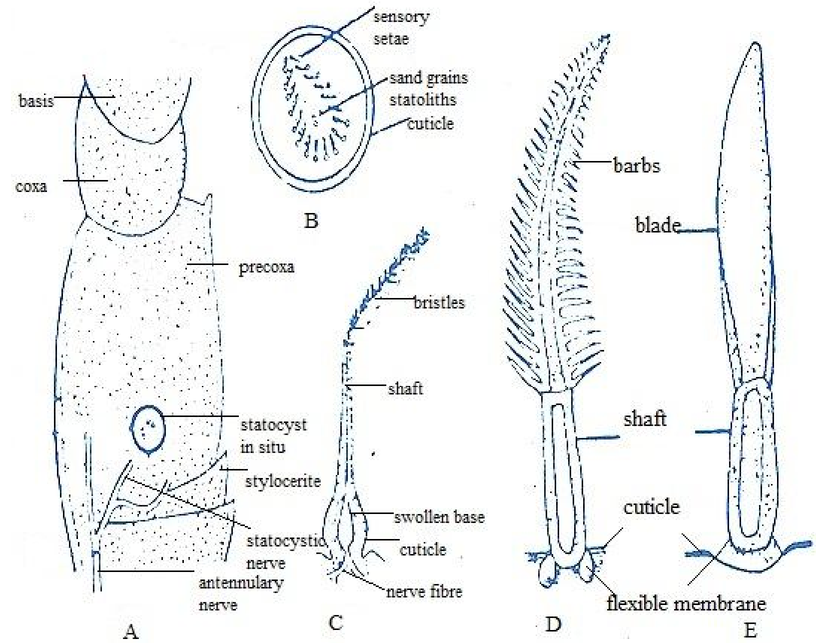


Fig: Palaemon. A- Precoxa of antennule showing statocyst in situ. B- T.S. of statocyst. C- A single receptor seta . D- A tactile seta (tangoreceptor). E- An olfactory seta (chemoreceptor).

3. **Tangoreceptor :**

   The prawn is without a sense of hearing. However, the animal is sensitive to touch by means of tactile organs or tangorecetors. These are in the form of plumose setae fringing the flattened portions of appendages, like the ramii of pleopods. Each tactile seta is a hollow cuticular outgrowth supplied with a nerve fibre. It consists of two segments. Basal segment or shaft is slightly swollen and attached to the integument by a membrane. Distal segment or blade gradually tapers and bears two rows of small barbs. The elongated feelers of both antennae are also said to be tactile in function.

4. **Chemoreceptor :**

   chemoreceptor or olfactory organs respond to chemical stimuli. They occur on mouthparts, flagella of antennules and inner wall of gill chambers in prawn. Inner smaller branch of outer feeler of each antennules bears a longitudinally groove containing numerous olfactory setae. Each seta consists of a basal segment or shaft which is attached to the integument by a flexible membrane, and a distal segment or blade which is bluntly rounded. A small nerve fibre from the olfactory branch of antennulary nerve innervates each seta.

5. **Propioreceptor :**

   These occur internally throughout the body. They perceive internal stimuli such as related to posture and muscular function. In cockroach campaniform sensillae, present on the joints of maxillary palps and legs, perceive strains set up in the cuticle during feeding and movement.

6. **Pectines :**

   In palamnaeus, a pair of remarkable comb- like sensory appendages,called pectines are found on the sternum of 2nd segment of preabdomen or mesosoma. Each pectine consists of a three segmental stem, shaft or handle. Along the posterior margin of shaft is a row of 4-36 narrow movable processes, just like teeth of a comb. Pectines are tactile or perhaps olfactory organs which enable the animal in finding the nature of substratum. Pocock noticed a scorpion walking over a cockroach until the pectines came in contact with it, when it at once moved back and ate it. Pectined are generally larger in male and sometimes curiously modified in female, so that sexual and other roles have also been suggested for them.

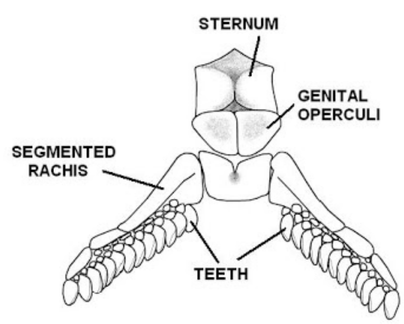


Fig: Palamnaeus. Genital operculum and pectine in ventral view

7. **Ocelli :**

   In cockroach, at the base of each antenna is a fenestra which represents a simple eye or ocellus. Each comprises of a single corneal facet. It is mainly concerned with light collecting rather than image forming. Probably it enhances the sensitivity of compound eye. In Grasshopper or Locust three ocelli are sensitive to light but may form crude images at close range. An ocellus consists of a group of photoreceptor cells or retinulae each ending in nerve fibre which leads to the brain. Outer end of each photoreceptor cell forms a Rhabdome. Cuticle covering the group of photoreceptor cells forms a thick, biconvex, transparent lens. Real function of ocelli is not clearly known.

8. **Auditory and stridulatory organs** :

   An organ of hearing is present on either lateral side in the tergum of first abdominal segment. It consists essentially of a tympanic membrane stretched within an almost circular chitinous ring. Attached to inner surface of tympanum is a whitish, sensory auditory apparatus or Muller's organ consisting of numerous three celled columns, called scolopidia, which are connected with metathoracic ganglion by an auditory nerve. Sound waves cause the tympanum to vibrate and the resultant sensory impulses are conveyed through scolopidia and auditory nerve to the metathoracic ganglion.

   Grasshopper produces sound by rubbing tibial spines of hind legs against a wing vein which vibrates. Only male grasshoppers have the ability to stridulate, that is producing sound. Some insects can hear sound beyond the range of human ear. Sound produced has some significance in mating as experimental study has demonstrated that insects can recongize sounds characteristics of their own species.

10.6 Receptors In Mollusca

1. **Osphradium :**

   Single osphradium is situated on the left side of the animal suspended from the roof of the mantle cavity close to the entrance through the left nuchal lobe. It is a small, elongated, oval structure, about 6-7 mm long. While broadest in the middle, its inner or right end is bluntly rounded and the outer or left end is somewhat pointed. It is bipectinate consisting of 22-28 thick, fleshy and roughly triangular leaflets, arranged in two rows along a slightly raised median or central axis. Leaflets are largest in the middle of the osphradium. Each leaflet is attached to the mantle wall by its broad base, to the central axis by its smaller inner side, while its outer longer side remains free. Osphradium is supplied by a nerve from the left pleural ganglion.

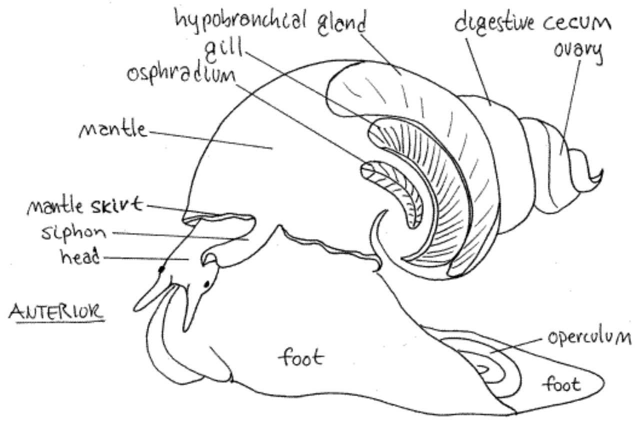


Figure: Osphardium in Pila

In a transverse section the osphradium consists of an outermost covering of a single layered epithelium, internally lined by a thin basement membrane, the interior filled up with nerves, connective tissue and blood spaces. Epithelial cells are elongated possessing basal nuclei and they are of three types—

a) Sensory ,
b) Ciliated and
c) Glandular.

The ciliated cells line the attached margin, while the sensory cells devoid of cilia cover the osphradium. Flask shaped glandular cells are found scattered among the sensory cells.

Osphradium hangs like a curtain in the path of the respiratory water current and probably serves as an olfactory organ. Its name has been derived from a Greek word, meaning to smell. It serves to test the chemical nature of the inspiratory water current. In case the water is foul, its entry into the mantle cavity is stopped by the closure of the left nuchal lobe. It may also help in the selection of the food material.

2. **Eyes :**

Snail’s head carries a pair of short fleshy and stump like stalks or ommatophores, one on either side, behind the second pair of tentacles. Each ommatophore bears a small, black and circular eye, slightly below its tip on the outer side.

In a section an eye looks a pyriform cup like invagination of epidermis, called the optic vesicle, surrounded by a firm sheath of connective tissue. Optic nerve enters the vesicle somewhat obliquely at its posterior end.

Cavity of the vesicle is filled up by an oval, structureless hyaline body, the lens.

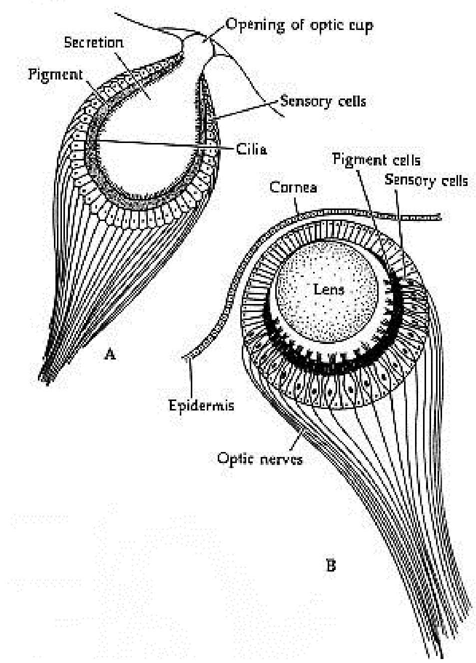


Fig: Pila. H.L.S. of eye.

Wall of the vesicle, formed by a single layer of epithelium, is modified posteriorly to form a sensory and pigmented retina containing two kinds of large cells (i) broad visual cells having a brush of hair like processes on their outer ends, (ii) narrow supporting or packing cells lying in between the visual cells. Anterior continuation of retina, in front of the lens, becomes transparent to form the inner cornea or pellucid interna, consisting of low cubical and non- pigmented cells having small spherical nuclei. General epithelial covering of the body and the eye stalk becomes thin and transparent in front of the eye, forming its outer wall termed the outer cornea or pellucid externa, consisting of similar small, squarish, non- sensory, non- pigmented and non- glandular cells with homogenous protoplasm.

In spite of their elaborate structure eyes of Pila are probably not true organs of sight. Sense of sight is greatly limited in range and the snail does not seem to distinguish objects, but only responds to changes in the intensities of light and detects quick movements. Most of the snails feed at night probably because their eyes are adapted to dim light. In some snails the lost eyes can be replaced by regeneration, a process which has been recorded to occur 20 times in succession.

In Sepia, paired eyes are large, efficient and bulge from the dorso lateral sides of the head. They bear striking resemblance to those of a vertebrate in that a cornea, iris, lens and retina are present. Lens projects an inverted image on the retina, as in the vertebrate eye. External muscle attachments enable limited movements of the eye. But the embryological development of the cephalopod eye is entirely different from that of the vertebrate eye, so that homologically they are different, for the vertebrate eye is formed as an outgrowth of the brain, while the cephalopod eye is formed by an ectodermal invagination. Similarity between the two is due to convergent evolution, that is similarity which is not due to phylogeny.

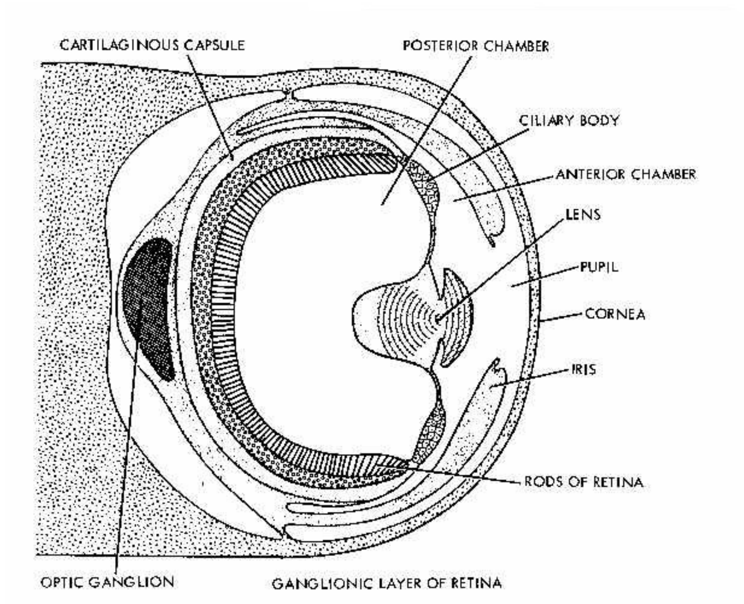


Fig: Sepia : Eye in section

Each eye lies within an orbit formed by cartilages. Outer wall of the eyeball or the sclerotic coat, is strengthened by cartilage, and covered by a silvery membrane. It extends in front as the contractile iris presenting a large central opening, the pupil, which can be increased or diminished by muscles. Just internal to the iris lies a large, almost spherical lens, consisting of two plano-convex halves, and held in place by a ciliary body. A choroid is absent. Inner sensitive layer, or retina is somewhat complicated in structure and is composed of a layer of parallel rods, there being no cones. Close behind the eyeball, the optic nerve swells up into the optic ganglion from which several bundles of nerve fibres are distributed on the posterior surface of the retina. A small optic gland or white body of unknown function lies near the optic ganglion. A true cornea is also lacking. Transparent horny portion of the skin, covering the exposed surface of the eye, is termed as the false cornea. Skin also forms protecting lids. Cavity of the eye is divided by the lens into a small anterior chamber filled with a water like aqueous humour, and a large posterior chamber containing a jelly like vitreous humour. Cephalopod eye can accommodate itself to light changes both by modification in the pupil's size and by the migration of pigment in the retina. It can probably detect colour.

3. **Statocysts :**

   Statocysts are a pair of small, pyriform and cream coloured sacs, lying one on either side attached to the pedal ganglion of that side by a band of connective tissue. Each statocyst lies in a depression, posterior and outer to the ganglion. Each statocyst is a hollow capsule surrounded by an outer thick, tough, leathery covering of connective tissue. Wall of the capsule is made of a single layer of ectodermal cells and supplied by a nerve from the cerebral ganglion. Cavity of the capsule is filled with a fluid and a variable number of minute, oval and calcareous particles, the statoconia. Statocysts are organs of equilibrium.

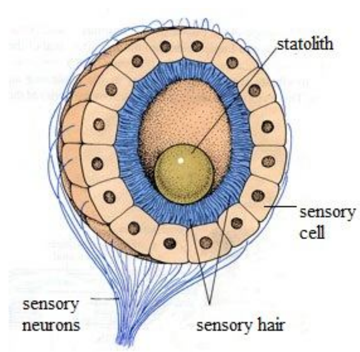


Fig: T.S. of statocyst

4. **Tentacles :**

   As already referred the snout of Pila is anteriorly prolonged into a pair of short, contractile and conical processes bordering the mouth. These are the labial palps or the anterior or first pair of tentacles. Behind them arise, one on either side, a pair of long, tapering, filamentous and highly contractile whip like processes, the true or second pair of tentacles.

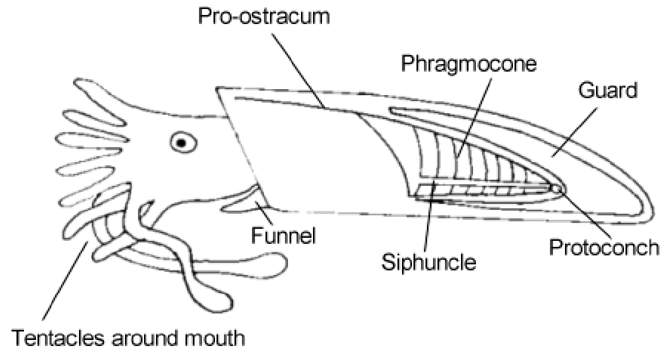


Fig: Tentacles

Tentacles are of the same colour as the snout and tactile in function. A sense of taste is doubtfully attributed to the labial palps.

5. **Olfactory pits :**

   Osphradia of the usual type are lacking. Instead, a small ciliated olfactory pit is situated posterior to each eye. Sensory cells of the pit are innervated from the small olfactory ganglion lying close to the optic ganglion.

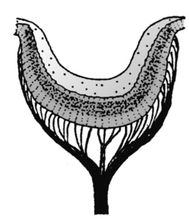


Fig: Olfactory pit

6. **Gustatory organ :**

   On the floor of the buccal cavity, just in front of the odontophore, is a small elevation covered with papillae. It is said to be the organ of taste.

10.7 Receptors In Echinodermata

1. **Neurosecretory cells :**

   These are distributed throughout the epidermis, especially concentrated in the suckers of the podia, at the terminal tentacles. Each neurosensory cell is fusiform, bears a thread like processes at its free end and is connected by fine fibres to the underlying sub epidermal nerve plexus. Neurosensory cells are of two types – tactile and olfactory. Former are more abundant in the tube feet and the latter, around the mouth.

2. **Eyes :**

Sea star possesses five bright red eye spots, one at the end of each arm at the base of the terminal tentacles, on the oral side. Each eye is formed by the special thickening of the radial nerve cord and thickening of the subepidermal nerve plexus (nervous layer) at the base of the terminal tentacle. It is therefore, also referred to as the optic cushion. Bright red eye spot infact consists of numerous photoreceptors or eye pits or ocelli. Each eye pit is cup shaped pocket of ectoderm filled with a transparent gelatinous tissue. It is covered externally by cuticle, below which is a transparent thickening or lens, formed by epidermis. Its wall is made up of pigment cells containing red pigment granules and visual or retinal cells. Inner end of each retinal cell is highly refractile and bulb like and projects into the cavity of the eye pit, while the outer end gives out a fine nerve fibre which joins the underlying radial nerve. Eye spots detect changes in light intensity.

10.8 Summary

- various types of receptor such as photoreceptor , mechanoreceptor, chemoreceptor etc. are present in different Invertebrate Phylum.
- Tentaculocyst or statocyst, ocelli and olfactory pits type receptor present in Coelentrates.
- Sense organs or receptors occurring in Planaria are : (i) a pair of eyes (photoreceptors), (ii) ciliated pits, grooves and auricular organs (chemoreceptor), (iii) Tangoreceptors and (iv) Rheoreceptors.
- Nuchal organs (in Annelida) are a pair of small pits on the posterior dorsal surface of prostomium behind eyes. They serve as organs of smell and chemoreception and help the worm in detecting prey.
- Different types of receptors are present in Phylum Arthropda i.e. compound eye, statocysts, tangoreceptor, pectines, chemoreceptor, propioreceptor, ocelli, Auditory and stridulatory organs.
- Statocysts perceive the direction of the force of gravity and function as the organs of orientation and equilibrium.

- Osphradium present in Mollusca as a chemoreceptor. It serves to test the chemical nature of the inspiratory water current. It may also help in the selection of the food material.

10.9 Glossary

- **Auditory** Relating to sense of hearing.
- **Chemoreceptor**A sense organ or cell that responds to chemical stimulus.
- **Ocellus** (pl. Ocelli) A small light perceiving eye chiefly of Arthropods.
- **Olfactory** Pertaining to smell.
- **Papilla** A small nipple like projection.
- **Peristome** Region around an opening or mouth.
- **Prostomium** Portion of the head situated before the mouth.
- **Receptor** A sensory end organ.
- **Statocyst** A sense organ of equilibrium.
- **Tentacles** Flexible arm like projection of coelenterates and some other animals.

10.10 Self-Learning Exercise

Section : A -Very short answer type

1. Define tangoreceptor?
2. What is pectines?
3. Superposition image form in dim light (during night). True / false
4. What is the function of statocysts?
5. Define rheoreceptor.

Section : B -Short answer type

1. Draw a labelled diagram of compound eye.
2. Write short notes on :
   a) Eyes in Planaria
   b) Nuchal lobes
3. Describe the structure and function of statocysts.
4. Write short notes on :
   a) Pectines
   b) Osphradium

Section : C -Long answer type

1. Explain structure and function of receptors in Phylum Mollusca.
2. Explain structure of compound eye and image formation process in eye of Prawn.
3. Write short notes on :
    a) Receptors in Coelenterata
    b) Ocelli
    c) Eyes in mollusca

10.11 References

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- Invertebrate Phyla Series By Hyman

Unit - 11

Endocrine system: endocrinal structures and their hormones: role of neurosecretions and hormones in developmental events of insects and crustaceans

Structure of the Unit

11.0 Objectives

After going through this unit you will be able to understand :

- What is endocrine system?
- Different types of endocrine glands and their hormones
- Regulation of functions and development in invertebrate animals .

- The role of neurosecretions and hormones in lower animals.

11.1 Introduction

This chapter will make you understand about the fundamental concepts of biological control systems and their regulation by hormones. An animal hormone is a chemical signal that is secreted into the circulatory system that communicates regulatory messages within the body. A hormone may reach all parts of the body, but only specific target cells respond to specific hormones. A given hormone traveling in the bloodstream elicits specific responses from its target cells, while other cell types ignore that particular hormone.

Animals have two systems of internal communication and regulation, the nervous system and the endocrine system. Collectively, all of an animal's hormone-secreting cells constitute its endocrine system. Hormones coordinate slow but long-acting responses to stimuli such as stress, dehydration, and low blood glucose levels. Hormones also regulate long-term developmental processes. Hormone-secreting organs called endocrine glands secrete hormones directly into the extracellular fluid, where they diffuse into the blood.

The nervous and endocrine systems overlap to some extent.

Certain specialized nerve cells known as neurosecretory cells release hormones into the blood. The hormones produced by these cells are sometimes called neurohormones. Chemicals such as epinephrine serve as both hormones of the endocrine system and neurotransmitters in the nervous system. The nervous system plays a role in certain sustained responses—controlling day/night cycles and reproductive cycles in many animals, for example—often by increasing or decreasing secretions from endocrine glands.

The fundamental concepts of biological control systems are important in regulation by hormones.

A receptor, or sensor (sense organ), detects a stimulus and sends information to a control center (brain). After comparing the incoming information to a set point, the control center sends out a signal that directs an effector (muscles) to respond. In endocrine and neuroendocrine pathways, this outgoing signal, called an efferent system, is a hormone or neuro-hormone, which acts on particular effector tissues and elicits specific physiological or developmental changes. The three types of simple hormonal pathways (simple endocrine pathway, simple neurohormone pathway, and simple neuroendocrine pathway) include these basic functional components. A common feature of control pathways is a feedback loop connecting the response to the initial stimulus.

In negative feedback, the effector response reduces the initial stimulus, and eventually the response ceases. This prevents overreaction by the system. Negative feedback regulates many endocrine and nervous mechanisms. However, a positive feedback reinforces the stimulus and leads to an even greater response.

11.2 Endocrine system

Invertebrate animals produce a variety of hormones in endocrine and neurosecretory cells. In many invertebrates, endocrine cells are found in most of the ganglia of the nerve chain. The invertebrate comprises 95 percent of the species in the animal kingdom. We might expect a correspondingly great diversity of invertebrate endocrine mechanisms. While this expectation may ultimately be confirmed, our present knowledge of the endocrine systems of many invertebrate groups is still highly incomplete. In most groups of invertebrates, neurosecretary system are distinctly more prominent than nonneural endocrine glands, indeed in many invertebrate group, nonneural endocrine glands appears to be absent. Neuroendocrine controls exist already in lower invertebrates, and during evolution, endocrine glands have appeared in molluscs, although endocrine cells may have appeared earlier. Some invertebrate hormones have homeostatic functions, such as regulation of water balance. Others function in reproduction and development.

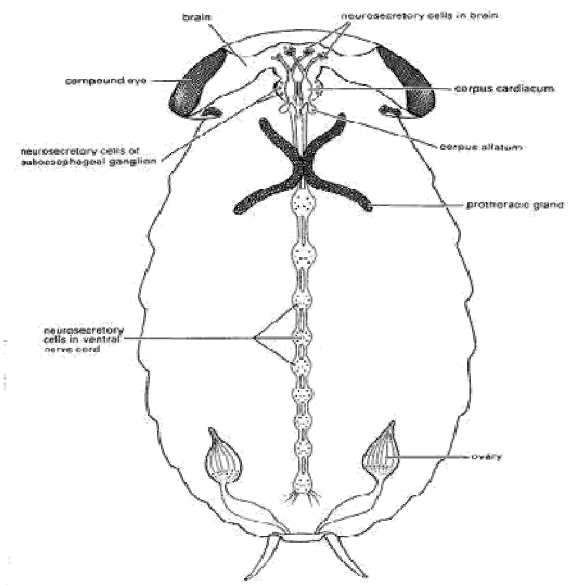
In hydras, one hormone functions in growth and budding (asexual reproduction) but prevents sexual reproduction. In the mollusc Aplysia, specialized nerve cells secrete a neurohormone that stimulates the laying of thousands of eggs and inhibits feeding and locomotion, activities that interfere with reproduction.

All groups of arthropods have extensive endocrine systems.

Crustaceans have hormones for growth and reproduction, water balance, movement of pigments in the integument and eyes, and regulation of metabolism. Crustaceans and insects grow in spurts, shedding the old exoskeleton and secreting a new one with each molt. In all arthropods with exoskeletons, molting is triggered by a hormone. Insects acquire their adult characteristics in a single terminal molt. Intensive investigation of insect endocrine and nervous systems in the last few decades has revealed structures of hundreds of neuropeptides that control practically all aspects of insect life.

Recent studies have shown that the metabolism and especially the generation of energy are controlled by adipokinetic hormones (AKHs), which are synthesized, stored and released by neurosecretory cells from the corpora cardiaca (CC), a neuroendocrine gland connected with the brain. The hormones have been isolated from representatives of many insect orders.

11.2.1 Endocrinal structures



Generalized scheme showing the location of various endocrine glands and neurosecretory cells in an insect (Source:http://www.faculty.ucr.edu/)

We shall begin with a look at the cnidarians, the simplest animals that possess a nervous system containing groups of fairly well-characterized neuroendocrine cells. From there, we will proceed to the two large lophotrochozoan phyla, annelids, and mollusks, to the ecdysozaoans, arthropods.

In cnidarians, endocrine cells occur as scattered neurons and epithelial cell in the epidermis and gastrodermis. Neurosecretory cells comprise both sensory cells (i.e. neurons integrated into the epidermis, with modified cilia acting as stimulus-receiving apparatus), as well as subepidermal ganglion cells. Cnidarians possess almost the full range of neurotransmitters, neurohormones, and non-neuronal hormones present in chordates or arthropods. A considerable fraction of both sensory and ganglion cells are neurosecretory. For example, in the planula larva, more than 40% of the neurons express the neuropeptide FMRFamide.

Neuropeptides in cnidarians act as transmitters mediating communication of neurons within the nerve net and stimulating effector organs. Peptides act as stimulators or inhibitors; no specific behavioral responses have been associated with any particular peptide. Beside their role as neurotransmitters, peptides have been shown to systemically act like true hormones on reproduction, development, and reproduction.

The neuroendocrine structure in lophotrochozoans: annelids and mollusks

Scattered Neurosecretory cells, similar to those described for cnidarians, can be found among central and peripheral neurons, as well as the gut epithelium, of all animal phyla. Many cells undergo further specializations that add to the complexity of the neuroendocrine system. In the brain, Neurosecretory cells cluster into several 'nuclei' whose neurites innervate specific compartments of the neuropile, and whose neurosecretory peripheral axons form specialized endings in association with the glial sheath covering the brain, with blood vessels, or with peripheral endocrine glands.

Variable clusters of Neurosecretory cells have been identified in representatives of all annelid taxa in both larval forms and adults.

Neurosecretory cells and neurohemal structures located in the glial sheath of the nervous system have been described in detail for several mollusk species. Outside the populations of Neurosecretory cells, several non-neuronal populations of endocrine cells, have been found. They are located within or close to the glial sheath around the brain, are possibly of mesodermal origin, and are innervated by brain neurons. Among these endocrine structures are the dorsal bodies and lateral lobes (in pulmonates) and optic glands (in cephalopods).

The lateral lobes are functionally related to the lateral growth cells and influence body growth; the dorsal bodies produce a female gonadotropic hormone, as well as ecdysteroid hormones.The optic gland in cephalopods produces gonadotropic hormones and receives inhibitory input from neurons of the brain.

Neuroendocrine structures of arthropods

The neuroendocrine system of arthropods shows strong homologies among different taxa of this phylum. The arthropod brain contains a wide variety (in regard to location, projection, and peptide content) of neurosecretory cells. Most are scattered cells with largely uncharacterized projections within the neuropile. In addition, subsets of neurosecretory cells form conspicuous clusters, whose axons leave the neuropile and project to neurohemal release sites and non-neuronal endocrine glands.

Insects

The neurosecretory system in insects consists of several sets of neurosecretory cells located in the brain and ventral nerve cord. The majority of neurosecretory cells are found in the dorso-medial protocerebrum, the so-called pars intercerebralis (PI) and pars lateralis (PL). These neurosecretory cells project their axons toward a set of endocrine glands, the corpora cardiaca (CC) and corpora allata (CA).

Crustaceans

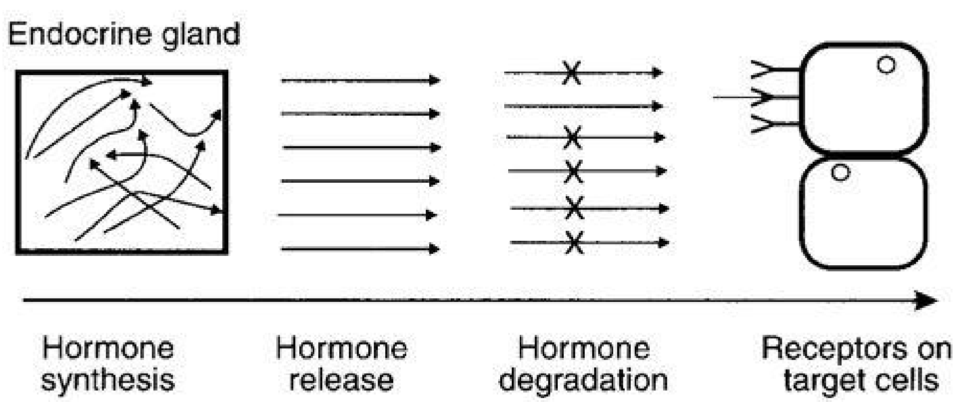
Numerous groups of neurosecretory cells with specialized neurohemal projections outside the neuropile have been identified in the brain and ventral nerve cord of crustaceans.

11.2.2 Hormones

Hormones are chemicals produced in a gland that are released into the blood and have their effect somewhere else in the animal body

Hormonal activity in the blood is influences by

1. Hormone synthesis-The effective titer must be reached to work
2. Hormone release
3. Hormone degradation
4. Receptors on the target cells-These change in number in particular tissues and at a particular time when needed



Areas of insect biology that hormones play a major role

1. Regulation of molting
2. Determination of form at metamorphosis
3. Effects on polymorphism
4. Regulation of diapause
5. Involvement in reproduction
6. Regulation of metabolic activities and general body functions
7. Regulation of behavior

Regulation of preprogrammed cell death

Most hormones found throughout the animal kingdom are short polypeptides, produced by proteolytic cleavage from larger precursor proteins, called prohormones. Similar to other secreted proteins, peptide (pro)hormones are produced in the rough endoplasmic reticulum, processed through the Golgi apparatus, and stored in membrane-bound vesicles. These vesicles, 100–300 nm in size, give peptide hormone-producing cells their characteristic granular appearance. Peptide hormone receptors belong to the class of seven pass transmembrane, G-protein-coupled receptors.

Beside peptides, lipids and amino acid derivatives act as hormones. The steroid hormones (e.g. cortisone or estrogen in vertebrates and ecdysone in arthropods) are derived from the lipid cholesterol. Juvenile hormone in insects is an ether derivative of a polyunsaturated fatty acid. Like other lipids, these hormones are synthesized in the smooth ER and are not stored in vesicles. Steroid hormone receptors belong to a class of transcription factors, called nuclear receptors that are localized in the cytoplasm in their inactive state; upon ligand binding, they will enter the nucleus and bind to DNA, thereby modulating gene expression.

11.2.3 Location of endocrine glands in insects

Not only does the location of the glands differ in different insect orders
but, the hormones used for various functions may also vary.

Prothoracic glands------Produce ecdysone

Corpora allata-----------Produces JH

Corpora cardiaca-------Stores and releases brain hormones. Also produces and releases some peptides such as adipokinetic hormones

Midgut endocrine cells-Produce various peptides. Open + closed cell types.

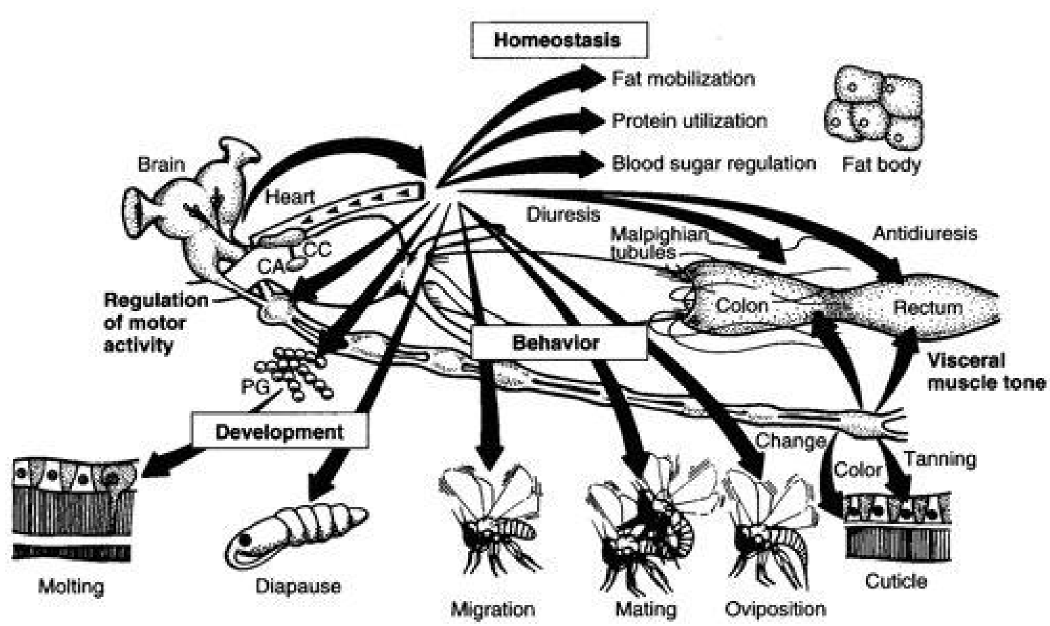
Epitracheal glands------Produce the ecdysis triggering hormone in Lepidoptera

Neurosecretory cells----Produce neurosecretion (peptides or biogenic amines); located in the various ganglia of CNS

11.3 Role of neurosecretions and hormones in developmental events of insects

The neurosecretions and hormones regulate the all physiological aspects of insect life.

- **Major physiological functions regulated by neurohormones** (Source:http://www.faculty.ucr.edu/)



Insect endocrine glands & neurosecretory cells & location

Types	Active Principle	Origin	Target	Role/function
Nonneural hormones				
(A) Immature insects	Ecdysone	ecdysial gland	epidermis	initiates molt
	Juvenile hormone	corpora allata	epidermis	controls or directs fate of metamorphosis at molt
(B) Adult insects	Ovarian hormone (ecdysteroids)	ovarian tissue- follicle cells	fat body	initiates + regulates the production of vitello- genin (VG)
	Juvenile hormone	corpora allata	fat body	Primes fat body to become competent to produce vitello- genin
			ARG's	Affects development and production of glandular secretions
			Follicle cells	Activates patency and uptake of vitellogenin

The process of development in insects is regulated mainly by the two hormones (a) Ecdysone and (b) Juvenile hormone. The hormone Ecdysone initiates the molting and key factor in its regulation is the Juvenile hormone.

Now few questions must arise in your mind:

What happens to the ecdysial or prothoracic glands in almost all adult insects?

What group do they remain during adulthood and keep on molting?

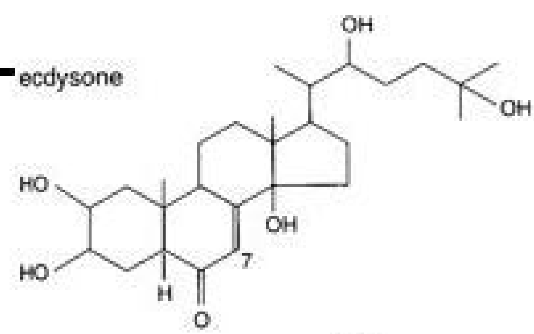
What signal is essential for their destruction or histolysis?

The answer is: *the absence of JH hormone*

ECDYSTEROIDS

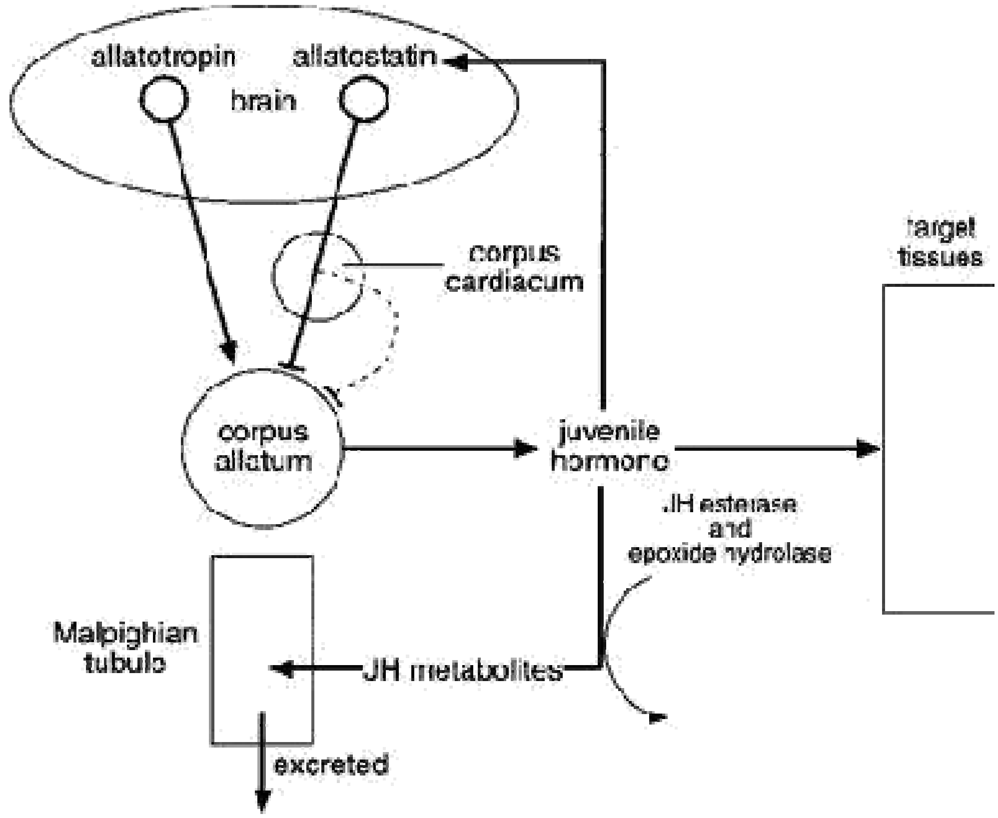
1. Ecdysone is a steroid hormone
2. Insects cannot synthesize sterols, they must get them in their diet (cholesterol or phytosterol)
3. There are several forms of the active molecule and it depends on the insect group which one is used.

ecdysone



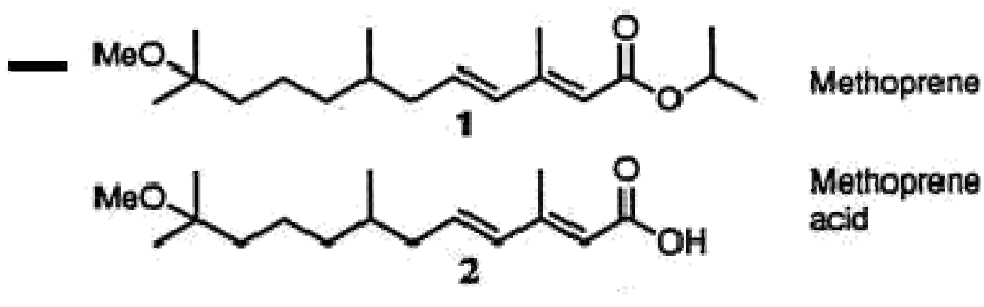
JUVENILE HORMONES

Are sesquiterpenes produced by the corpora allata. Several different forms have now been discovered. Analogues of JH, especially methoprene have been successfully used in insect control. Used against mosquito larvae and fleas (Siphotrol).



Methoprene is a JH analogue and is used in insect control and experiments

The regulation of JH in insects during development process is demonstrated as follows:



It involves the balance between synthesis in the corpora allata and degradation and excretion by the Malpighian tubules

11.3.1 Vertebrate hormones in insects

Insulin-like peptide.

In 1975, T. Normann suggested that an insulin-like activity in decapitated blowfly, *Calliphora*, was due to a lack of a hypotrehalosemic hormone of cephalic origin. He suggested that the neuroendocrine gland complex, the corpus cardiacum-corpus allatum was the likely site for its release. Chen and Friedman (1977) also made a similar assumption using *Phormia regina* and pointed to the CC-CA as the site of the compound.

The "Insulin-like peptides (ILPs) exist in insects and are encoded by multigene families that are expressed in the brain and other tissues. Upon secretion, these peptides likely serve as hormones, neurotransmitters, and growth factors, but till date only a few direct functions have been demonstrated.

11.3.2 Mode of action of hormones

1. Activity within a cell depends on specific receptors for that hormone
2. The response of different tissues depends on the presence + number of receptors. This varies with development. Thus, different tissues will respond at different times.
3. Receptors are in the cell membrane or within the cell
4. Both Ecdy. + JH are lipophilic so they pass through the cell membrane and have their effect within the cell
5. Cause inactive genes to become active or can inactivate other genes
6. In immature insects, JH has no effect by itself but it modifies the responses to ecdysteroids. In adult insects JH can produce an effect by itself.
7. Peptide hormones and biogenic amines are lipophobic, thus they will not pass through the cell membrane. Specific receptor proteins for these substances are present in the cell membranes. Activation of these receptors activates secondary messengers (e.g., cAMP + cGMP) with the cells

So up to now we have understood that, both molting and metamorphosis are controlled by hormones. Molting is initiated when sensory receptors in the body wall detect that the internal soft tissues have filled the old exoskeleton and trigger production of a hormone from neurosecretory cells in the brain. This hormone acts upon the prothoracic gland, an endocrine gland in the prothorax, which in turn secretes the molting hormone, a steroid known as ecdysone. Molting hormone then acts on the epidermis, stimulating growth and cuticle formation. Metamorphosis likewise is controlled by a hormone. Throughout the young larval stages a small gland behind the brain, called the corpus allatum, secretes juvenile hormone (also known as neotenin). As long as this hormone is present in the blood the molting epidermal cells lay down a larval cuticle. In the last larval stage, juvenile hormone is no longer produced, and the insect undergoes metamorphosis into an adult.

However, among holometabolous insects the pupa develops in the presence of a very small amount of juvenile hormone.

Crustaceans

Numerous groups of neurosecretory cells with specialized neurohemal projections outside the neuropile have been identified in the brain and ventral nerve cord of crustaceans. Compared with insects, where the PI (pars intercerebralis), PL (pars lateralis), and tritocerebrum form a relatively uniform central neuroendocrine system, the diversity of central neuroendocrine cells in crustaceans is considerable. A conspicuous group of neurosecretory cells with no obvious counterpart in insects, called the X-organ, forms part of the proximal optic lobe. Axons of the X-organ and most other neurosecretory cells of the brain project toward the ventral surface of the optic stalk where they terminate in a large neurohemal structure called the sinus gland. Two other neurohemal structures, called the postcommissural and the pericardial organs, receive projections from neurosecretory cells in the brain and ventral nerve cord. A large variety of neuropeptides influencing pigmentation, carbohydrate levels, osmoregulation, growth/molting, and reproduction are released from each of these sites. Whereas the sinus gland/X-organ system associated with the crustacean optic lobe has no obvious counterpart in insects, the pericardial organ may be considered homologous to the insect corpora cardiaca. Beside nerve terminals from the brain and ventral cord, the pericardial organ contains intrinsic endocrine cells which produce, among others, crustacean hyperglycemic hormone (CHH), which controls hemolymph sugar and fatty acid levels, similar to AKH (adipokinetic hormone) produced in the insect corpora cardiac. CHH also affects heart beat and molting. Beside the pericardial organ, the X-organ/sinus gland complex is another source of CHH. Homologs of the insect growth/molting controlling non-neural endocrine glands, the corpora allata and prothoracic gland, exist in crustacean and appear to develop in a similar fashion from ectodermal invaginations of the head segments. One gland, called the Y-organ, produces ecdysteroids; the other gland, the mandibular organ, releases a hormone (methyl farnesoate, MF) similar to juvenile hormone in insects.

11.4 Summary

An animal hormone is a chemical signal that is secreted into the circulatory system that communicates regulatory messages within the body. A given hormone traveling in the bloodstream elicits specific responses from its target cells, while other cell types ignore that particular hormone. The whole working system consists of the endocrinal structures and their hormones and their effects on different organs in the process of development.

Among invertebrates the arthropods have well developed endocrine systems in particular the insects and crustaceans. both molting and metamorphosis are controlled by hormones. Molting is initiated when sensory receptors in the body wall detect that the internal soft tissues have filled the old exoskeleton and trigger production of a hormone from neurosecretory cells in the brain. This hormone acts upon the prothoracic gland, an endocrine gland in the prothorax, which in turn secretes the molting hormone, a steroid known as ecdysone. Molting hormone then acts on the epidermis, stimulating growth and cuticle formation. Metamorphosis likewise is controlled by a hormone. Throughout the young larval stages a small gland behind the brain, called the corpus allatum, secretes juvenile hormone (also known as neotenin).

As long as this hormone is present in the blood the molting epidermal cells lay down a larval cuticle. In the last larval stage, juvenile hormone is no longer produced, and the insect undergoes metamorphosis into an adult.

The knowledge of insect development and hormones would contribute immensely towards the biological control of insect pests.

11.5 Glossary

- **Corpora allata:** small glands behind the brain that produce juvenile hormone. Homologous
- **Diapause:** a state of suspended animation. During diapause, development, growth and metabolic activity are reduced. In some insects diapause is obligate, while in others it is dependent on external stimuli and is regarded as an adaptation to increase the

probability of survival during environmentally unfavourable conditions because it allows the insect to keep its life cycle synchronised with seasonal progression.

- **Efferent system:** the systems which which moves away from the active organ
- **Exoskeletons:** the external skeletal structure of the insect body
- **Hemolymph:** the blood-like nutritive fluid found in lower invertebrates with open circulatory systems. The fluid fills the entire body cavity and surrounds all cells. Haemolymph consists of water, inorganic salts (Na, Cl, K, Mg, and Ca), and organic compounds (carbohydrates, proteins, and lipids).
- **Inhibitors:** the compounds which ceases the activity by binding with the active site
- **Juvenile hormone (JH):** hormone released by the corpora allata into the haemolymph. Juvenile hormone suppresses the development of adult characters and the amount of juvenile hormone released determines the outcome of a moult.
- **Malpighian Tubules :** the main excretory organs of insects. They primarily function in elimination of nitrogenous wastes and the maintenance of internal ionic balance.
- **Metamorphosis:** the physical transformation an insect undergoes during successive stages of development
- **Molting:** the process by which insects shed elements of the integument during growth.
- **Neurohormones**: the compounds synthesized and produced by the nerve cells and act as hormones
- **Neurosecretory cells:** the nerve cells which secrets the compounds/hormone
- **Nonneural hormones:** the hormones which are produced by the organs other than the nerve cell
- **Polymorphism:** members of same species showing many morphological forms

- **Preprogrammed cell death:** A process under which the death of the cell is self regulated also referred as Apoptosis
- **Receptors:** the structures on the cell membrane where a hormone binds with and stat the activity
- **Stimulus:** a response received from the external environment by sense organs or the active cells
- **Target cells:** the cells which are specifically possessing the receptors for any particular compound/hormone

11.6 Self-Learning Excercise

Section -A (Very Short Answer Type)

1. Name the any two endocrine organs in insects.
2. Define the term hormone?
3. What signal is essential for destruction or histolysis prothoracic gland?
4. Ecdysone hormone is secreted by ___________________ .
5. What is the full form of ILPs ?

Section -B (Short Answer Type)

1. Write a note on the neuroendocrine regulation in invertebrates.
2. Briefly explain about the sinus gland in crustaceans.
3. Mention the role of adipokinetic hormones in insects.
4. Define the role of juvenile hormone.

Section -C (Long Answer Type)

1. What are hormones? Discuss the role of hormones in development of insects.
2. Write an explanatory note on regulation of development in crustaceans.
3. Discuss the importance of nonneural hormones in insects.

Answer Key of Section-A

1. Corpora allata , Prothoracic gland

2. An animal hormone is a chemical signal that is secreted into the circulatory system that communicates regulatory messages within the body
3. Absence of juvenile hormone
4. Prothoracic gland
5. Insulin-like-peptides

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Unit - 12

Reproduction: Reproduction in Protozoa, Porifera and Metazoa

Structure of the Unit

12.0 Objectives

After going through this unit you will be able to understand

- What is reproduction?
- Sexual and asexual reproduction in Protozoa.
- Different reproductive methods in Porifera and Metazoa

12.1 Introduction

This chapter is very important for a student before you proceed further about the study of complex animals (invertebrates and vertebrates) their distribution, classification and structures. Let's begin with fundamental that, all animals reproduce and give rise to off springs, as the process of reproduction is the crux of survival as a species. Whether the animals are unicellular or multicellular they have different strategies for successful reproduction, which depends on the environmental conditions: asexual methods and sexual methods.

Animal life is widely present at every place of the earth. They have been recorded throughout from upper reaches of the atmosphere, driest desert, and wettest rainforests. They are also reported from frozen Antarctic and on the ocean floor of the Abyssal Sea.

The entire fauna (animal population) of the world is classified as the largest unit and called as Kingdom Animalia. It is further divided into two subkingdoms: *Protozoa* and *Metazoa*

The Protozoans are the primitive animals (nearly 50,000 species are reported) they are unicellular and their grade of organization is protoplasmic. Natural death does not take place due to lack of a body; hence often termed immortal. They reproduce mostly by asexual methods and sexual reproduction is rare. In terms of the frequency of reproduction, they either reproduce once (semelparity) or several times (iteroparity) in a life time.

The subkingdom Metazoa includes multicellular animals, which on the basis of grade of organization is further subdivided into three branches:1. Mesozoa, 2. Parazoa and 3. Eumetazoa.

Mesozoa (Middle animals) is a small group of animals (about 50 species) mostly parasitic. Mesozoans were described by Van Beneden (1876) who considered them to be missing link between Protozoa and Metazoa Body with an outer single layer of ciliated digestive cells enclosing one or several reproductive cells.

Parazoa (Sponges) branch includes animals with cellular grade of organization. There are approximately 9000 species in a Phylum: Porifera. They are referred as sessile animals living in solitary or colonial manner. Sponges seem to have diverged very early in evolution from the main metazoan lineage and have not ever since evolved into any other kind of organism but maintained their distinctness and remained unchanged since Palaeozoic period. They still maintain their isolated phylogenetic position and hence most workers prefer to place them in a separate branch Parazoa.

Eumetazoa branch includes all the multi-cellular animals with tissue to organ system grade of organization. They are referred to be true Metazoa. This branch includes lower animals like Coelenterates to higher chordates. Coelenterates are radially symmetrical diploblastic Metazoa while others from helminths onwards are bilaterally symmetrical and triploblastic.

The first question that arises in our mind is: **What is reproduction?** Certainly we can say that it is a process by which a living organism maintains itself as a species on this planet. The reproduction involves a number of processes, which occur in sequence to produce healthy, fertile offspring. Animals undergo the reproduction process with unique strategies in accordance with the environmental conditions. The principal methods are the process of asexual and sexual reproduction.

Asexual reproduction is the method wherein the animal reproduces and the offsprings are having identical genetic constitution i.e. genetically identical. In asexual form of reproduction favorable conditions are prerequisite and it takes place without the fusion of pronuclei. The favourable conditions are - optimum temperature, availability of nutrients and other suitable ecological conditions of water etc. Asexual reproduction is the creation of a clone of genetically identical individuals whose genes come from one parent. It enables successful clones to spread. It also enables isolated animals to reproduce without locating mates. It contributes towards the exponentially multiplication of organisms in short span of time.

Whereas the Reproduction that takes place by the fusion of pronuclei with or without the formation of gametes is - **Sexual reproduction.** Genetic recombination occurs during - Sexual reproduction. Sexual reproduction enhances the survival of organisms in changing environments. In the present unit we shall understand the methods of reproduction in **Protozoa, Porifera and Metazoa.**

12.2 Reproduction in Protozoa

Protozoa are unicellular eukaryotes. Most of them are free-living. Some of them are symbiotic. Some have both haploid and diploid phases in their life cycle. They show a diversity of reproduction that shares some common important basic characteristics with multicellular organisms. Reproduction in protozans takes place by - **asexual and sexual methods.**

12.2.1 Asexual Reproduction

The young ones show uniparantal inheritance, without any genetic variation (clone) in - asexual reproduction. In asexual reproduction - genetic recombination does not occur.

The methods of asexual reproduction are –

- **Binary fission,**
- **Multiple fission,**
- **Budding or gemmation,**
- **Plasmotomy**

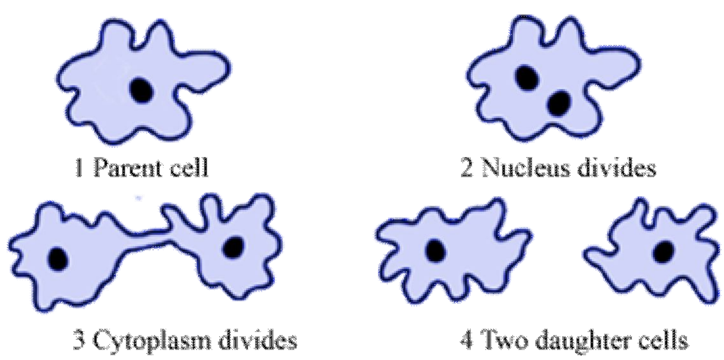
12.2.1.1Binary fission

The most common type of asexual reproduction in protozoans is - **Binary fission.** This involves the division of one individual into two approximately equal parts. The division is not a mere fragmentation but a complicated process of mitosis, during which the division of nuclei is called - **Karyokinesis** is always followed the division of cytoplasm- **Cytokinesis.** The two daughter organisms produced as a result of binary fission carry all the cytoplasmic organelles of the parent individual. Some organelles like mitochondria, divide at the time of division, while others, like oral apparatus, flagella, and contractile vacuoles, are formed afresh by one of the daughters

.**Types of Binary fission**

The binary fission may take place at different planes such as transverse or longitudinal, depending on the axis of cell separation

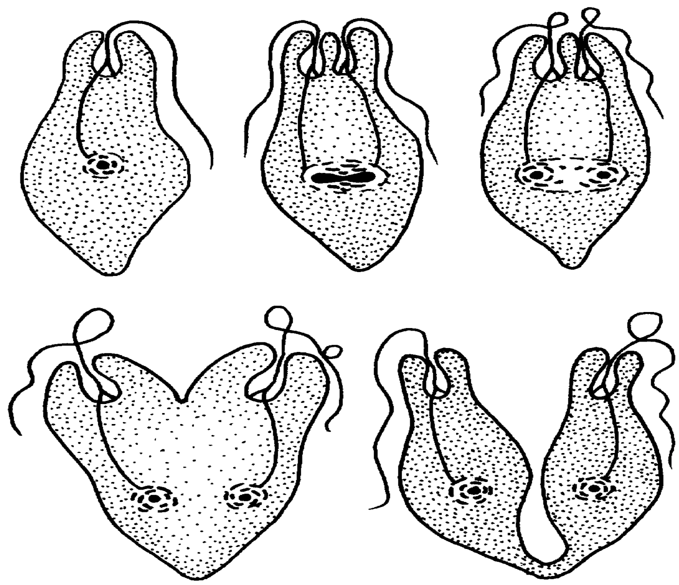
A. **Irregular- Binary fission**



The binary fission is irregular in - **Amoeba proteus.**

B. **Longitudinal- Binary fission**

Longitudinal binary fission is common in – Mastigophores. The plane of fission is Longitudinal in –**Euglena**



Binary fission in Euglena takes place during - **fovourable conditions and also in the encysted state.** During binary fusion of Euglena karyokinesis - Occurs by mitosis**.** The cytokinesis takes place by - a longitudinal furrow from the anterior end which proceeds towards the posterior end. With the result of the karyokinesis and cytokinesis Euglena divides into - **two daughter individuals.** Besides the nucles, the organelles that undergo division are - **blepharoplasts and chloroplasts.**

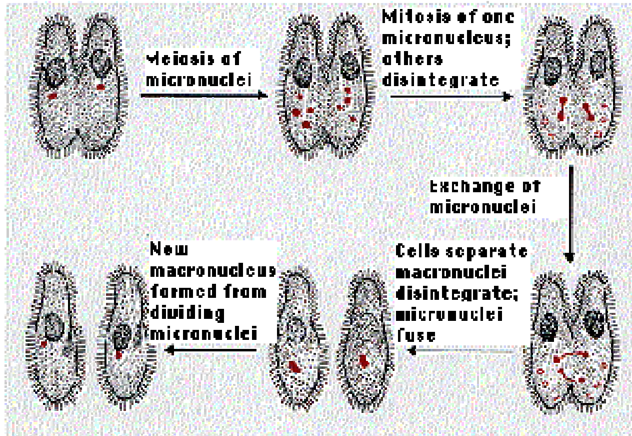
The old flagella go to one daughter individual and the other individual develops the new flagella.

The organelles which disappear (donot divide) during binary fusion and newly developed by the daughter individuals are - **the contractile vacuole, stigma and paraflagellar body.**

The daughter Euglenae formed as a result of Binary fission is like mirror images, hence called **Symmetrogenic division.**

C. Transverse- Binary fission

Transverse in – **Paramecium**



Paremecium is a - **Ciliate protozoan**

The body is - **slipper shaped** (hence the common name is slipper animalcule) the oral surface is - **flat** and the aboral surface is - **convex**, the oral surface contains - oral groove, which opens into the cytopharynx through cytostome. The ectoplasm contains - infraciliary system and trichocysts. The endoplasm contains - **two nuclei and two contractile vacuoles, food vacuoles.** The contractive vacuoles are present - **one at each end.** The two nuclei are large kidney shaped **macronucleus** and a small spherical **micronucleus.**

Macronucleus controls - **vegetative function**

Micronucleus controls - **reproductive function**

During binary fission Paramecium - stops feeding and the oral groove disappears**.** During Karyokinesis: Macronucleus divides by - A**mitosis** and Micronucleus divides by - M**itosis** and forms each two daughter nuclei. Then two oral grooves begin to appear - one in the anterior half and another in the posterior half.

During cytokinesis - a constriction appears in the middle of the body. By the deepening of the constrictin transversely - two daughter cells are formed. The plane of fission is at right angles to - **Kinetia (perikinetal fission)**

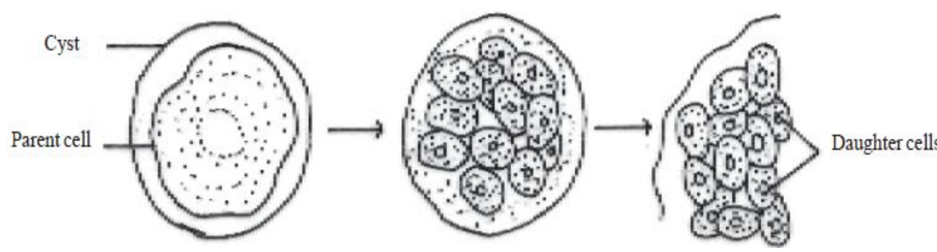
The anterior daughter individual is called – **Proter**. The posterior daughter individual is called – **Opisthe.** Each daughter individual receives - One **contractile vacuole** of the parent **and t**he second contractile vacuole is formed - newly by each daughter individual. The process of binary fission in paramecium is compled in about - **2 hours**

All the Paramecia produced asexually by repeated binary fissions from a single parent constitute - **a clone.** The transverse binary fission in Paramecium is called - **homothetogenic binary fission**

12.2.1.2 Multiple fission

The division of the parent into numerous daughter individuals is called - **multiple fission or sporulation**. During multiple fission, nuclear division is not followed immediately by division of cytoplasm. First, nucleus undergoes a series of divisions either by repeatedly binary fissions as in *Plasmodium*, or by simultaneous multiple divisions, as in *Aggregata*.

divides into as many parts as there are daughter nuclei which usually arrange themselves at the periphery, each getting surrounded by a fragment of cytoplasm. Thus the parent body simultaneously divides into as many daughter individuals as there are nuclei. The number of ofspiring greatly varies among different and the same species and sometimes runs into thousands. Multiple fission is common in – the Foraminifera, Radiolaria, Sporozoans and certain Mastigophora.



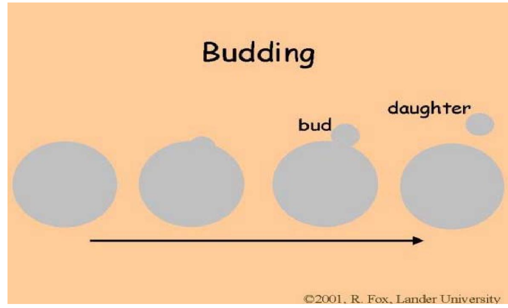
Multiple fission in Plasmodium

Schizogony is - **asexual multiple fission.** The end products of schizogony grow into - **trophozoites**

The multiple fission by which gametes are formed is - **Gamogony**

The multiple fission by which spores or sporozoites are formed is - **Sporogony.**

12.2.1.3Budding or gemmation



Budding implies modified fission resulting in a small daughter individual in the form of a bud. When the bud breaks off, it grows to full size. Budding is common in - **Suctorian protozoans eg : Acinata**

Therefore we can say that a bud is - a smaller individual formed after nuclear division.

If only one bud is formed at a time such budding is called - **monotonic budding.**

Monotonic budding occurs in - **Vorticella**

Multiple buds are formed in - **Suctorians.**

Exogenous buds are formed in **- Ephelota**

Endogenous buds are formed in - **Acineta**

12.2.1.4 Plasmotomy

It is a special type of binary fission concerned with the division of a multinucleate protozan into two or more smaller multinucleate duaghter individuals by cytoplasmic division but without nuclear divisional is called - **Plasmotomy eg : Opalina**

12.2.2 Sexual Reproduction

Reproduction that takes place by the fusion of pronuclei with or without the formation of gametes is called as **Sexual reproduction.** The offspring so formed are the resultant of genetic recombination occurs during - **Sexual reproduction.** In Protozoa, the main processes of sexual reproduction are:-

- Syngamy
- Conjugation

12.2.2.1 Syngamy

The Complete fusion of two gametes or sex cells is called – **Syngamy.** It results in the formation of a zygote. The fusion nucleus of zygote is known as **synkaryon.** Depending upon the degree of differentiation displayed, by the fusing gametes, syngamy is of the following types:

a) Hologamy

The two ordinary mature protozoan individuals do not form gametes but themselves behave as gametes and fuse together to form zygote. Hologamy occurs in a few Sarcodina and Mastigophora (e.g. *Copromonas*)

b) Isogamy

The fusion of similar gametes is called - **Isogamy e.g : Monocystis.** The fusing gametes are similar in size and shape but differ in behavior, they are called **isogametes.** Isogametes are generally produced by multiple fission.

c) Anisogamy

The fusion of dissimilar gametes is called - **Anisogamy e.g : Plasmodium**. The fusing gametes differ morphologically as well as in behavior, they are called **Anisogametes.** Usually small and motile gametes are the male or microgametes and large non-motile ones are the female or macrogametes.

d) Autogamy

It is the fusion of gametes derived from the same parent cell, as in Actinophrys and Actinosphaerium. In Actinophrys, during sexual reproduction, pseudopodia are withdrawn and a cyst is formed. Now meiotic division takes place and two daughter nuclei with half number of chromosomes are formed. No cell division takes place. After sometime, gametic nuclei fuse to form a zygote nucleus. It mostly occurs when cell go into starvation after active reproduction under well-fed conditions.

12.2.2.2 Conjugation

The scientists who defined conjugation as a temporary union between two ciliates belonging to two different mating types for the exchange and reconstitution of nuclear materials (nuclear reorganization) is - **Wichterman. (1953).** During conjugation a temporary pairing of two individuals for the exchange of the pronuclei and the fusion of pronuclei takes place, usually the union occurs at oral or buccal regions of their body. It is characteristic of Suctoria and Holotrich ciliates. Fusion of protoplasm occurs at the place of contact. Macronuclei break up and disappear. The micronuclei undergo meiotic division now all but one micronuclei degenerate. The remaining micronucleus again divides forming two gametic micronuclei. Out of these two, one is considered a male pronucleus and other is female pronucleus. Male pronucleus of one conjugant move through fused protoplasm into the other conjugant. In each conjugant, these male and female pronuclei fuse together forming a zygote nucleus. Now two individuals separate and are called **exconjugants**. Each exconjugant undergoes further nuclear and cytoplasmic divisions forming four daughter individuals.

Association in conjugation is not at random but indicates a high level of specialization.

Factors and conditions for conjugation:

- Unfavorable conditions like shortage of food.
- Conjugation occurs between two inactive individuals, which have lost their vigour and vitality due to chromosomal imbalance in their macronuclei, caused by repeated amitotic divisions.
- Conjugation does not take place during favorable conditions.

Significance of Conjugation:

- The vigour and vitality lost due to chromosomal imbalance is regained (Rejuvenation) during - Conjugation.
- The macronucleus, which becomes senile (inactive) due to - **repeated binary fission.** During conjugation new and active macronucleus is formed from - **micronucleus.**
- Conjugation is a process of - **nuclear reorganization**
- As meiosis and gametic nuclear fusion of different parentage occur during conjugation, it results in - **gene recombinations and genetic variations.**

Other than the sexual and asexual reproduction methods the two more phenomenon are found:

Parthenogenesis

In Actinophrys, the gametes which fall at cross-fertilization, develop parthenogenetically. It also occurs in Chlamydomonas and others when syngamy has been missed. Individuals of polytoma, which are potential gametes, can grow and divide parthenogentically.

Regeneration

Most Protozoa can regenerate their lost parts, as normally displayed at fission or encystment. Parasitic Protozoa usually have slight regenerative capacity. Nucleus plays an important role in the process. Relative quantities of nuclear and cytoplasmic material and the size of the broken piece affect the rate and the result of the process of regeneration.

12.3 Reproduction in Porifera

Porifera are most primitive type of multicellular animals, called sponges. They exhibit typical morphology usually referred to as 'pore bearers'. They are found in marine as well as in fresh water. Sponges reproduce both asexually and sexually and they also possess the power of regeneration.

12.3.1 Asexual Reproduction

Asexual reproduction in Porifera is by budding, branching fission or asexually formed embryos like reduction bodies and gemmules. The sponges, correlated with their low grade of organization, have a high capacity to regenerate.

12.3.1.1 Regeneration

All sponges possess a remarkable ability to regenerate lost parts. A piece cut from the body of a sponge is capable of growing into a complete sponge. If a sponge is cut into small pieces and squeezed through a fine silken mesh to separate cells, the separated amoebocytes will reunite and in a few days will develop canals, flagellated chambers and skeleton and grow up into a new sponge. This power of regeneration helps the sponges to repair the damage caused in the harsh environment. **H. V. Wilson (1907)** is credited for demonstrating the regenerative capacity of these animals. According to **Humphrey**, Ca+ and Mg+ (ions) are necessary for regeneration, along with certain cell surface factors.

12.3.1.2 Budding & Branching

In budding, numerous archaeocytes gather near the surface resulting in a small outgrowth on the pinacoderm. The bud thus formed grows outward to produce a small individual, which either remains attached with the parent individual or gets detached and attached to a nearby rock to grow into an independent colony. Branching is accomplished by new horizontal branches arise from

Stolon of the sponge which grows over the rocks, and give rise to new vase-shaped cylindrical body, which upon growth brakes through as an osculum. By branching and secondary branching and many small vertical buds grow out of it.

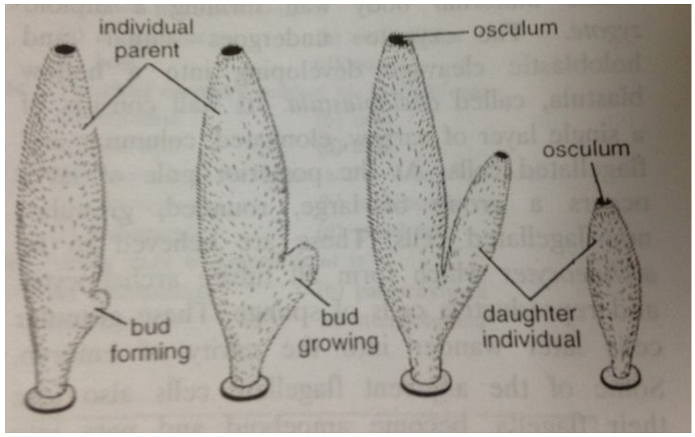


Fig.; Leucosolania showing budding

12.3.1.3 Fission and Fragmentation

In some sponges' multiplication takes place by developing a line of fission and throwing off parts of the body which later can develop into a new sponge. Sponges can break into several pieces along several lines of weakness and breaking into fragments that are capable to tide over unfavorable environmental conditions and grow into complete sponges in the following favorable season.

12.3.1.4 Reduction bodies

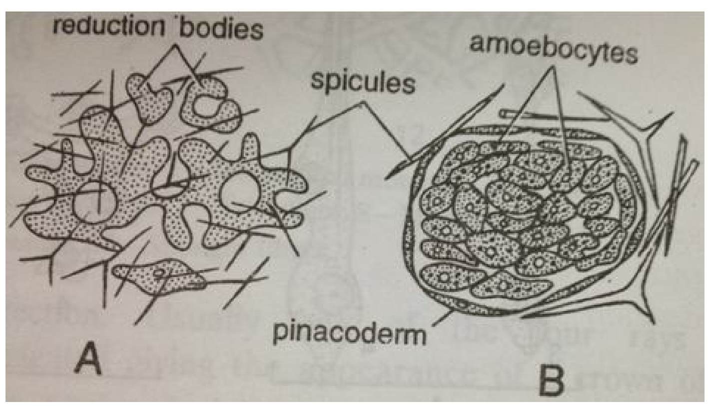


Fig.: A-reduction bodies of a sponge; B- Reduction body in section

Many fresh water and marine sponges disintegrate in adverse environmental conditions particularly in winter, leaving small rounded balls called reduction bodies. Each body consists of an internal mass of amoebocytes, covered externally by a pinacoderm and spicules. When favorable conditions return, these reduction bodies grow into complete new sponges.

12.3.1.5 Gemmules

Fresh water sponges such as *Spongilla* as well as some marine forms such as *Ficulina, Suberites,* and *Tethya*possess the remarkable ability to produce specialized bodies called *gemmules*, which survive during unfavorable conditions and germinate to produce new sponges. For gemmule formation, archaeocytes laden with food material in the form of glycoprotein or lipoprotein get aggregated into a mass. Amoebocytes surround the central mass of archaeocytes and secrete a thick hard chitinous inner layer and an outer membranous layer over it. Scleroblasts secrete amphidisc spicules between the inner and outer membranes. A fully formed gemmule is a small hard ball having a mass of food laden archaeocytes enclosed in a double layered tough envelope with amphidisc spicules in between. There is a small opening the micropyle through which the cells come out during development in favorable conditions.

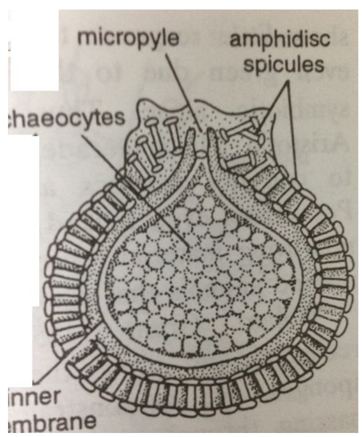


Fig.Section of Gemmule

In autumn fresh water sponges die and disintegrate, leaving behind a large number of gemmules, which remain viable throughout the winter. Same thing happens during summer when water available is low. In favorable conditions with abundance of water the gemmules begin to hatch and their living contents escape through micropyles and develop into new sponges by collecting themselves together.

12.3.2 Sexual Reproduction

Majority of the sponges are monoecious (**hermaphrodite**) but dioecious sponges are also found. Sexual reproduction involves formation of sperms and ova. The sex cells arise either from archaeocytes or choanocytes which undergo **gametogenesis**. Although most sponges are hermaphrodite but cross-fertilization is the rule because eggs and sperms are produced at different times.

Oocytes are produced inside the body and remain inside mesogloea waiting for fertilization. In sperm formation, archaeocyte and trophocyte cells are involved and in demospongiae choanocytes form sperms and leave the body of sponge through osculum in large numbers.

Sperms from water enter the body of another sponge through canal system and reach the flagellate chambers, where choanocytes trap them. Acting as nurse cells, choanocytes transport the sperm body without tail to the mature ova that wait in the mesogloea. The sperm nucleus then fuses with the nucleus of ovum, ensuring internal fertilization.

12.4 Reproduction in Metazoa

As we know, the branch Eumetazoa includes the animals which are multicellular and have complex body systems. The grade of organization reached up to the organ system level. They are found in nearly all aquatic and terrestrial habitats from poles to the tropics. The reproductive biology of these animals is highly variable. They reproduce through sexual or asexual methods. Most species use one mechanism only, but some use a combination of asexual and sexual procedures. In those species in which both methods are found, asexual reproduction enables growth or expansion into a particular niche, whereas sexual reproduction is often the dispersal phase. In a life cycle the generation may alternate between sexual and asexual reproduction, a phenomenon called as '**Alternation of generation'** for e.g. jelly fish and tapeworm.

Sexual reproduction is predominant reproductive method among metazoans. In majority of sexually reproducing species sexes are separate (gonochoristic). However, hermaphroditism occurs in many phyla and some are exclusively so.

12.4.1 Asexual Reproduction

Asexual reproduction in many species is through the typical methods like budding, fragmentation, fission and parthenogenesis. Regeneration is also observed in many of the metazoans. The lower invertebrates (Coelentrata or Cnidaria) are acoelomate with radial symmatary exhibit the two morphologyical forms viz. *Polyps* (sessile; e.g. Hydra) and *Medusae* (free swimming; e.g. Aurelia). Some pass through both stages in their life cycle with an *alternation of generation* (e.g. Obelia).

In order to understand the methods of asexual reproduction among metazoans, we shall study the following methods –

- **Budding**
- **Fragmentation**
- **Fission**
- **Parthenogenesis**

12.4.1.1 Budding

A number of species of different aquatic invertebrate phyla replicate by budding to produce individuals that can form a colony. During summers, when the conditions are favorable budding is the common method of rapid reproduction. New individuals arise from bits of tissue that are budded off from a parent, or by a parent dividing lengthwise or crosswise into two smaller individuals. Polyps that remain physically attached to one another or embedded in a common mass of tissue constitute a colony. In some colonies, polyps share a common coelenteron through which food captured by any member is distributed to others. Polyps that are produced asexually and then physically separate are called clones, or ramets. In this way, a single genotype can be represented by many separate "individuals."

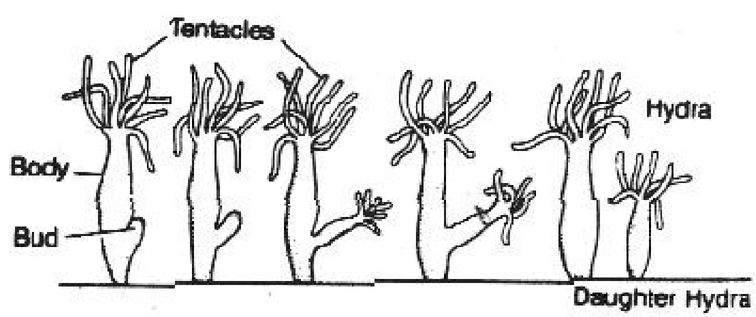


Fig. Showing the budding method in *Hydra*

The bud in hydra grows with its wall consisting of epidermis and gastrodermis and the interior lumen in continuation with parent's gastrovascular cavity. The bud enlarges, develops a mouth and a circlet of tentacles at its free end; up on further growth, the bud constricts at the base and finally separates from the parent body. It feeds and grows into an adult individual. At times, several buds occur at the same parent, and these in turn may develop secondary buds, and give rise to a structure appear like a colony-**hydroid.**

In some cases, the individuals with in the colony are interconnected (e.g. coral polyps)

12.4.1.2 Fragmentation

In this process of asexual reproduction, the animal's one part or part of the body may become separated from the adult and develop into a new individual.

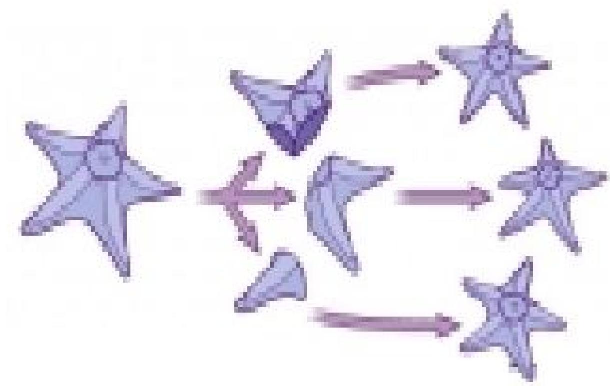


Fig.; Fragmentation in Starfish

The classical example is of some species of starfish (Phylum Echinodermata) which can split in two, each section growing new arms to form two individuals. This process is known as fragmentation. In polychaetes the fragmentation by two ways is used the rare is *Spontaneous fragmentation* and *Orderly fragmentation.*

12.4.1.3 Fission

The asexual reproduction by fission is also considered as regeneration method of reproduction. In metazoans, regeneration of lost body parts requiring the formation of a blastema is known as epimorphic regeneration. A blastema is composed primarily of two cell populations: an outer cell layer or ectoderm, derived from the epidermis that covers the wound surface after amputation or fission; and mesenchymal cells that proliferate and accumulate beneath this wound epidermis, eventually differentiating into the lost body parts.

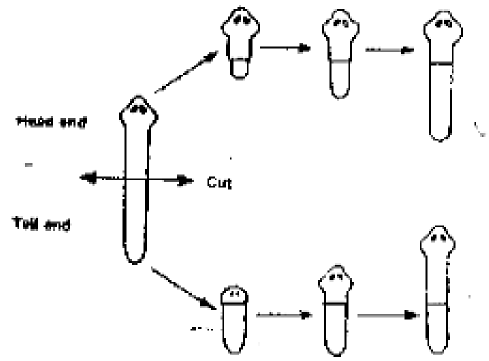


Fig. Reproduction in *Planaria*

During the summer, planarians reproduce asexually by catching their posterior end (behind pharynx) on a sharp object and stretching until the body tears in two. Each part regenerates the wanting structures. This mode of asexual reproduction is termed as fission (Transverse binary fission)

12.4.1.4 Parthenogenesis

Parthenogenic reproduction involves individuals within a species being able to produce fertile offspring without the need for a fusion of gametes between individuals of opposite sexes. Often referred to as unisexual reproduction; it is also called as virgin birth.

Species that alternate between parthenogenesis and bisexual reproduction (heterogenetic species) often do so in response to changes in population density, food availability, or other environmental conditions. **White** (1978) estimates at least 1000 species are known to be exclusively parthenogenic and the vast majority of these are invertebrates, parthenogenesis in invertebrates is not restricted to the arthropods but there are isolated members in many other phyla.

Parthenogenesis is thought to be most advanced form of asexual reproduction in animals**.**

12.4.2 Sexual Reproduction

Sexual reproduction is the method in which genes from two individuals mix, and produces an individual with a new combination (fresh set of working genes). The vast majority of invertebrate only reproduce sexually. Asexual reproduction by means of bipartition, budding, or similar processes has not been observed in higher animals and their ability to regenerate is limited.

Compared to asexual reproduction, sexual methods regarded as being energetically more expansive. It includes the process of gamete formation to locating, courting and securing a mate; copulation, and providing nutritional resources for developing young. So the whole process is energy requiring event. In many species, therefore, the cost of sexual reproduction is reduced longevity and fitness. This is perhaps why reproduction is usually the first activity to cease, when animals are stressed or food is in short supply. However, sexual reproduction brings about the advantage of variations through mixing of genes.

Sexual reproduction requires that haploid gametes are brought together and that inhabit aquatic environment this can occur either outside the body of parent (External fertilization) or within the reproductive tract (Internal fertilization). The terrestrial metazoans (invertebrates) only reproduce by internal fertilization. Whilst fertilization is left to chance in case of external fertilization, a number of mechanisms have evolved to increase fertilization success including:

- Production of large number of small gametes
- Gamete chemotaxis and recognition
- Parent aggregation and
- Synchronization of spawning

The internal fertilization has required the evolution of more complex reproductive systems and mechanism of sperm transfer.

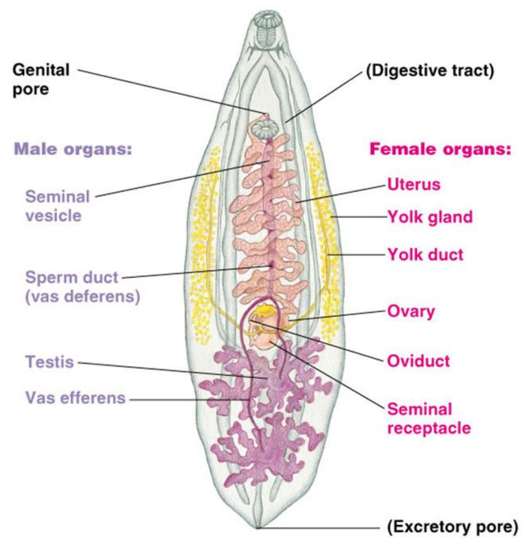
The process initiate with **Gametogenesis** (production of male-sperms and female-ovum) which is highly variable in animals.

12.4.2.1 Gametogenesis

It is the mechanism of production of gametes i.e. sperm and ovum. The process by which the production of male gametes (sperm) takes place is known as **spermatogenesis**. The process of production of female gametes (egg or ovum) is termed as **oogenesis**. Ovum (egg) from the female parent (Usually large and non-motile) and Spermatozoan (sperm) from the male parent (Usually small and highly motile) is formed as a result of meiosis with in gonads (testes in male; ovaries in female) subsequent gamete fusion (syngamy) to produce a diploid zygote. The fusions of gametes that differ in size are known as anisogamy.

12.4.2.2 Hermaphroditism

Many taxonomic groups of animals (mostly invertebrates) do not have separate sexes. In these groups, **hermaphroditism** is a normal condition, enabling a form of sexual reproduction in which both partners can act as the "female" or "male". For example, the great majority of pulmonte snails, opisthobranch snails and slugs are hermaphrodites.



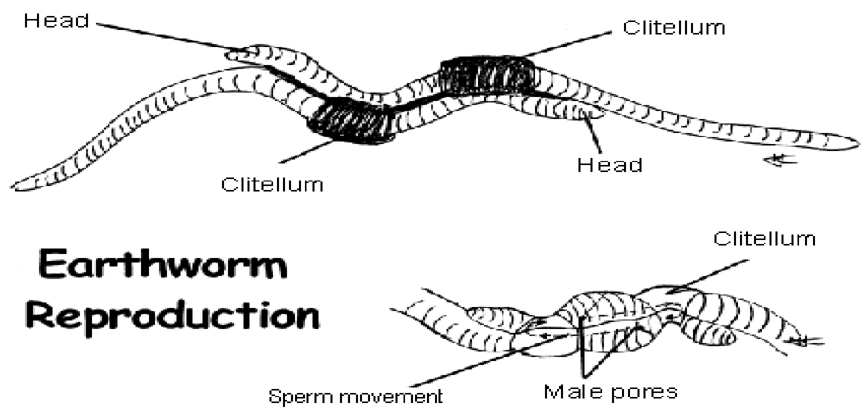
There are a number of forms of hermaphroditism. Some invertebrate species are *simultaneous hermaphroditism* i.e. producing both eggs and sperms at the same time, either in the same gonads (an ovotestis) or in a separate ovary and testis. An individual will have both male and female reproductive organs.

In other group: *Sequential hermaphroditism* sex change occurs in beginning their life as males, before becoming a functional female later (**protandry**). In cases where the animal exhibit female first sequential hermaphrodite (**protogynous),** while some species sequentially alternate between male and female phases.

The predominantly hermaphroditic taxa are Ctenophora, Platyhelminthes, Molluscs, Clitellata of Annelida. Hermaphroditism is particularly common in clonal and colonial species. Hermaphroditism can be governed by the enviormental factors for e.g. Annelids and Molluscs are hermaphrodite in freshwater and terristial environment, where as their marine relatives are nearly all gonochoristic.

Hermaphroditism is also more common in deep-sea crustaceans when compared to those from shallow-waters.

Earthworms show *simultaneous hermaphroditism*. Earthworms are cross-fertilizing hermaphrodites. Two earthworms exchange sperm and then separate.The received sperm are stored while a special organ, the clitellum, secretes a mucous **cocoon**. As the cocoon slides along the body, it picks up eggs and stored sperm and slides off the body into the soil.

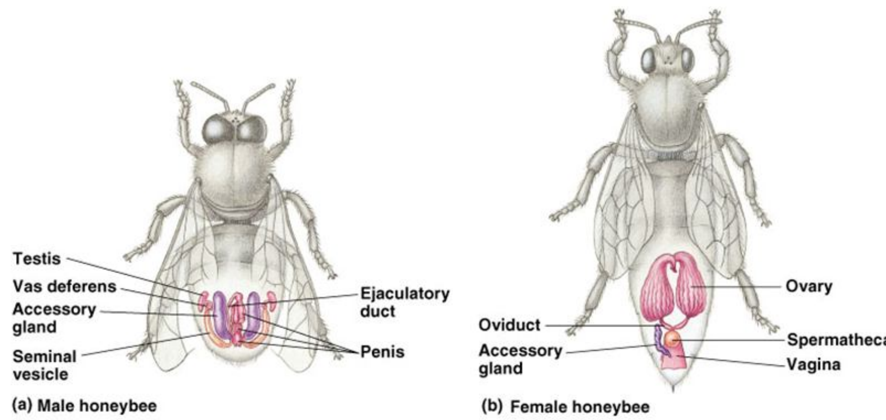


Most mate with another member of the same species. Each individual receives and donates sperm. Results in twice as many offspring as would occur if only one set of eggs were fertilized.

12.4.2.3 Sexual reproduction in insects

Insects are the largest class of animal kingdom, they are considered to be most suitably adapted on earth. Reproduction is usually sexual, with separate male and female individuals. The process is performed in following steps:

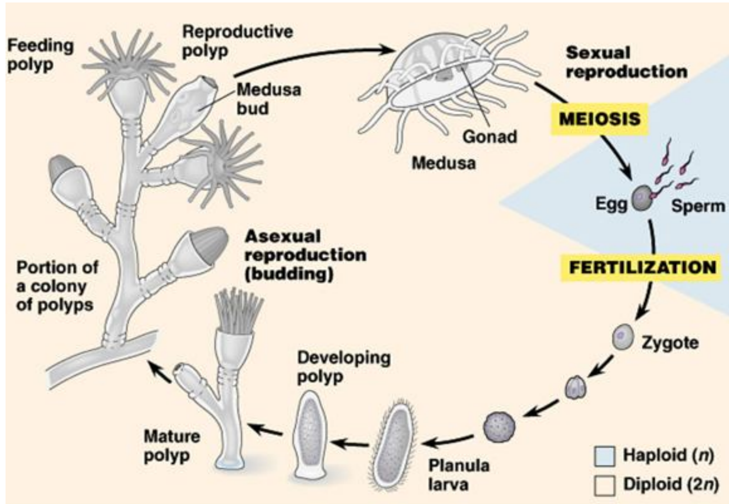
- Coloration, sound, or odor bring together opposite sexes at the appropriate time. In most species, sperm cells are deposited directly into the female's vagina at the time of copulation. In a few species, females pick up a sperm packet deposited by a male.
- The females store sperm in the spermatheca, in some cases holding enough sperm from a single mating to last a lifetime.
- After mating, females lay their eggs on a food source appropriate for the next generation.



Some other organisms, such as the spiders, exhibit what is known as **big-bang reproduction**, where large numbers of offspring are produced in each reproduction, after which the individual often dies. This is also known as **semelparity.** By contrast, some organisms produce only a few eggs during **repeated reproductive** episodes. This is also known as **iteroparity**.

12.4.2.4 Alternation of generation

Many animals use a strategy of combination of asexual and sexual procedures. In those species in which both methods are found, asexual reproduction enables growth or expansion into a particular niche, whereas sexual reproduction is often the dispersal phase. In a life cycle the generation may alternate between sexual and asexual reproduction, a phenomenon called as '**Alternation of generation'.** This phenomenon is quite common in parasitic animals for e.g. class Trematoda (Platyhelminthes) parasitizes a wide range of hosts, and most species have complex life cycles with alternation of sexual and asexual stages. Many require an intermediate host in which the larvae develop before infecting the final hosts (usually a vertebrate) where the adult worm lives.



Most hydrozoans alternate polyp and medusa forms, as in the life cycle of *Obelia*

12.5 Summary

After going through this unit you have understood that the animal life is widely present at every place of the earth. Kingdom Animalia is further divided into two subkingdoms: *Protozoa* and *Metazoa*. What is reproduction? And how the simplest unicellular to complex multicellular organism reproduce? Asexual and sexual methods of Protozoa, Porifera and Metazoa. Among the Protozoan the methods of asexual reproduction are – Binary fission, Multiple fission, Budding or gemmation, and Plasmotomy. While the main processes of sexual reproduction are:-Syngamy and Conjugation. Porifera – the sponges reproduce both asexually and sexually and they also possess the power of regeneration. Metazoa animals have highly specialized asexual reproduction in lower invertebrates and exhibit typical sexual methods including hermaphroditism and alternation of generation.

The understanding of reproduction is key for knowledge of comprehensive animal biology.

12.6 Glossary

- **Cytokinesis:** the division of cytoplasm
- **Exconjugants:** two individuals separate after conjugation
- **Gamogony:** The multiple fission by which gametes are formed
- **Iteroparity:** the animals reproduce several time, but in lesser quantity
- **Karyokinesis:** the division of nucleus

- **Lineage:** in the same or linear sequence
- **Multicellular**: Organisms/animal made of many cells
- **Offsprings**: the individuals formed as a result of reproduction
- **Organ** : Different tissues perform towards single function
- **Organ system**: Different organs perform together to execute a physiological function
- **Polymorphism:** Occurrence of several forms in a species
- **Ramets**; the identical individuals
- **Schizogony:** is - asexual multiple fission.
- **Semelparity:** the animal reproduce once in very high number
- **Sporogony:** The multiple fission by which spores or sporozoites are formed
- **Symmetrogenic division:** Binary fission is like mirror images
- **Tissue**: Structurally and functionally similar group of cells
- **Unicellular**: Organisms made up of single cell

12 .7 Self-Learning Excercise

Section -A (Very Short Answer Type)

1. Name the division of nuclei.
2. The fusion of dissimilar gametes is called?
3. Define multiple fission or sporulation?
4. Sperm receiving structure in earthworm ___________________.
5. The females insects store sperm in the _______________

Section -B (Short Answer Type)

1. Write a note on the Binary fission.
2. Briefly explain about the parthenogenesis..
3. Distinguish between asexual and sexual reproduction
4. Define the Fragmentation in Starfish.

Section -C (Long Answer Type)

1. Give a detailed account of asexual reproduction in Porifera.

2. Explain how hermaphroditism may be advantageous to animals that have difficulty encountering a member of the opposite sex?
3. Discuss the significance of 'Alternation of generation' in metazoans?

Answer Key of Section-A

1. Karyokinesis
2. Anisogamy
3. It is the division of the parent into numerous daughter individuals
4 Cclitellum
5. Spermatheca

12.8 References

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Unit - 13

Origin of multicellularity: Phylogenetic relationship between - Parazoa, Mesozoa, Metazoa (Eumetazoa) ; Radiata , Bilateria; Pesudocelomate groups

Structure of the Unit :

13.0 Objectives

After going through this unit you will be able to understand -

- How on earth, first cells appeared?
- How single cell organisms started living together and formed colonies ?
- How multicellularity came into existence?
- You will also understand the very basic norms of classification ; meanings of metazoa parazoa and mesozoa ; radiata, bilatria and pseudocoelomata and their phylogenetic relationship.

13.1 Introduction

Animal life began in Precambrian seas with the evolution of multicellular forms that lived by eating other organisms. Early animals populated the seas, fresh waters, and eventually the land.

Abiogenesis is the natural process of life arising from non-living matter such as simple organic compounds. Evolutionary relationship of animal Groups(phylogeny) is established by comparative study of anatomical and embryological features. Taxonomy deals with naming of groups based on individual traits at Genus and Species level.

In unit -3 of this booklet you have already understood how traits like level of body organization, number of germ layers, type of body plane and symmetry, fate of blastopore, fate of blastomeres and different coelom are used to classify animals.

Cells are divided into two main classes-

(a) First organisms without nucleus and nuclear envelop , smaller and simpler called **Prokaryots** (bacteria) - not included in this unit.

(b) **Eukaryots** that have a nucleus in which the genetic material is separated by nuclear envelop from the cytoplasm(all other organisms).

(c) **Eukaryotes** include parazoa, mesozoa(included in this unit)

(d) **Higher** multicellular animals having cells differentiated into tissues and organs and usually a digestive cavity and nervous system are included in subkingdom **Metazoa** except protozoans and parazoa (sponges).

Before start reading this unit you must be familiar with :

Phylogeny- which deals with evolutionary relationship of animal groups and is established by comparative study of homologies(similarities) such as - Anatomical, Embryological and Molecular.

Taxonomy- is naming of groups ,based on phylogenic relationships and homologies at Domain, Kingdom, Phylum level further based on individual traits at Genus & species level.

The study of animal phylogeny has different hypotheses regarding the evolutionary relationships between animals, in this unit we will try to simplify phylogeny to help us understand the enormous diversity among animals.

(i) Numerical/ phenetic taxonomy - that classify organisms based on overall similarity, usually morphology or other observable traits, regardless of their phylogeny or evolutionary relation.

(ii) Evolutionary taxonomy - which classify organisms using a combination of phylogenetic relationship and overall similarity.

(iii) Cladistics taxonomy– classify organisms solely on the basis of phylogeny . In the 18th century, Carolus Linnaeus published a system of taxonomy based on resemblances .The taxonomic groups from broad to narrow are **domain**, **kingdom**, **phylum**, **class**, **order**, **family**, **genus**, and **species .** A taxonomic unit at any level of hierarchy is called a **taxon .** The two-part scientific name of a species is called a **binomial; t**he first part of the name is the **genus ; t**he second part, called the specific epithet, is unique for each species within the genus ; the first letter of the genus is capitalized, and the entire species name is italicized eg *Homo sapiens* . A **clade** is a group of species that includes an ancestral species and all its descendants.

13.2 Origin of Life

13.2.1 Single cell

13.2.2 Formation of colony

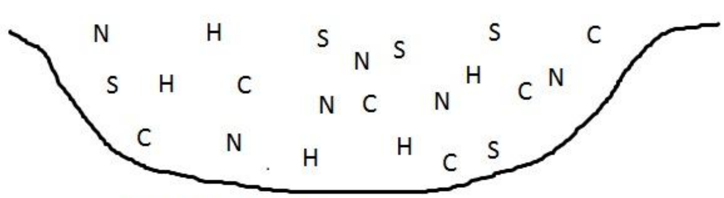
13.2.3 Multicellularity

13.2.1 Single cell:

Earth was formed 4.6 billion years ago .First life emerged at least 4 billion years ago, after the earth cooled down .Earth , at this time, had mixture of gases - methane, ammonia and hydrogen and liquid was predominantly ammonia. This was called primordial soup, it is a term introduced by the Soviet biologist **Alexander Oparin** In 1924, he proposed the theory of the origin of life on Earth through the transformation, during the gradual chemical evolution of molecules that contain carbon nitrogen, hydrogen and sulphur in the primordial soup. Biochemist Robert Shapiro summarized the "primordial soup" theory of Oparin as follows:

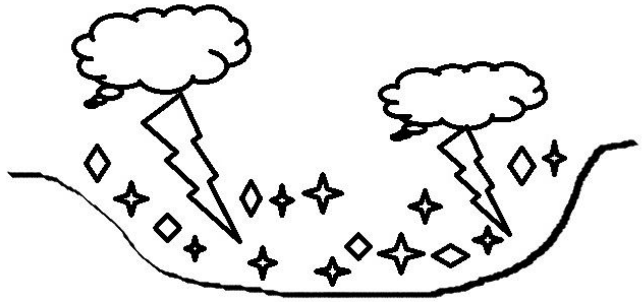
1. The early Earth had a chemically reducing atmosphere.
2. This atmosphere, exposed to energy in various forms, produced simple organic compounds ("monomers").
3. These compounds accumulated in a "soup", which may have been concentrated at various locations (oceanic vents , shorelines and hot springs).
4. By further transformation, more complex organic polymers like amino acids developed in the soup.

Origin of first cell is a matter of imagination . At the time life arose, the atmosphere of Earth had no free oxygen, but had CO_2 and N_2 in addition to gases H_2, H_2S, and CO , this atmosphere provided reducing conditions in which organic molecules, in presence of energy of sunlight and electrical discharge, reacted and formed organic molecules. This was first demonstrated experimentally in the 1950s, by **Stanley Miller** that the discharge of electric sparks into a mixture of H_2, CH_4, and NH_3, in the presence of water, formed variety of organic molecules, including several amino acids.



PRIMORDIAL SOUP

The next step in evolution was the formation of macromolecules. Heating mixtures of amino acids, resulted in their polymerization to form polypeptides. It was a strand of macromolecule which had the capability to replicate itself, i.e self replicating RNA. First of this kind was seen in bacteria called



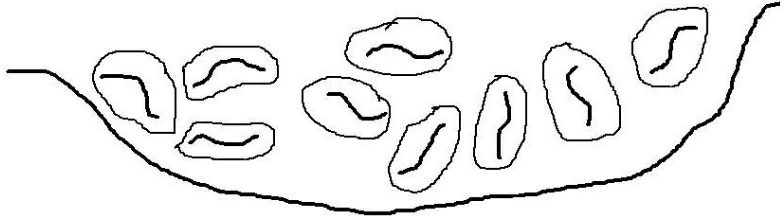
LIGHTENING OVER PRIMORDIAL SOUP

Prokaryots.

FORMATION OF SINGLE STRAND REPLICATION MOLECULE

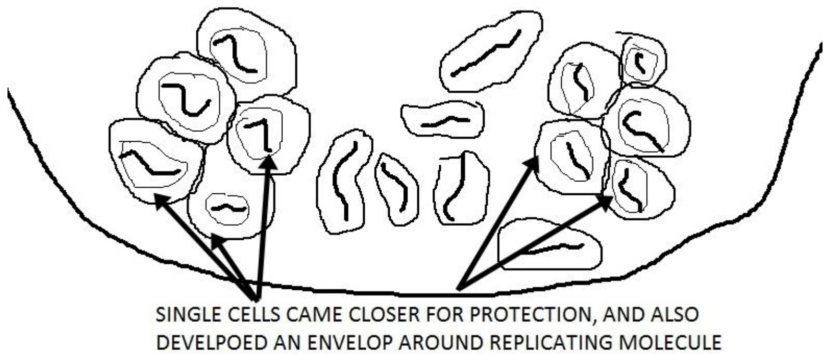
Replicating molecules became enclosed within a cell membrane. enclosing its self-replicating RNA (nuclear membrane) composed of phospholipids giving rise to Eukaryots.

The evolution of a membrane surrounding the genetic material provided two advantages: (i) the products of the genetic material could be kept close by and the internal environment of this proto-cell could be different than the external environment. (ii) Cell membranes were advantageous that these encased replicators quickly outnumbered "naked" replicators.

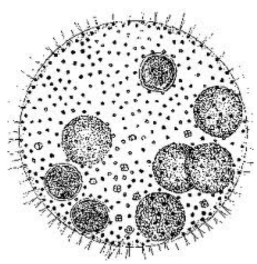


DUE TO COMPETITION MOLECULES FORMED A COVERING AROUND THEM SELVES ENSURING ENOUGH SUPPLY OF N,H,S AND C

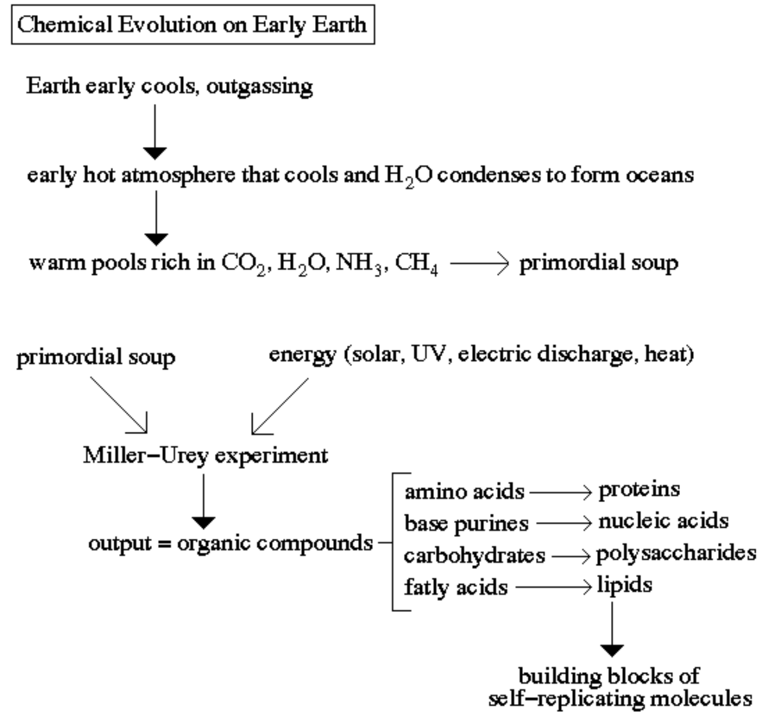
13.2.2 Formation of Colony:



A good example is volvox - Volvox is a genus of chlorophytes, a type of green algae. It forms spherical colonies of up to 50,000 cells. Cell membrane also enclosed the hereditary material forming a proper nucleus.



The flow chart below explains, what has just been taught to you above.



13.2.3 Multicellularity /origin of Metazoa:

Before we start with origin of life, remember-all animals evolved from ancestral colonial choanoflagellates(The choanoflagellates are a group of free-living unicellular and colonial flagellate eukaryotes considered to be the closest living relatives of the animals.).

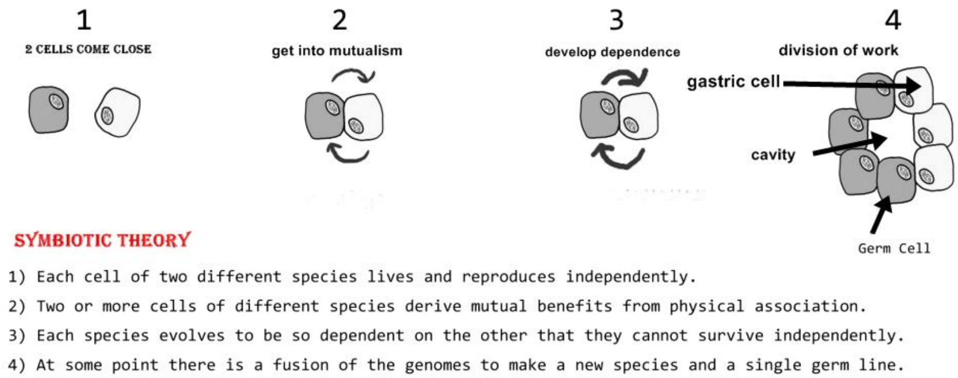
There are three theories on how multicellularity evolved -

13.2.3.1 Symbiotic theory

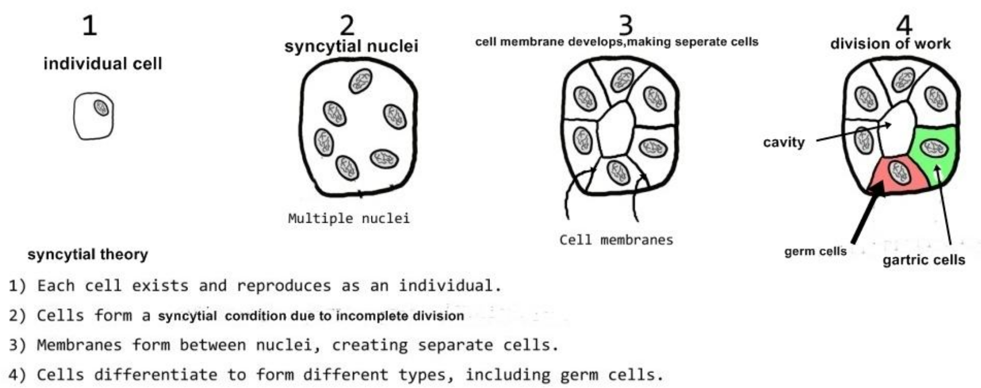
13.2.3.2 Syncytial Theory

13.2.3.3 Colonial theory

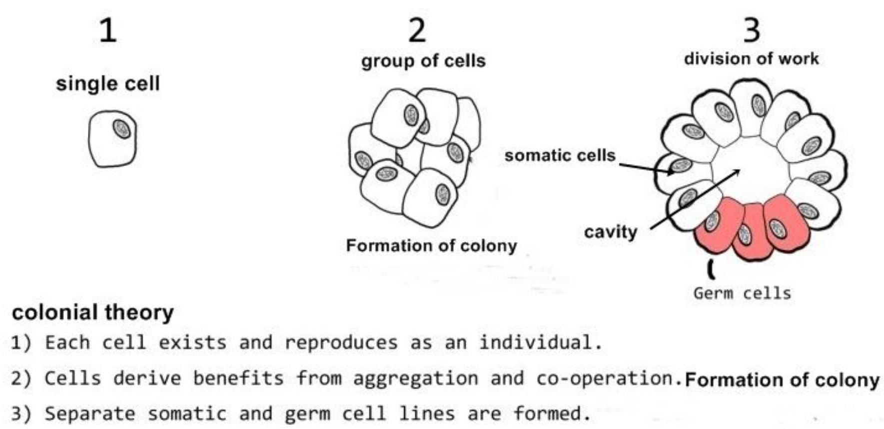
13.2.3.1 Symbiotic theory:



13.2.3.2 Syncytial Theory:



13.2.3.3 Colonial theory :



The cells of many algae (e.g., the green alga *Volvox*) associate with each other to form multicellular colonies, which are thought to have been the evolutionary precursors of present-day plants. Increasing cell specialization probably led to the transition from colonial aggregates to truly multicellular organisms. Continuing cell specialization and division of labor among the cells of an organism have led to the complexity and diversity observed in the many types of cells that made **Parazoa.**

Advantages of Multicellularity:

1. Multicellular organisms are able to complete much more complicated tasks and are much more efficient at completing the simpler tasks.
2. If one cell dies, that's not the death of the organism
3. Increased genetic variability in daughter generations

Multicellular organisms (metazoans) are divided into **two grades:**

A. **Parazoa** (phylum Porifera)

B. **Mesozoa** - Phylum coelenterate, Platyhelminthes and Nematoda

(Both will be explained in this chapter)

13.3 PARAZOA : (This has only one phylum ie porifera, all remaining Phyla belong to the subkingdom eumetazoa.), this is one lineage (branch) which never evolved beyond the sponges. This lineage is sometimes referred to as an evolutionary dead end . Sponges are ancient, with a fossil record dating back to the early Cambrian.

13.3.1 General Characters

1. Sponges operate at the **cellular-level organization**, meaning that their cells are
2. specialized so that different cells perform different functions, but similar cells are not organized into tissues .
3. Bodies are just a sort of loose aggregation of different kinds of cells. This is
4. the simplest kind of cellular organization .
5. No true tissues or organs.
6. No germinal layers.
7. Intracellular digestion.
8. Sessile sponges draw food and water into their body.
9. Porifera means “pore-bearing”; their sac-like bodies are perforated by many pores.
10. Sponges use flagellated “collar cells”, or choanocytes, to move water.

11. Most of the approximately 5000 species of sponges are marine; a few live in
12. brackish water and some 150 live in fresh water. 6. Marine sponges are found in all seas and at all depths; they vary greatly in size.
13. Their embryo is free swimming.
14. Sponges are asymmetrical.
15. The skeletal structure of a sponge can be fibrous and/or they have calcareous or
16. siliceous needle like structures called spicules.
17. One form of collagen, spongin is found as binding agent.
18. Body openings consist of small incurrent pores or **dermal ostia**.
19. Incurrent pores have an average diameter of 50 µm
20. Inside the body, water is directed past the **choanocytes** where food particles are
21. collected.
22. Choanocytes or flagellated collar cells line some of the canals.
23. Two other cell types, pinacocytes and archaeocytes, play a role in sponge feeding.
24. Have different Canal Systems to circulate water through ostia and porous body.

13.4 Metazoa/ Eumetazoa :

The first split in the early organisms resulted into two subkingdoms:

1.Subkingdom **Parazoa** which has only porifera, as described above**.**

2.Subkingdom **Metazoa** / also called **Eumetazoa**

This split is also called the **Parazoa Eumetazoa split (bifurcation).**

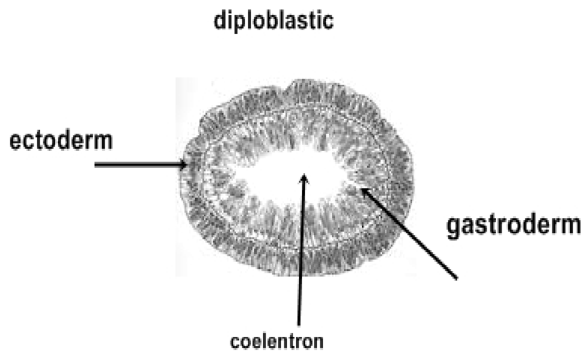
All multicellular animals are called **metazoans or Eumetazoans.** Metazoans are a **monophyletic group**, i.e. they have a common great grand ancestor from there with time, they diversified.

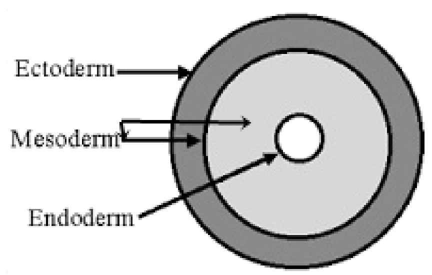
13.4.1 Characteritics of the Eumetazoa-_

(1) **True tissues-** Similar cells are grouped together and perform common function as a coordinated unit

(2) Tissues are assembled into larger functional units called **organs**. **Germinal layers present.**

(3) During gastrulation either two germinal layers are formed called **diploblastic (eg coelenterates) or** three layers are formed called **triploblastic (all other animals).**





Triploblastic

The simplest eukaryotes are the yeasts. Yeasts are more complex than bacteria, but much smaller and simpler than the cells of animals or plants .Multicellular organisms evolved from unicellular eukaryotes at least 1.7 billion years ago.

13.5 Mesozoa

(Mesozoa, the "Middle Animal"): The **Mesozoa** are mysterious, minuscule, worm-like parasites of marine invertebrates. They have very simple bodies, often consisting of less than 50 cells arranged in two layers that are not equivalent to the layers of metazoans.

1. Named by **Van Beneden in 1876**, he believed mesozoa was a link between protozoa and metazoa.
2. All are parasites in marine invertebrates.
3. They are small, made of 20–30 cells in two layers but these are not germ layers.
4. There are two classes; some consider them separate phyla.

13.5.1 Characteristics of Mesozoa:-

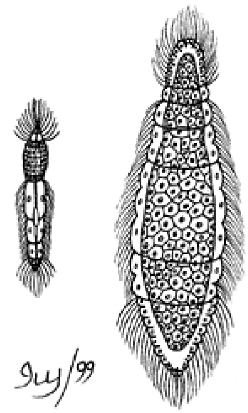
1) Bilaterally symmetrical.
2) Has no organs or tissues.
3) Body contains no internal cavity.
4) Body possesses no digestive tract (gut).
5) Body only two cell layers in most places.
6) Has no nervous system.
7) Has some cells develop inside other cells.
8) Reproduction quite complex involving both sexual and asexual aspects.
9) All are endoparasites on other marine invertebrates.
10) Its locomotion is carried out by cilia

It has two classes -

13.5.2 Orthonectida - are parasites on a wide range of marine invertebrates including (1) Platyhelminthes, Echinodermata, Mollusca and Annelida. During the sexual stage they are gonochoristic (male and female). eg Rhopalura.

1) They parasitize a variety of invertebrates, including brittle stars, bivalve molluscs, polychaetes and nemerteans.
2) Life cycles include sexual and asexual stages.
3) The asexual stage is different from rhombozoans; it forms a multinucleated mass where division gives rise to males and females.
4) During this phase they have no central tube-cell, instead the space within the layer of ciliated cells is filled with eggs or sperm. The males release their sperm into the sea. the sperms enter the body of any females they find and fertilize her eggs.
5) These fertilized eggs grow into a ciliated larva (consisting of only a few cells). This larva now leaves the mothers body and enters the body of a suitable host. Inside the host it loses its cilia and grows larger to form a plasmodium (something a bit like a multicellular amoeba).
6) This plasmodium has many nuclei and is called multinucleate. Bits of this plasmodium break off and form new plasmodia. Eventually the plasmodia give rise to

the sexual which soon leave the host and the life cycle is complete.



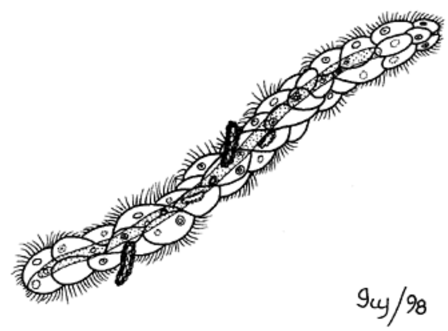
RHOPALURA

13.5.3 Rhombozoa - : also called Dicyemida are parasites of cephalopods (Octopus and Squid), they live in the animals kidneys. eg Dicyema .

1) Rhombozoas live in the kidneys of benthic cephalopods.
2) Adults are long, slender vermiforms.
3) Inner reproductive cells give rise to vermiform larvae that grow and reproduce.
4) When they are crowded, reproductive cells develop gonad-like structures that make male and female gametes.
5) Zygotes grow into unique minute ciliated infusoriform larvae shed in urine.
6) Rhombozoans have a more complicated life cycle. Their basic body plan is a long thin central cell, called an axial or tube cell, surrounded by a coat of smaller ciliated cells which are arranged spirally around the axial cell. Some authors equate this with a two cell-layer body plan.
7) The axial cell contains smaller cells called axoblasts. These axoblasts give rise to either, vermiform(long and thin) asexual larvae called nematogens sexually reproducing individuals called rhombogen.
8) The two forms are almost identical ; the only difference being that in the nematogen stage the axoblasts produce more nematogens and in the rhombogen stage they produce infusorigens which serve as the animals gonads (organs which produce eggs and sperm).

9) The eggs are fertilized inside the axial cell where they develop into infusoriform larvae which quickly develop the adult number of cells. Each species has a definite number of cells in its adult form.

10) This infusoriform larvae then leaves the axial cell and the hosts body, with its urine. They then sink to the sea floor where they grow by means of cell enlargement rather than by cell addition.



Dicyema

13.6 Radiata and Bilatria

Animals can be **asymmetrical**, that is, possessing no organized body plan. Only the Sponges(parazoa) fall into this category. Animals can also be **radially symmetrical**, where the body is arranged around a central point at all stages of life. Many in the phylum Coelenterate are radially symmetrical. All other animals are **bilaterally symmetrical (except gastropods and echinoderms)**, that is, their bodies can be bisected into two identical, making mirror image halves. (Symmetry has been well explained in unit 3 . Go back and read it once again) .

Hatschek as early as 1890 had divided **Eumetazoa** into two groups, namely, **Radiata** and **Bilateria** depending on the symmetry they possess, the former includes coelenterates and ctenophores and the latter includes all phyla from helminthes to chordates. It is universally believed that the first metazoans were radially symmetrical, and bilateral symmetry evolved later owing to the creeping habit acquired by the animals to feed on detritus on the bottom. There are theories to explain the origin of Bilateria from Radiata.

13.6.1 Ctenophore-polyclad theory

This theory was proposed by **Kowalevsky** (1880) and **Arnold Lang** (1881-84) and emphasizes that polyclads evolved from ctenophore-like ancestor. Modern polyclads, such as *Leptoplana* and *Notoplana* are marine, free-living, bottom dwelling turbellarians that belong to Order Polycladida or Phylum

Platyhelminthes. They creep on the bottom and use their ventral mouth to feed on detritus. On the other hand ctenophores are freely floating animals exhibiting radial as well as bilateral symmetry that is also termed as biradial symmetry. Ciliary bands are radially placed on the body while a pair of antennae is bilateral. A ctenophore-like ancestor could have given rise to bilaterally symmetrical animals by acquiring bottom crawling mode of life. There are some crawling ctenophores existing today, e.g. *Ctenoplana* and *Coeloplana.*

13.6.2. Ctenophore-trochophore theory

This theory takes into consideration the larval stages of coelenterates, ctenophores, helminthes and annelids and tries to establish evolutionary relationship among them. Planula larva of coelenterates has elongated and cylindrical body that is ciliated all over. Cydippid larva of ctenophores is also ovoid in shape but has longitudinal ciliary bands arranged radially around the body. Muller's larva of Polycladida (Helminthes: Turbellaria) also has ciliary bands on swimming arms and apical tuft of cilia on the anterior side. Mouth is ventral in this larva and there is no anus. The trochophore larva of Polychaeta resembles Muller's larva in having ciliary bands and apical tuft of cilia and ventral mouth. Since cydippid larva of ctenophore, Muller's larva of polyclads and trochophore larva of polychaetes all resemble one another in structure and ciliary band, this theory considers larvae of acoelomate bilateria (flat worms) as early stages of trochophore.

13.6.3. Planuloid-Acoeloid theory

This theory was first proposed by **Ludwig von Graff** (1882) and later elaborated by **Hyman** (1951). The theory postulates that the primitive acoelomate bilateria (helminths) evolved from some planuloid ancestor which was very similar to the planula larva of coelenterates. The planuloid ancestor must have been free-living, radially symmetrical, ciliated and with a diffused nerve net. Such planuloid must have developed into a gastrula-like ancestor by the formation of mouth and archenteron and adopted a bottom creeping mode of living rather than free swimming habit of planula. Creeping habit produced cephalisation of nervous system towards the anterior side and since the food was available at the bottom, the anterior mouth moved to the ventral side and the body became dorso-ventrally flattened, as is the case in turbellarian helminths of today.

13. 7 Pseudocoelomata

Pseudocoelomates belong to the **Protostomia** division of the **bilateral** animals . When body cavity lacks the peritoneal lining (made from mesoderm) found in the true coelomates, it is called a pseudocoel, and the animals possessing it are called pseudocoelomates eg platyhelminths.

Body cavity, spongocoel, coelenterone, acoelom, pseudocoelom, true colelom, schizocoelous coelom and enterocoelous coelom are well explained to you in unit 3. Go back and read it once again to understand it here.

Vertebrates and higher invertebrates have a true coelom , or peritoneal cavity , which is formed in the mesoderm during embryonic development and is , therefore , lined with a layer of mesodermal epithelium , the peritoneum. The pseudocoelomate phyla have a pseudocoel rather than a true coelom . It is derived from the embryonic blastocoel rather than from a secondary cavity within the mesoderm . It is a space not lined with peritoneum , between the gut and the mesodermal and ectodermal components of the body wall (for diagram refer unit 3).

Seven distinct groups of animals belong to the pseudocoelomate category . These are Rotifera , Gastrotricha , Kinorhyncha , Nematomorpha , Acanthocephala , Entoprocta (all minor phyla), and Nematoda.

13.7.1 Characteristics of pseudocoelomates

a. Symmetry bilateral; unsegmented ; triploblastic (three germ layers)

b. The body has a pseudocoel body cavity between the body wall (longitudinal muscles) and (the endodermis of) the gut

c. Size mostly small; some microscopic**;** a few a meter or more in length

d. Body vermiform; body wall a syncytial or cellular epidermis with thickened cuticle , sometimes molted ; muscular layers mostly of longitudinal fibers; cilia mostly absent

e. digestive system (lacking in acanthocephalans) complete with mouth , enteron , and anus; pharynx muscular and well developed ; tube-within-a-tube arrangement ; digestive tract usually only an epithelial tube with no definite muscle layer

f. Circulatory and respiratory organs lacking

g. Excretory system of canals and protonephridia in some ; cloaca that receives excretory , reproductive , and digestive products may be present

h. Nervous system of cerebral ganglia or of a circumenteric nerve ring connected to anterior and posterior nerves ; sense organs of ciliated pits , papillae , bristles , and some eyespots.

i. Reproductive system of gonads and ducts that may be single or double ; sexes nearly always separate , with the male usually smaller than the female ; eggs microscopic with shell often containing chitin

j. Development may be direct or with a complicated life history ; cleavage mostly determinate ; cell or nuclear constancy common

13.8 Phylogenetic relationship between - Parazoa, Mesozoa ,Metazoa (Eumetazoa) ; Radiata , Bilateria; Pesudocelomate groups.

Major Events in Animal Phylogeny include following phylogenic splits:

13.8.1 The Parazoa-Eumetazoa Split

Two basic kinds of animals evolved early in animal evolution.

A. Parazoa ("beside the animal") - animals that lack true tissues. e.g., Sponges

B. Eumetazoa - animals with well defined tissue layers,

e.g., essentially all other animals.

13.8.2 The Radiata-Bilateria Split

The eumetazoa are divided into 2 major branches depending on the type of body symmetry

Some organisms exhibit **radial symmetry,** and are called the **Radiata**

Other eumetazoa exhibit **bilateral symmetry,** and are called the **Bilateria**

The Radiata-Bilateria split is also defined by the differences in the number of germ layers that are formed in the embryo during **gastrulation**

The Radiata are referred to as **diploblastic** - two germ layers form

Ectoderm - covering the surface of the embryo; gives rise to the epidermis and in some phyla the nervous system.

Endoderm - inner most germ layer; lines the primitive gut; gives rise to the lining of the digestive tract and associated organs, such as the liver and lungs of vertebrates

The Bilateria are **triploblastic;** in addition to the ectoderm and endoderm they produce a third germ layer, the **mesoderm**

Mesoderm - germ layer between the ectoderm and the endoderm; gives rise to muscles and to most other organs

13.8.3 The Acoelomate-Coelomate Split

A. Acoelomates - animals with solid bodies; there is no body cavity between the gut (endoderm) and the outer body wall.

The other 2 body plans are often referred to as a *tube within a tube body plan*; a fluid filled sac separate the gut from the outer body wall.

A second important difference between acoelomates and animals having a body cavity is that animals with a body cavity have some sort of **blood vascular system**

B. Pseudocoelomates - animals in which the body cavity is not completely lined with mesodermal tissue

The body cavity is called a **pseudocoelom**

C. Coelomates - animals that have a fluid filled body cavity that is completely lined with tissue that is derived from the mesoderm.

This kind of body cavity is called the **coelom**

13.8.4 The Protostome-Deuterstome Split

Coelomates, can be divided into 2 distinct groups: **protostomes** and **deuterostomes**.

They are distinguished based upon fundamental differences in early development, including cleavage, fate of the blastopore, and coelom formation.

animalia

Protozoa Metazoa

Parazoa Eumetazoa

Radiata Bilateria

Acoelomate Pseudocoelomate

Coelomate

Deuterostomes

Protostomes

mollusks, annelids, arthropods

echinoderms, chordates

Enterocoelous

Schizocoelous

see one more flow diagram at the end of unit 3.

13.6 Summary

This unit deals with Origin of life taking you through probable origin of Single cell , how they formed Colonies and led to Multicellularity through symbiosis,or creating syncytial condition or forming a colony.

All living animals are divided into prokaryotes and eukaryotes . The Eukaryotes comprise of Parazoa, Metazoa and Mesozoa.

Parazoa includes sponges only.Mesozoa includes Orthonectida and Rhombozoa.Metazoa includes all other multicellular animals.

Early invertebrates were either asymmetrical or radially symmetrical eg coelenterates , this group later gave rise to Bilaterally symmetrical animals.

In phylogeny one comes across body cavity called coelom, which is found in higher animals, less evolved animals either didn't have a body cavity, or if they had like nematods it was a false coelom called Psudocoelome. origin of metazoans is monophylatic, during the course of evolution four major splits are reported by scientists **-** Parazoa-Eumetazoa Split ,

Radiata-Bilateria Split, Acoelomate-Coelomate Split and Protostome-Deuterstome Split.

13.7 Glossary

- **Cell-** smallest structural and functional unit of animal
- **Prokaryote-** cell without definite nucleus
- **Eukaryote-** cells with definite nucleus
- **Parazoa-** tissue level of body organization
- **Metazoa-** organ and organ system level of body organization
- **Mesozoa-** are mysterious, minuscule, worm-like parasites of marine invertebrates
- **Radiata -** radially symmetrical animals
- **Bilateria-** Bilaterally symmetrical animals
- **Psudocoelomata -** body cavity not lined by mesoderm from both sides.

13 .8 Self-Learning Excercise

Section -A (Very Short Answer Type)

1. Phenomenon of the natural process of life arising from non-living matter is called ....
2. Cells with definite nucleus are called ....
3. 1880 **Ctenophore-polyclad theory was proposed by ....**
4. **Hatschek** as early as 1890 had divided **Eumetazoa** into two groups, namely ....

5. ....proposed that the discharge of electric sparks into a mixture of H_2, CH_4, and NH_3, in the presence of water, formed variety of organic molecules,

6. Van Beneden in 1876, he believed mesozoa was a link between protozoa and metazoa.- true/false

7. Primordial soup term was coined by **Alexander Oparin True/false**

8. Parazoa includes only porifera True/false

Section -B (Short Answer Type)

1. Write characters of Parazoa
2. Give examples of mesozoa, and write on any one type
3. Define symmetry, radial and bilateral
4. Explain syncytial theory of multicellularity
5. Define coelom and pseudocoelom

Section -C (Long Answer Type)

1. Differentiate between taxonomy and phylogeny. Explain prokaryotes and eukaryotes. What do you understand by parazoa,mesozoa and metazoa?
2. Define multicellularity, describe three theories related to its origin.
3. What is a body form? Define radial and bilateral symmetries, with suitable diagrams.
4. with the help of diagrams explain coelom, acoelom and psudocoelom.

Answer Key of Section-A

1. Abiogenesis
2. Eukaryote
3. Kowalevsky
4. Radiata and Bilateria
5. Stanley Miller
6. True
7. True
8. True

13.9 References

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- Invertebrate by Hymen
- Invertebrate by Sedgwick
- Invertebrate by Kotpal

Unit – 14

Phylogenetic relationship between the coelomate, Affinities of the invertebrate deuterostome phyla

Structure of the Unit

14.0 Objectives

After going through this unit you will be able to understand -

- How basic structural features like coelom and fate of blastopores are used to classify animals .
- You will understand how a body cavity evolved and differentiated into acoelome , pseudocoelome and true coelom.
- What does blastopore of gastrula forms in adult-mouth or anus ? Protostome or Deuterostom ?

14.1 Introduction

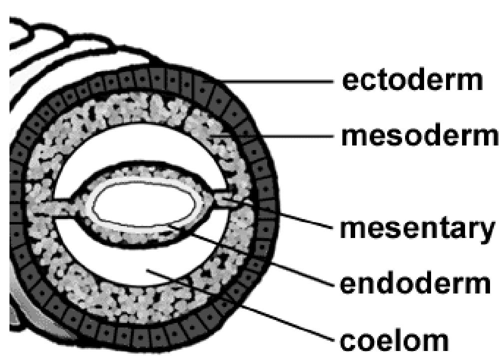
Before you start studying morphology, physiology of invertebrates it is essential to know the basis of classification and phylogeny. Similarity between the animals which are grouped together . Origin of multicellular animals is monophylatic ie they have evolved from a common ancestor. You have already read in unit 13, how single cell came into existence, then evolution of colonial organisms, then true multicellular animals. In unit 3 you have understood that animals have different types of cavities inside their bodies, simple to complex . During development of embryo, what does blastopore form mouth or anus? Accordingly animals are classified under two categories-deuterostom and protostome. Though you have already covered part of it in unit 3 and 13, here is some more information.

14.2 Body cavity

Animals have a cavity inside their body. The primitive form can be seen in porifera and coelenterates. what is a true coelom ?

14.2.1 True Coelom :

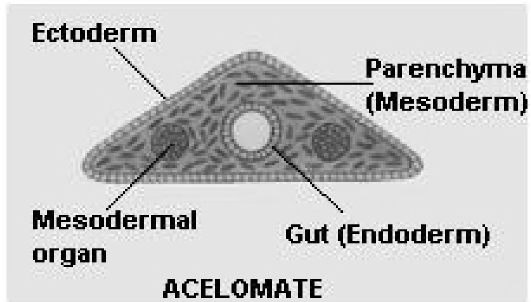
A cavity found between the body wall (ectoderm) and alimentary canal (endoderm) and it is lined by the mesoderm from its both sides. See the diagram below:



if you have understood what is true coelom it would be much easier to understand acoelome, psudocoelom , schizocoelous and enterocoelous coelom.

14.2.2 Acoelom :

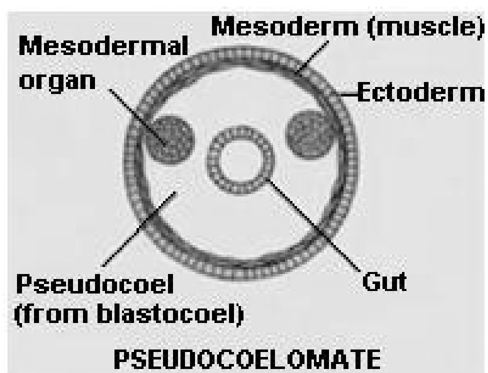
A cavity found between the body wall (ectoderm) and alimentary canal (endoderm) and mesoderm, instead of lining it (as per definition) , fills the cavity, leaving no space. When you see the following diagram , you will understand it better.



This kind of coelom is found in animals of platyhelminthes.

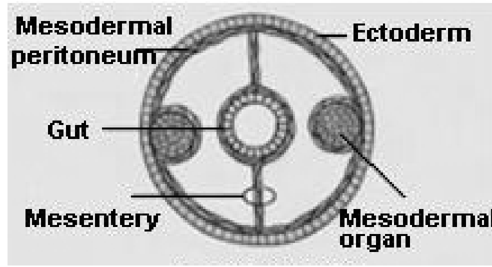
14.2.3 Psudocoelom :

It is the body cavity found between the ectoderm and endoderm, but mesoderm does not line it from both sides, instead, mesoderm is found in patches, making it a false cavity. Therefore, it is called psudocoelom. It is found in animals of phylum nematoda.



14.2.4 True coelom : Schizocoelous and Enterocoelous :

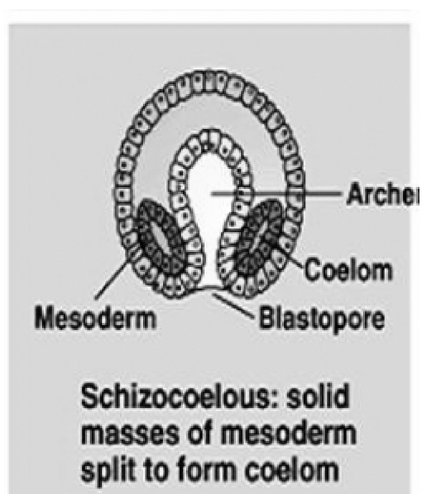
Please read the definition of coelom under 1.4.2 - A cavity found between the body wall (ectoderm) and alimentary canal (endoderm) and it is lined by the mesoderm from its both sides. Following diagram makes it clear:



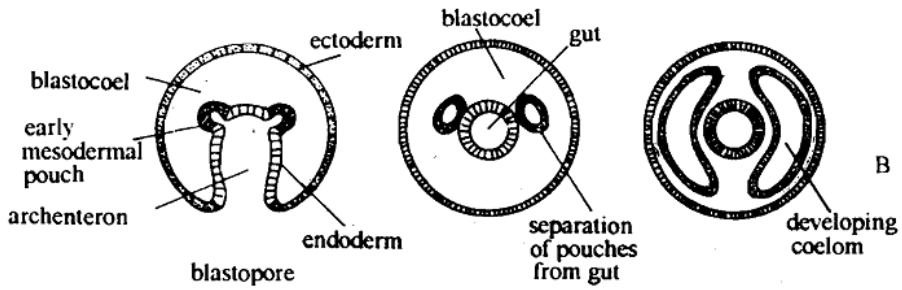
Difference between schizocoelous and enterocoelous types can only be seen during embryonic development, once the coelom is fully developed they cannot be differentiated.

Schizocoelous coelom : Is found in Annelids, Arthropods and molluscs.

- A single micromere or mesentoblast cell pinches off from archenteron and it multiplies and proliferates to from mesodermal patches between the developing archenteron (endoderm) and the body wall (ectoderm)
- A split appears within each patch making them hollow and creating a cavity
- The cavity formed by the splitting of mesodermal band is the Schizocoelom.



Enterocoelous coelom : It is found in Echinoderms and all vertebrates



- In this, two small pouches appear from archenteron called mesodermal pouches they grow inside the cavity, get separated from gut and develop a cavity between the body wall(ectoderm) and the gut(endoderm); this cavity is lined by mesoderm from its both sides. This is called enterocoelous coelom. Coelom holds, protects mesodermal derivatives ie all visceral organs.

14.2.5 Evolutionary advantage and functions of coelom - The advent of a coelom , the body cavity completely lined with gave an evolutionary advantage.

(i) The coelom's lining is called the peritoneum. The mesentery, a folded membranous connection between body cavity and gut, originates from the peritoneum. The mesentery holds body organs within the coelom in place but allows growth and movement.

(ii) One basic advantage for those organisms with a coelom is greater control over locomotion. Soft-bodied animals use the coelomic fluids to from a hydrostatic skeleton as muscular pressure against the fluids gives the body a rigidity and provides a resistant base for the action used in burrowing.

(iii) Storage of energy rich compounds (fat)

(iv) Reproductive products – eggs, sperm, embryos

(v) Organs can develop with separation from other tissues

(vi) Allows for specialization of regions of the digestive system

(vii) Water filled space can be used to move body parts

(viii) Allows for circulation of fluids around organs

(ix) Hydrostatic skeleton; housing and cushioning of internal organs/organ systems. (x)The circulatory system is closed, and is contained within the coelom

(xi) Reduces vestigial space around the heart, gonads, part of the intestine and reproductive organs .

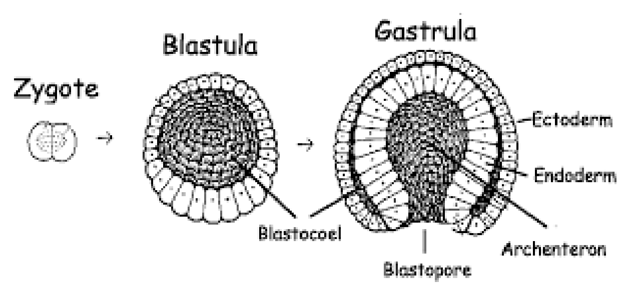
(xii) In echinoderms coelom gives rise to the water-vascular system, used for locomotion and in some species, prey capture .

(xiii) In chordates, coelom houses the internal organs, and provides fluid cushioning for

organs and organ systems. (Your own coelom is the space lined by your peritoneum -the mesodermal tissues anchoring your internal organs in their proper place in the abdomen) as well as the mesodermally lined space in your thoracic cavity.

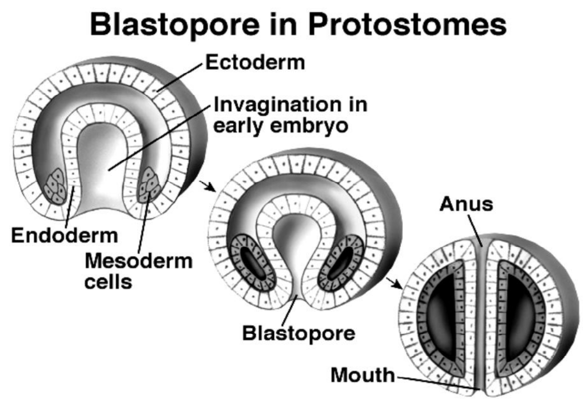
14.3 Fate of Blastopore

The fertilized egg divides to form a zygote, it divided and first forms a morula and later develops into balstula , this changes into gastrula, forming future ecto,endo and meso derms, creating archenteron (future alimentary canal), a blastopore and a cavity between ectoderm and endoderm called blastocoel.



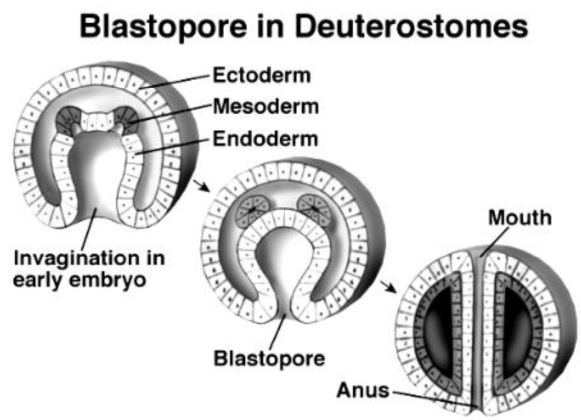
14.3.1 Protostome :

- Protostomes are those animals in which the blastopore becomes the oral aperture (mouth). Members of phylum Annelida, phylum Arthropoda and phylum Mollusca are included in this group.



14.3.2 Deuterostome:

- Deuterostomes are those animals in which the blastomere forms the anus. The oral aperture appears much later as a separate slit. Members of the phylum Echinodermata and Chordata exhibit this condition.



14.4 Phylogenetic relationship

It has already been mentioned in details in unit 13 how from monophylatic origin different invertebrates evoled.

14.4.1 The Parazoa-Eumetazoa Split (The Parazoa-Eumetazoa split has been estimated at 940 million years ago).

Two basic kinds of animals evolved early in animal evolution.

A. Parazoa ("beside the animal") - animals that lack true tissues. e.g., Sponges.

B. Eumetazoa - animals with well defined tissue layers,

e.g., essentially all other animals.

14.4.2 The Radiata-Bilateria Split

The eumetazoa are divided into 2 major branches depending on the type of body symmetry Some organisms exhibit **radial symmetry,** and are called the **Radiata.**

Other eumetazoa exhibit **bilateral symmetry,** and are called the **Bilateria.**

The Radiata-Bilateria split is also defined by the differences in the number of germ layers that are formed in the embryo during **gastrulation .**

The Radiata are referred to as **diploblastic** - two germ layers form.

Ectoderm - covering the surface of the embryo; gives rise to the epidermis and in some phyla the nervous system.

Endoderm - inner most germ layer; lines the primitive gut; gives rise to the lining of the digestive tract and associated organs, such as the liver and lungs of vertebrates.

The Bilateria are **triploblastic;** in addition to the ectoderm and endoderm they produce a third germ layer, the **mesoderm.**

Mesoderm - germ layer between the ectoderm and the endoderm; gives rise to muscles and to most other organs.

14.4.3 The Acoelomate-Coelomate Split

A. Acoelomates - animals with solid bodies; there is no body cavity between the gut (endoderm) and the outer body wall.

The other 2 body plans are often referred to as a tube within a tube body plan; a fluid filled sac separate the gut from the outer body wall.

A second important difference between acoelomates and animals having a body cavity is that animals with a body cavity have some sort of **blood vascular system.**

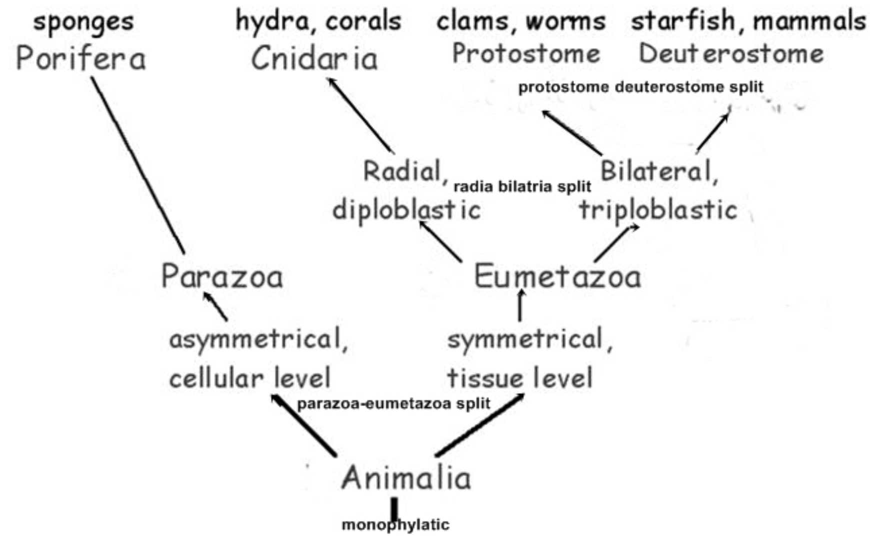
B. Pseudocoelomates - animals in which the body cavity is not completely lined with mesodermal tissue . The body cavity is called a **pseudocoelom.**

C. Coelomates - animals that have a fluid filled body cavity that is completely lined with tissue that is derived from the mesoderm. This kind of body cavity is called the **coelom.**

14.4.4 The Protostome-Deuterstome Split

Coelomates, can be divided into 2 distinct groups: **protostomes** and **deuterostomes**.

They are distinguished based upon fundamental differences in early development, including cleavage, fate of the blastopore, and coelom formation.



14.5 Affinities of Deuterostomes (Echinodermata with chordate)

Although echinoderm adults have radial symmetry, they evolved from ancestors that were bilaterally symmetrical. They have free-swimming, bilateral larvae that metamorphose (change as they mature) into adults with radial symmetry.

Chordates evolved from some deuterostome ancestor (echinoderms, hemichordates, pogonophorans etc.) as they have similarities in embryonic development, type of coelom and larval stages. Fossils of the earliest vertebrates are known from the Silurian-Devonian period, about 400 million years ago. The following theories have been given to explain the origin of chordates:

1. **Echinoderm Origin.** The theory was given by **Johannes Muller** (1860) and is based on the comparative studies of larval stages of echinoderms and hemichordates. Tornaria larva of hemichordates resembles echinoderm larvae such as Bipinnaria, Auricularia, Dipleurula and Doliolaria, which all possess ciliary bands and apical tuft of cilia. Also like chordates, echinoderms are also deuterostomes .

2. Jeffries' Hypothesis is based upon archaelogical findings that show that ancestral echinoderms had 4 of the 5 chordate characters:

   (i) A notochord,

   (ii) dorsal nerve chord,

   (iii) pharyngeal gill slits, and

   (iv) the post-anal tail.

   These ancestral echinoderms were called Calcichordata from Ordovician period (450 mya) further confirmed echinoderm ancestry of chordates. Calcichordates were asymmetrical animals which demonstrate affinities with both echinoderms and chordates but their skeleton is made of CaCO3whereas in vertebrates the bones are made of hydrated Ca and phosphate.

3. **E.J.W. Barrington** (1965) proposed that the common ancestor of echinoderms and chordates was a sessile ciliary arm feeder that lived in the plankton-rich environment of the Cambrian. Modern Echinodermata and hemichordates evolved from a similar ancestor by retaining the original mode of feeding, perhaps because they continued to inhabit the same environment as occurred in ancestral days.

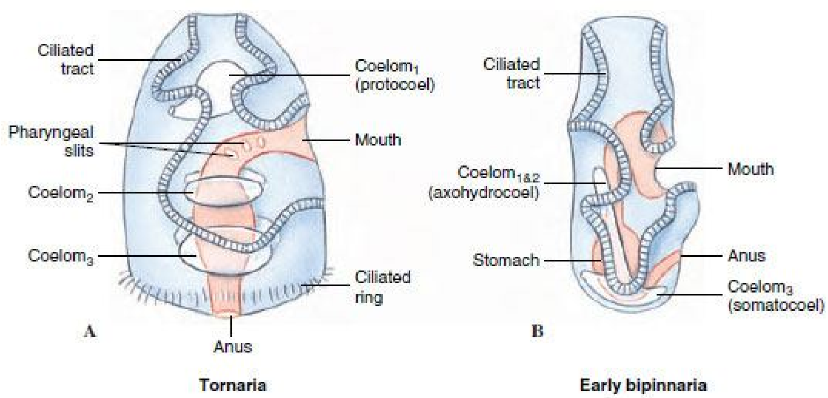
Adult resemblances:-

Adult Balanoglossus(chordate) and echinoderms are structurally quite different. So it is difficult to draw their phylogenetic relationship between themselves. However, some resemblances are there:-

1. Enterocoelic origin of coelom.
2. Heart vesicles and glomerulus of Balanoglossus are considered homologous to the dorsal sac and axial gland of echinoderm.
3. Nervous system poorly developed and forms epidermal nerve plexus.
4. Proteins and phosphagens present in Balanoglossus closely resemble those of echinoderms.
5. Both have common habits, echological niches and remarkable power of regeneration.

Larval resemblances:-

1. Tornaria larva of Balanoglossus has striking, structural similarities with Bipinnaria larva of echinoderms.
2. Larvae are small, pelagic, transparent and oval.
3. Identical ciliated bands taking up a similar twisted course.
4. Enterocoelic origin and similar development of coelom.
5. Proboscis coelom of Tornaria is comparable to hydrocoel of echinoderm Dipleurula.
6. Deuterostome and digestive tract is complete with mouth and anus.



14.6 Summary

This unit deals with interrelationship in phylogeny through coelom, which is found in higher animals, less evolved animals either don,t have a true body cavity, or a false coelom called Psudocoelome as in nematods. origin of metazoans is monophylatic, during the course of evolution four major splits are reported by scientists - Parazoa-Eumetazoa Split , Radiata-Bilateria Split, Acoelomate-Coelomate Split and Protostome- Deuterstome Split.

14.7 Glossary

- **Coelom** : Body cavity found between the body wall and alimentary canal and is lined by mesoderm from both sides.

- **Acoelom**: Body cavity filled by mesoderm
- **Psudocoelom**: Body cavity which in not lined by mesoderm
- **Schizocoelous**: The cavity formed by the splitting of mesodermal band
- **Enterocoelous** : Cavity formed from mesodermal pouches
- **Protostome**: Blastopore of embryo forms mouth in adult
- **Deuterostom**: Blastopore of embryo form anus in adult

14 .6 Self-Learning Exercise

Section -A (Very Short Answer Type)

1. Larva of balanoglossus is called.......
2. Larva of echinoderms is called ....
3. coelome formed by pinching off of mesentoblast cells is ....
4. acoelom is found in ....
5. In Protostomes blastopore becomes the oral aperture True/False
6. coelom which is not lined by mesoderm from its both sides is.........
7. Chordates evolved from echinoderms.this theory was proposed by ......
8. E.J.W. Barrington (1965) proposed that the common ancestor of echinoderms and chordates was a sessile ciliary arm feeder True/False

Section -B (Short Answer Type)

1. Describe psudocoelom and acoelom
2. write about enterocoelous coelom
3. what do you understand by deuterostomes?
4. Draw diagram of Tornaria larva
5. Draw diagram of Bipinnaria larva
6. Explain Protostomes

Section -C (Long Answer Type)

1. Discuss affinity between deuterostomes, draw necessary diagrams
2. Explain acoelom, psudocoelom and coelom with the help of diagrams and examples
3. What do you understand by fate of blastopore? Draw diagrams where necessay.

Answer Key of Section-A

1. Tornaria
2. Bipinnaria
3. schizocoelous
4. platyhelminths
5. True
6. True
7. psudocoelom
8. Johannes Muller

14.9 References

- The Invertebrates: A Synthesis by R.S.K. Barnes , P. Calow , P.J.W. Olive , D.W.Golding , 2012
- Biology of the Invertebrates : Author: Pechenik, Jan A. 2009
- Invertebrate Zoology A Functional Evolutionary Approach Author: Ruppert, Edward E., Fox, Richard S., Barnes, Robert D. 2003
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- Biology of the Invertebrates Jan A. Pechenik 2009
- Invertebrates by Kotpal 2014

Unit - 15

Invertebrates larvae : larval form of free living invertebrates; parasites strategies and evolutionary significance of larval forms; importance of planula larva

Structure of the unit

15.2.5 Arthropoda:

15.2.5.1 Crustacea

15.2.5.1.1 Nauplius

15.2.5.1.2. Metanauplius

15.2.5.1.3. Protozoaea

15.2.5.1.4. Zoaea

15.2.5.1.5. Cypris.

15.2.5.1.6. Mysis or Schizopod

15.2.5.1.7. Megalopa

15.2.5.1.8. Phyllosoma

15.2.5.1.9. Alima

15.2.5.2 Insecta

15.2.5.2 .1 Oligopod

15.2.5.2 .2. Protopod

15.2.5.2 .3. Polypod

15.2.5.2 .4. Apodous

15.2.6 Mollusca

15.2.6.1 Veliger Larva:

15.2.6.2 Glochidium larva

15.2.7 Echinodermata

15.2.7.1 Dipleurula Larva or Early Bipinnara

15.2.7.2 Bipinnaria Larva

15.2.7.3 Brachiolaria larva

15.2.7.4 Ophiopluteus Larva

15.2.7.5 Echinopluteus Larva

15.2.7.6 Auricularia larva

15.2.7.7 Doliolaria or Vitellaria larva

15.2.7.8 Pentachrinoid Larva

15.3 Evolutionary significance of larval life

15.4 Importance of planula larva

15.0 Objective

Objective of the present unit is to understand the various larval forms found in the lifecycle of various invertebrate phyla. It mainly aims at the description of phylumwise larval forms and their evolutionary significance especially the importance of planula larva.

15.1 Introduction

Useful distinction can be made between three modes of development, one is **Oviparity,** in which the parents release eggs at an early stages of their development or even before cleavage has begun. In **Ovoviviparity,** eggs are retained within the parents, but are still surrounded by egg membranes and retained up to their development, nutrition being derived mainly or entirely from the **Yolk.** In **Viviparity** eggs are retained within the parents, with some loss of their membranes, nutrients being derived mainly from the parental tissues and young ones are laid. The difference between direct and indirect developments is a familiar future of life history. In the former (direct) the adult stage is attained by progressive growth and differentiation, where as in the later there is a larval stage differing both in its structure and its habit from the adult, and acquiring adult form through gradual or sudden metamorphosis.

Three main types of larvae can be distinguished: firstly the **lecithotrophic larva**, so called because it feeds exclusively on yolk which is originally laid down in the eggs and does not take any food from the external sources. A far commoner type of larva is the **planktotrophic larva,** so called because the yolk reserves of the eggs are exhausted and the organism has to feed on plankton. Such larvae are usually well developed for prolonged movement. They swim actively for 2-4 weeks in summer months and perhaps for as long as three months during the winter. There are other planktonic larvae with only a short period of free swimming life; it is of few hours to many days. **Pelagic larva** have the potential to disperse long distances, colonize new territory, and move away from habitat that has become overcrowded or otherwise unsuitable.

Pelagic larvae avoid bentic predators and appears to be absent from arctic waters.

15.2 Types of Larvae

15.2.1 PORIFERA: Poriferans are pore bearing animals commonly called sponges, diploblastic, acoelamate, generally sessile and mostly marine. Reproduction is by asexual as well as sexual, through a larval form. Following larval forms are exhibited in the Phylum.

15.2.1.1 Amphiblastula :- In calcareous sponges, such as Sycon, Grantia etc. cleavage is holoblastic and form a stomoblastula which consists of small and columnar cells called as micromeres, which develop flagella at their inner end and face towards the spongocoel (blastocoel). While a few posterior cells remain large, rounded and granular called as macromeres. An opening called mouth is present in the center of micromeres. Later this stomoblastula undergoes a process called inversion in which it turns itself out through the month, so that the flagella are directed outside. The embryo is now called the amphiblastula larva, because its one half bears the flagella and other half i.e., anterior formed by small slender flagellated cells. Now the flagella are directed towards exterior and the posterior half is formed by large rounded non-flagellated and granular cells. (Fig.1)

The amphiblastula larva does not stay within the maternal mesenchyme but passes out in the water through the canal system with the outgoing water current. The amphiblastula swims freely into water, while swimming, the flagellated pole is directed anteriorly and the force for swimming is supplied by the beating of flagella.

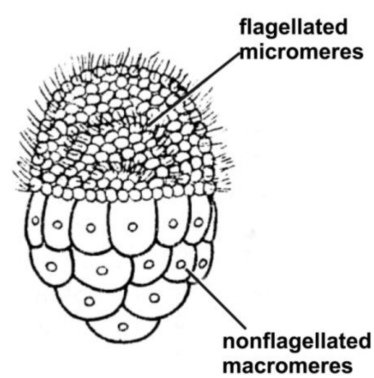


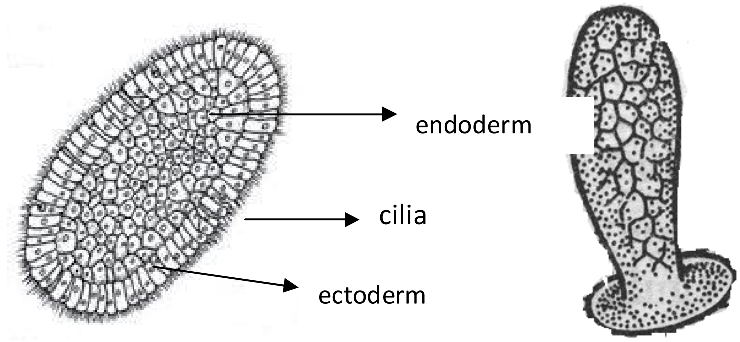
Fig.1 Amphiblastula – Free Swimming (Source: Invertebrate by Kotpal).

This amphiblastula then undergoes Gastrula stage which is completed by the invagination of the flagellated half into the non-flagellated cells, now it becomes a typically two walled gastrula. Flagellated cells become the **choanocytes** while the non flagellated form the dermal epithelium. Mesoglea and amoebocytes are derived from both the layers of cells and in the center a spongocoel is developed.

15.2.2.2 Coeloblastula : In primitive myxospongida a coeloblastula larva is formed which escapes as completely flagellated larva. While swimming, the cells at the posterior side lose their flagella and become granular resulting into amphiblastula. The anterior flagellated half now invaginates into the posterior non-flagellated half and the hemispherical gastrula settles down with blastopore pointing at downward direction.

15.2.2 Coelenterata :- Coelenterates are acoelomate, diploblastic and have tissue grade of body organization, central body cavity is called coelenteron or gastrocoel. These are marine as well as fresh water, reproduce both sexually as well as asexually. Following larval forms are involved in their lifecycle.

15.2.2.1 Planula Larva:- During developmental stages in the life history of *Obelia*, a free swimming ciliated larva called planula larva is developed which represents the gastrula stage in development. The planula larva has an oval body consisting of an outer layer of ciliated ectodermal cells and an inner solid mass of endodermal cells which later splits to mark the begining of the coelenteron. The larva exhibits the marked polarity with a broad anterior and a narrow posterior end. It also shows a marked histological differentiation having columnar ectodermal, sensory, nerve, gland cells, muscular processes and nematocysts. Planula larva of *Obelia* is similar to that of *Aurelia,* but there are some differences like planula of *Obelia* is without a blastopore and coelenteron. It grows into a simple Hydra like hydrula stage which produces directly by budding a new complete branching *Obelia* colony, while planula of *Aurelia* grows into a trumpet shaped scyphistoma



(A) (B)

Fig. Planula larva : (A) free swimming (B) attached to the substratum

15.2.2.2 Scyphistoma – The ciliated free swimming planula larva are attached with the substratum. The cilia are lost and a mouth opens at its free end (distal). The larva now becomes elongated and metamorphose into a small trumpet shaped, about 5 mm high, called as **hydrula** or young scyphistoma. Its proximal part is narrowed into a stalk like organ, attached to the substratum by an adhesive basal disc. Tentacles bud out around the mouth. Thus 16 long and slender tentacles are formed and the mouth becomes square in shape. (Fig.2)

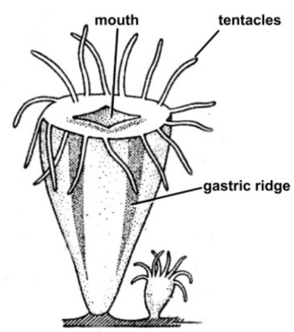
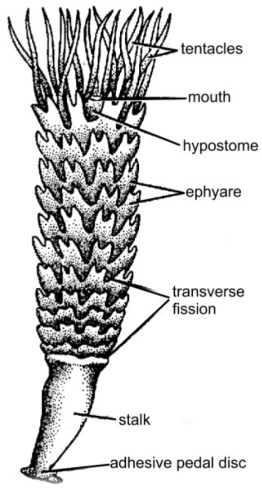


Fig. 2 Aurelia : A young Scyphistoma(Source: Invertebrate by Kotpal).

15.2.2.3 EPHYRAE :- In autumn or winter, the scyphistoma undergoes a remarkable process of budding or transverse fission called strobilation. The whole body develops a series of ring like transverse constrictions which gradually become deep and the organism resembles a pile of minute saucers or discs placed one above the other. At this stage the scyphistoma with a segmented body is called a **strobila** (Fig.3 A) and each of the segments is called ephyra larva. Ephyra is a young medusoid form with a well developed tetramerous symmetry. (Fig.3 B)The edge of its umbrella is greatly being produced into 8 arms or 8 bifid lobes. Each lobe is deeply notched to form a pair of marginal lappets. Each notch bears a small tentaculocyst between the marginal lappet. Manubrium with a mouth is present in the middle on the sub umbrellar surface.

Gastric radial, pre radial and inter radial canals are also seen. Ephyra larva swims actively in the water and metamorphose into adult *Aurelia*.



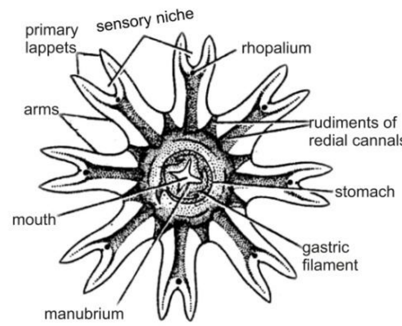


Fig 3 A) Aurelia: A Strobila **Fig 3 B)Aurelia: Free Ephyra**

(Source: Invertebrate by Kotpal)

15.2.3 Platyhelminthes :- Platyhelminths are acoetomate, triploblastic, Dorso ventrally flattened organisums and have organ grade of body organization, mostly parasitic and rarely free living. Generally Sexual reproduction is found. Due to endoparasitic in nature their life cycle is very complicated and completed through various larval stages. Particularly in case of liver fluke, there are five different types of larvae which are as follows.

15.2.3.1 MIRACIDIUM LARVA: It is the first in a series of larval stages of the life cycle of *Fasciola hepatica*. Externally, it is a minute (.07 mm long), oval, elongated, richly ciliated, active creature with its broader anterior end produced into a mobile and non ciliated optical papillae. The body is covered with flattened ciliated epidermal plates which are arranged in 5 rows.Beneath the epidermal plate is a five layered of sub epidermal musculature consisting of outer circular and inner longitudinal fibres below which is a layer of cells forming the sub epithelium. The epidermal plates, sub epidermal musculature and sub epithelium form the body wall of miracidium. (Fig.5)

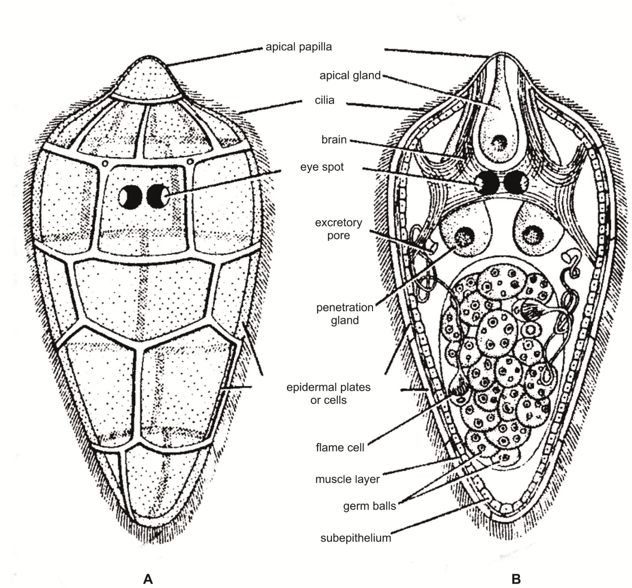


Fig. 5 Miracidium larva (A) External Morphology (B) Internal Structure(Source: Invertebrate by Kotpal)

Internally apical glands, cephalic or peneteration gland, x–shaped brain, two flame cells, rudimentary gut and germ cells are present in miracidium. Miracidium larva swims in search of an intermediate host which is *Limnaea truncatula* for about 4-30 hours. After getting the suitable host, it penetrates into tissues of snail by apical papilla. After 14 days it develops into the second larval stage i.e. the sporocyst larva.

15.2.3.2 Sporocyst Larva

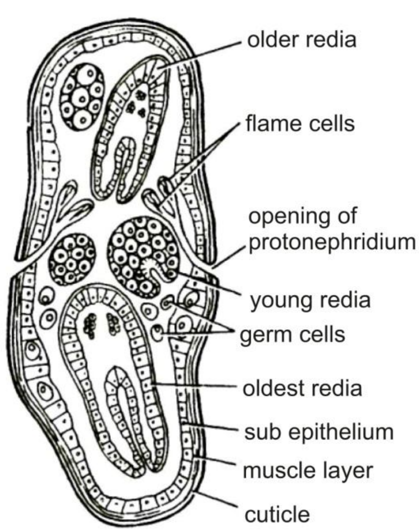


Fig. 6. Sporocyst (Source: Invertebrate by Kotpal)

Sporocyst is developed from the miracidium larva in the pulmonary chamber of snail. It looks like an elongated sac about 7mm long. The hexagonal cells and cilia which cover the body of miracidium are shed. Apical gland, cephalic glands, brain, eye spots and primitive gut of miracidium are degraded. It is covered by a cuticle membrane, body wall which consists of sub-epithelial cells, muscles and mesenchyme. Body sacs have flame cells and germ cells. (Fig. 6) These germs cells multiply and give rise to next larval stage known as Redia Larva.

15.2.3.3 Redia Larva

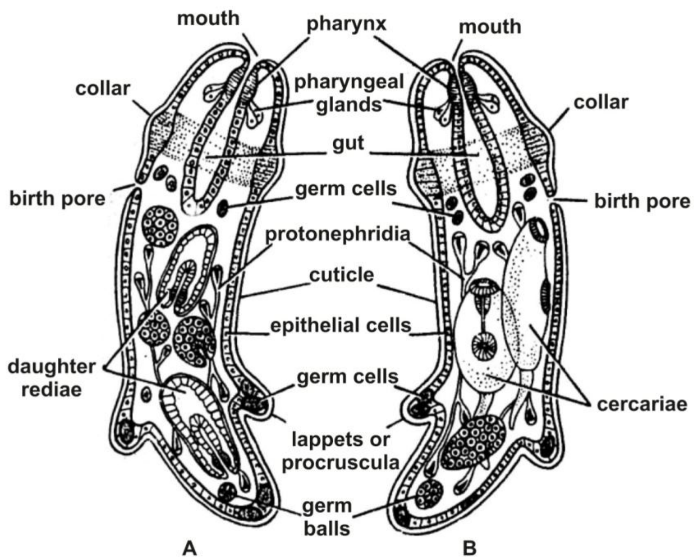


Fig.7. Redia Larva (A) Redia with daughter Redia (B) Redia with Cercaria (Source: Invertebrate by Kotpal)

Redia larva develops from the germ cells of the sporocyst. The body of Redia is elongated. Sac like anterior end bears the mouth leading into muscular pharynx, which finally leads into sac like intestine. Just behind the pharynx is a muscular ring like structure known as collar which helps in locomotion. Posterior region is also provided with two stumpy processes known as lappets which also help in locomotion. Just posterior to collar, a permanent aperture called birth pore is present. The space between the body wall and Intestine contains few germ cells which often give rise to second generation, the daughter rediae. (Fig.7) These Rediae give rise to new type of larva known as cercaria larva. Cercaria larva comes out from Redia through birth pore.

15.2.3.4 Cercaria Larva

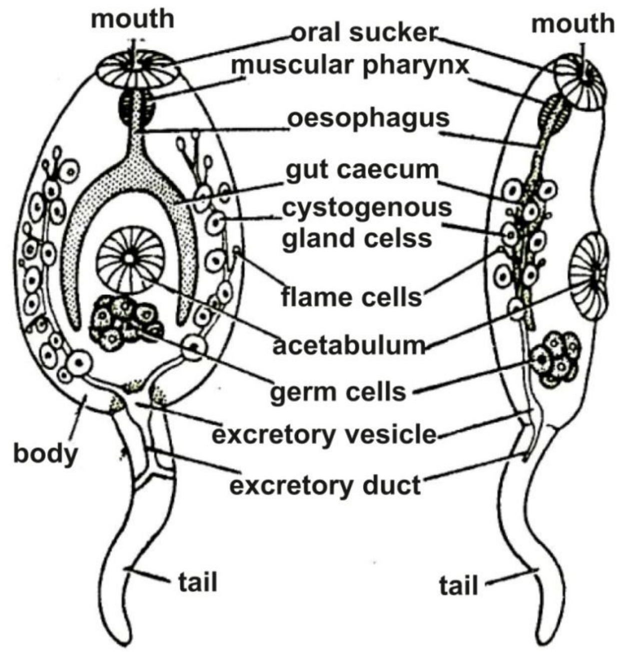


Fig : 8. Cercaria Larva (Source: Invertebrate by Kotpal)

Body of Cercaria is flat and oval bearing a tail. The whole body is covered by cuticle and body wall consists of muscle and mesenchyme. It has two suckers, an anterior oral sucker surrounding the mouth and a ventral sucker situated in the mid line of the body. Digestive system consists of mouth, muscular pharynx, oesophagus and inverted "U" shaped intestine. Body space is filled with parenchyma and few cystogenous glands on each side, which form the cyst of the future larva. Rudimentary reproductive organs are also present. (Fig.8) Cercaria larva comes out from the redia through the birth pore and also from the body of snail. It is a free swimming larva and after swimming for a short period, it attaches to the aquatic plants. Finally cercaria larva undergoes encasement and the encysted larva is known as metacercaria which is swallowed by the final host i.e. sheep.

15.2.3.5 Metacarcaria

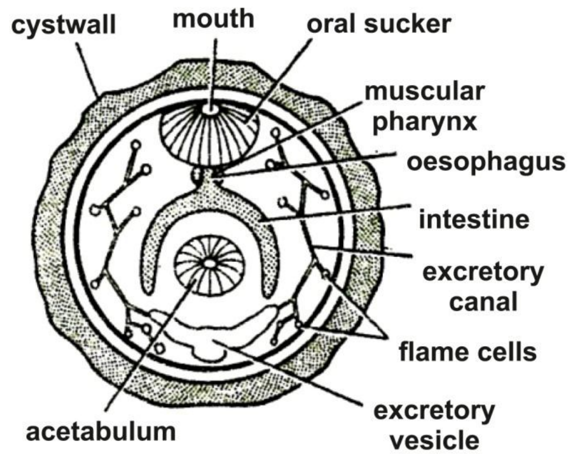


Fig. 9. Metacarcaria(Source: Invertebrate by Kotpal)

They are rounded and very minute in size around 0.2mm long. It is different from the cercaria larva in having a thick hard cyst and large numbers of flame cells, it lacks tail and cystogenous gland cells. Its excretory bladder opens directly through a single pore. Germ cells or the genital rudiments are present as such. The cyst of metacercacia provides protection against short period of desiccation. (Fig. 9) The larva developes into adult only inside its definitive host, when the host (sheep) eats such grasses on which these metacarcaria larvae are attached. Its cyst wall is dissolved in the proximal part of the intestine and then liberates the larva into coelomic cavity. Now it infects the liver, feeds on its tissue, and grows in size in five to six weeks. It then takes up its position in the bile duct, where it finally attains a sexual maturity and starts laying eggs (capsules).

15.2.3.6 Hexacanth and Onchosphere larva: During the embryonic development of *Taenia solium,* morula, at its morphologically posterior end, develops three pairs of chitinous hooks secreted by differentiated cells, called onchoblasts.(Fig.15) This six hooked embryo, called hexacanth, possesses a pair of large penetration glands. It is surrounded by two hexacanth membranes. The hexacanth, together with all the membranes surrounding it, is known as onchosphere. By the time onchosphere is formed the mature proglotid of tape worm detach (apolysis) and passes out with host's (man) faeces. The secondary host (pig), when feeds on human excreta, gets infected with onchosphere larva.

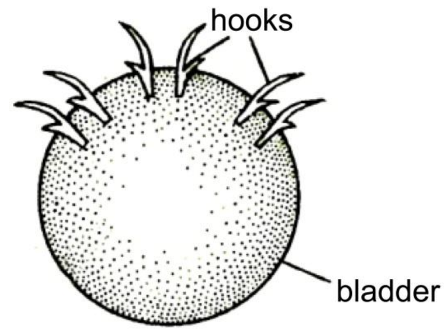


Fig.15. Hexacanth larva of *Taenia solium* (Source: Invertebrate by Kotpal)

15.2.3.7 Cysticercus or Bladderworm Larva: Onchosphere larva loses its outer membrane, becoming hexacanth, passes into the intestine, where it is attached to the wall with the help of hooks. Through the course of infection when hexacanth reaches the muscles, it changes into bladderworm. Hexacanth, now sheds hooks and grows in size of about 18mm. A central cavity appears as cells in that region breakdown. It enlarges and becomes filled with a fluid consisting mainly of blood plasma of the host. A scolex possessing suckers, hooks and rostellum at anterior end of bladder is formed and this stage is called as bladderworm. Bladderworm is of cysticercus type with large vesicle and one scolex. That is why the bladderworm is also referred as cysticercus. (Fig.11)

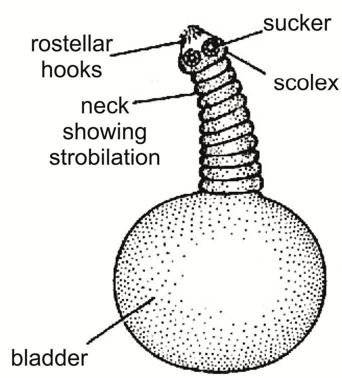


Fig.11. Cysticercus or Bladderworm Larva of *Taenia solium* (Source: Invertebrate by Kotpal)

15.2.4 Annelida: Annelidans are protostomate, schizocoelomate, triploblastic, dorsoventrally flattened and have organ grade of body organization. Reproduction is of sexual type, cleavage is spiral and determinate, larva when present, is Trochophore.

15.2.4.1 **Trochophore Larva:** Trochophore larva is characteristic larva of Polychaetes, molluscs and many other marine Protostomes. A typical Trochophore larva is top shaped with a tuft of cilia at the apical end. The distinguishing feature is a conspicuous girdle of cilia called the prototroch which rings the body about one third to one half of the distance from the apical tuft. The gut is a complete tube and the mouth opens just below the prototroch. In the Trochophore of many polychaete and some other groups, a second girdle of cilia, called the metatroch develops below the mouth and a third, the telotrochis found just below the anus at the posterior end. (Fig. 12)

Internally the old blastocoel remains as a large cavity between the gut and the outer Ectoderm. A pair of protonephridia are also present on either side of the gut. A cerebral ganglion as a brain rudiment is usually evident beneath the apical organ.

A fully developed Trochophore larva can be divided into three regions.

1. Prototrocal region consisting of the apical plate, the protoroch and the mouth region.
2. The Pygidium consisting of the telotroch and the anal region behind it.
3. The growth zone.

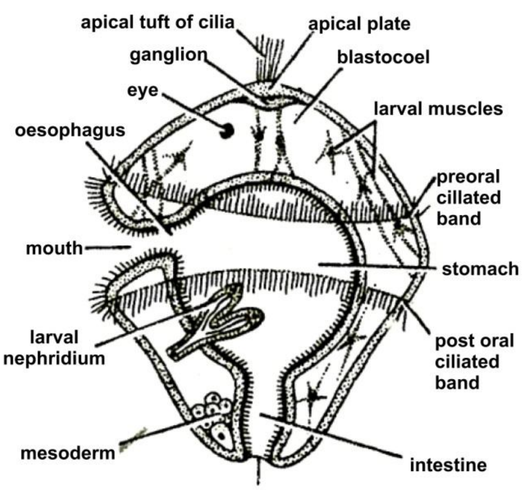


Fig. 12 A typical Trochophore larva(Source: Invertebrate by Kotpal)

15.2.5 Arthropoda:

15.2.5.1 Crustacea

Crustaceans show both direct and indirect development. In direct development (e.g., Palaemon, crayfish), the adult is attained by progressive growth and differentiation of the embryo, so that the newly hatched young resembles the parents in general structure. In indirect development, there is a larval stage which differs from the adult in many features and acquires adulthood through metamorphosis. Many of the crustaceans undergo indirect development, involving a wide variety of larval forms. Of these 3 main larval forms are nauplius, zoaea and megalopa. Intermediate stages receive different names such as metanauplius, cypris and protozoaea. Modified and distinctive forms of zoaea are given special designation, such as mysis of lobsters, phyllosoma of spiny lobster, and allima of squilla.

15.2.5.1.1. Nauplius. Characteristic of the class, nauplius is the simplest and commonest type of larva, found in most marine crustaceans and a few malacostracans. When development proceeds through many larval forms, the nauplius is the earliest and the basic larva. The body is minute with 3 indistinct regions, a single median eye, often referred as nauplius eye and three pairs of jointed appendages — the uniramous antennules, mainly the balancing organ; biramous antennae, principal locomotor organs and mandibles, which alongwith antennae may share for food collection. (Fig. 13) In branchiopods the nauplius develops straight away into the adult, but in mostly other crustaceans it may give rise to other intermediate larval forms, such as metanauplius, protozoaea, zoaea, mysis, etc.

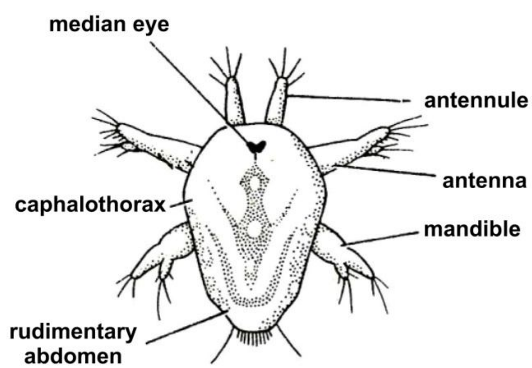


Fig.13. Nauplius larva of Cyclops(Source: Invertebrate by Kotpal)

15.2.5.1.2. Metanauplius. Metanauplius is the later nauplius instar and results by the process of moulting and growth. Its body is divisible into a broad cephalothorax and an elongated abdomen, terminating into a pair of caudal forks. Besides 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 and some notostracans (e.g., Apus) begin their life history with the free-swimming metanauplius larva. (Fig. 14)

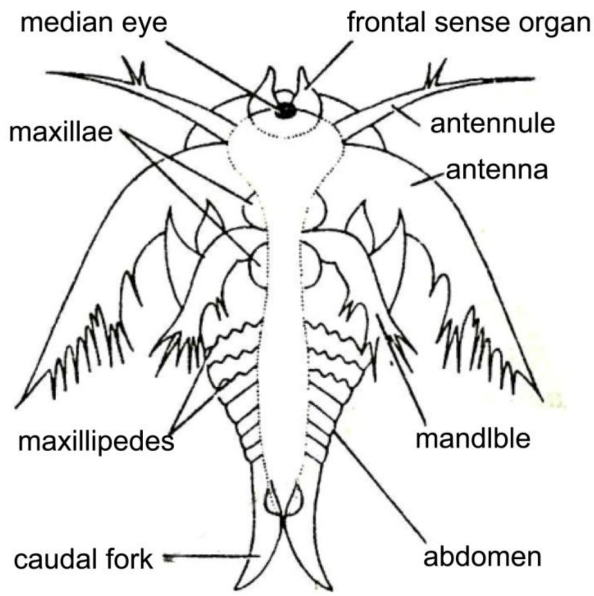


Fig.14. Metanauplius larva of Apus(Source: Invertebrate by Kotpal)

15.2.5.1.3. Protozoaea. In case of marine prawns (e.g., *Penaeus*), and sergestid decapods, the earliest nauplius, by growth and moulting, develops into a protozoaea larva. Its body is divisible into a broad segmented cephalothorax covered with a small carapace and a slender abdomen which is unsegmented and bear no appendages terminating in a forked telson. There is a single median nauplius eye and the appendages comprise of the antennules, antennae, mouthparts and first and second maxillipedes. (Fig. 15)The protozoaea later modifies into the zoaea. (Fig. 16)

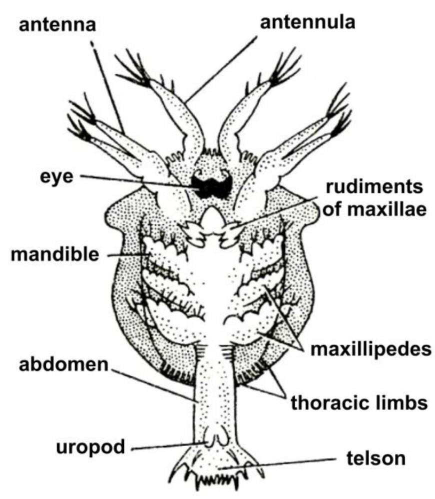


Fig.15. Protozoaea Larva of Euphausea(Source: Invertebrate by Kotpal)

15.2.5.1.4. Zoaea. In almost all marine decapods, except peneids and sergestids, hatching takes place at the *zoaea* stage (as in true crabs). Zoaea has a broad cephalothorax and a curved abdomen, which assists in swimming, is provided with a forked telson. Helmet-like carapace bears two long spines, a median dorsal and a *median rostrum, two lateral spines* are often met with. A pair of large stalked movable compound eyes are present. In addition to protozoaeal appendages, there appear rudiments of thoracic appendages. Biramous maxillipedes are used for swimming. (Fig.16)

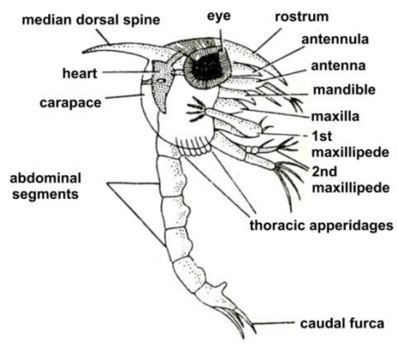


Fig.16. Zoaea larva of Crab(Source: Invertebrate by Kotpal)

15.2.5.1.5. Cypris. In Cirripedia (*e.g. Lepas, Sacculina*), the nauplius larva passes into the cypris stage. In this form the body and appendages are enclosed within a bivalved shell provided with adductor muscle as is seen in an ostracod adult, Cypris. Its modified antennules have cement glands at their bases. All other cephalic appendages with a compound eye only, except antennae, are present. Six pairs of biramous thoracic limbs are formed. It has abdomen with 4-5 segments. (Fig.17)

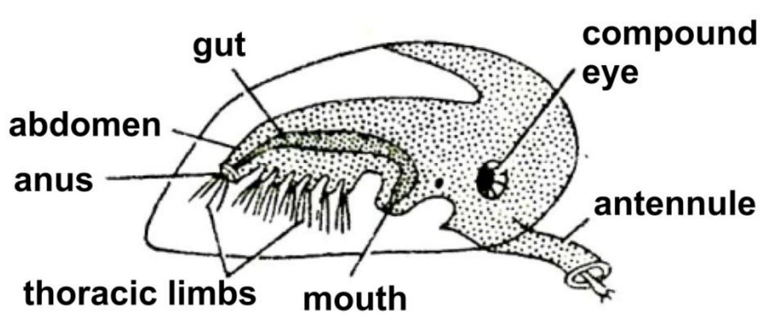


Fig. 17. Cypris larva of Lepas(Source: Invertebrate by Kotpal)

15.2.5.1.6. Mysis or Schizopod. In peneid decapods (e.g. penaeus) and lobsters zoaea is modified into Mysis or Schizopod larva. It bears 13 pairs of appendages and resembles adult Mysis. It has 5 pairs of posterior biramous thoracic appendages. Abdomen is posterior similar to that of adult with 5 pairs of biramous pleopods and a pair of uropods and telson. (Fig.18) In some lobsters mysis marks the begining of the life history as the naupleus and zoaea are passed within the egg but at the same time it marks the end of the life history of a prawn.

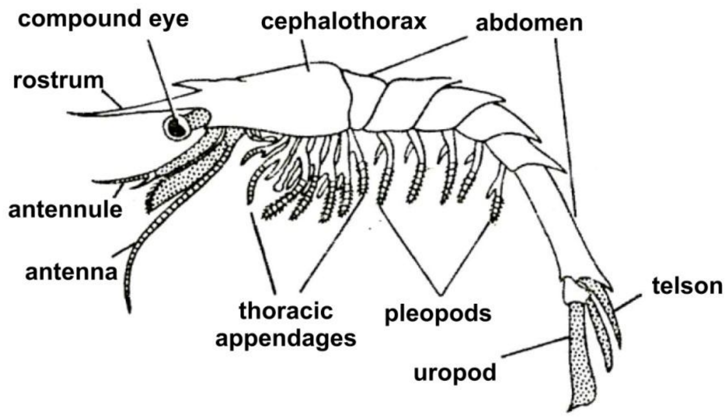


Fig. 18. Mysis larva of Penaeus(Source: Invertebrate by Kotpal)

15.2.5.1.7. Megalopa. In brachyuran decapods (true crabs), zoaea metamorphoses into the megalopa larva. It resembles, to some extent, the adult crab and possesses all 13 pairs of appendages. Abdomen bears 6 pairs of pleopods and is placed straight in line with cephalothorax.(Fig.19) In crabs nauplius stage is passed within egg which hatches as zoaea. it then by moulting forms megalopa to be metamorphosed into adult.

In hermit crabs, the *glaucothoe* corresponds to a megalopa with symmetrical abdomen and swimming pleopods.

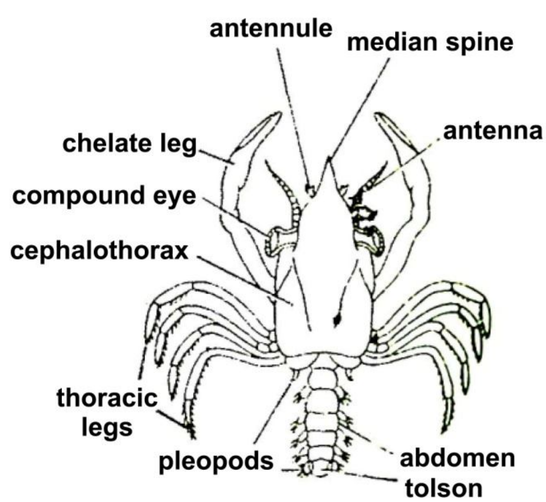


Fig.19. Megalopa larva of Crab(Source: Invertebrate by Kotpal)

15.2.5.1.8. Phyllosoma. Larva of Palinurus, the spiny crab or rock lobster, is called *Phyllosoma* or glass crab. It is a modified mysis stage. It is remarkably large, flattened, leaf like, delicate and glassy. Body is distinguished into head, a transparent thorax and abdomen. Eyes are compound and stalked. Out of six pairs of thoracic appendages, the first or maxillipedes are rudimentary, second are uniramous, third well formed biramous succeeded by rest 3 (4th, 5th and 6th) pair of long biramous legs. A segmented but limbless abdomen is present. Before reaching an adult stage, it undergoes several moultings. (Fig.20)

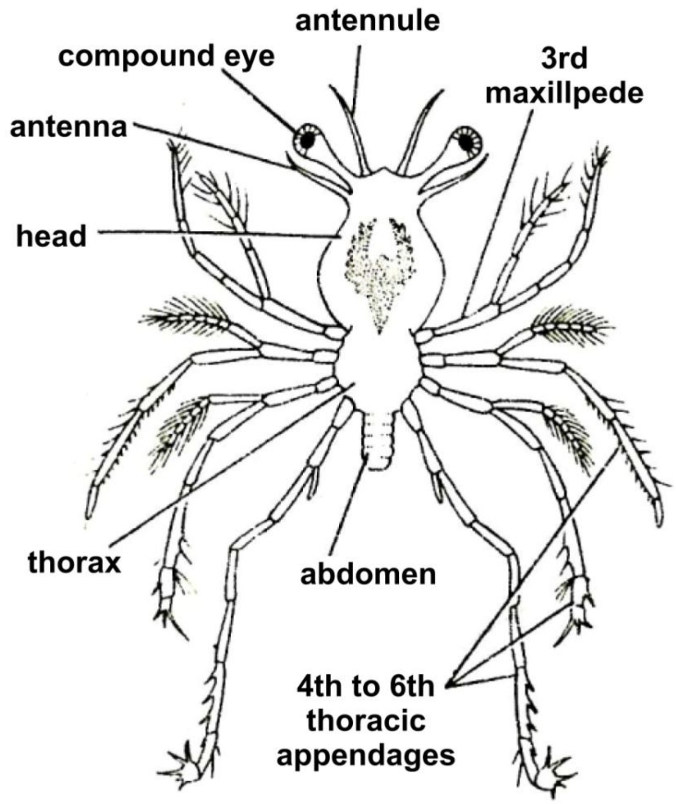


Fig.20. Phyllosoma larva of Palinurus(Source: Invertebrate by Kotpal)

15.2.5.1.9. Alima. It is modified form of zoaea found in some malacostracan (e.g. *Squilla*) which hatches from egg. It is a pelagic form with glassy transparency having a slender body. It hears short and broad carapace: It has all the cephalic appendages but only first two thoracic ones. A six segmented abdomen with 4 or 5 pairs of pleopods, is present. It differs from zoaea in having well formed second maxillipedes and the armature of the telson.(Fig.21)

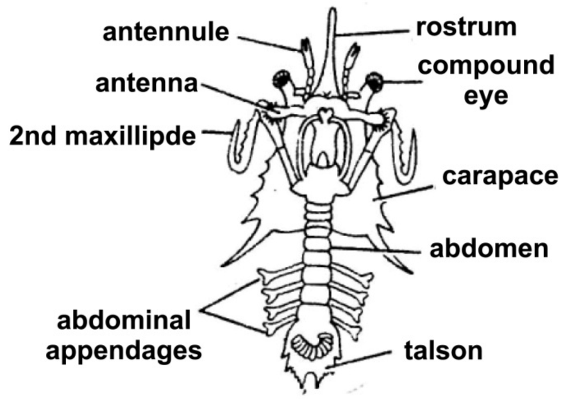


Fig.21. Alima larva of *Squilla*(Source: Invertebrate by Kotpal)

15.2.5.2 Insecta

Insects, which are primarily terrestrial forms, have necessarily lost any traces of whatever pelagic larvae may have been possessed by their unknown aquatic ancestors. The Plecoptera (stoneflies), Ephemeroptera (may-flies), Odonata (dragonflies), and Hemiptera (bugs), however provide examples of the establishment of aquatic habits in the nymph. This has been achieved by the secondary invasion of water from the land, with perhaps an intermediate stage of association with the damp earth at the edges of fresh water. Insects have developed a new type of larval history, one that presents, both in its origins and its functional significance an instructive comparison with those of aquatic invertebrates.

It has something been held that insect life histories are composed of a series of stages of progressive differentiation, a view which implies that the larvae have imperfectly developed adults. This is a misleading interpretation as larvae are evolved as a mode of life distinct from that of their adult stages. We have seen that this divergence permits many invertebrates to separate dispersal, in the larval stages, from reproduction, in the adult ones.

Ametabolous insects have series of young stages (instars) interrupted by periodical moults or ecdyses, eg. Thysanura (silver-fish). Here the only major difference between the young stages and the final adult instar is the appearance of the mature reproductive organs in the latter and hence they are termed ametabolous.

Hemimetabolous insects like cockroaches, have the young stages (nymphs) differ from the adults in lacking fully developed wings, although these are growing externally during the nymphal period. Nymphs also lack the sexual armature of the adults, but in other respects they resemble the abults quite closely; they possess for example, compound eyes. Thus the metamorphosis, although clearly discernible, is comparatively slight (hemimetabolous).

Holometabolous insects like Lepidoptera, have the more-advanced type of life cycle and is characterized by the young stages lacking compound eyes, and differ from the adults very markedly in many other respects, including body form, mouth parts, and often mode of life, which may be adapted to a habitat, remote in character from that of adults. The young stages are now called larvae, and the metamorphosis is a drastic one (holometabolous). Following types of larvae are found in life cycle of holometabolous insects:

15.2.5.2.1. Oligopod:- These are characterized by the presence of more or less well developed thoracic legs and the absence of abdominal appendages. However, in certain cases a pair of cerci or caudal processes are present. They may be further divided into two groups-

(i) **Campodeiform larvae**:- These are elongated with long or short sickle-like mandibles, and often well developed antennae and cerci. They have no compound eyes or ocelli. They are represented by members of the Order Ephemerida, Odonata, Neuroptera, Plecoptera and Strepsiptera.

(ii) **Scarabaeiform larvae :-** They are stout, sub cylindrical and C-shaped. They have short thoracic legs, soft fleshy body without abdominal legs. They are found in Order Coleoptera.

15.2.5.2.2. Protopod:- These larvae are found in some parasitic forms of order Hymenoptera, which emerge early in their embryonic development and have the internal systems poorly developed.

15.2.5.2.3. Polypod:- They have well defined segmented body with small thoracic legs and a number of abdominal pro-legs. The tracheal system is well developed and provided with a number of spiracles. The typicals of this type are seen in eruciform larvae of Order Lepidoptera.

15.2.5.2.4. Apodous:- They are degenerate type of larvae which are legless, robust, C-shaped or spindle shaped, with or without well developed head. They may be subdivided into three types on the basis of the degree of the head development and their shape.

(a) **Curculionoid :-** These are robust c-shaped with well developed head and also known as Eucephalus. It is common in most Coleoptera and some Diptera.

(b) **Muscoid:-** These are spindle shaped or cylindrical and trunctate. They have no obvious head capsule and therefore, sometimes also termed as Acephalus. This type of larvae are known as maggots which are commonly found in the flies of the Order Diptera.

(c) **Apoid:-** These are robust, with well developed head, cared for by daily feeding in provisioned brood cells. This is common in ants, bees, wasps and certain parasitic forms.

Mollusca:

Molluscs are soft bodied animals, schizocoelomate, triploblastic, protostomium, have organ grade of body organization. Body is covered by shell which may be internal or external, and usually marine. A close relationship with annelids is seen in the occurrence of trochophore larva in many forms, particularity in Archeogastropods (eg. Patella) and in the Bivalvia. It is found also in the development of Chitons (Amphineura) and Dentalium (Scaphopoda). This larva is rapidly transformed into a more complex stage, the veliger larva which is particularly characteristic of Gastropods and Bivalvia.

15.2.6.1 Veliger Larva

In this the prototroch is present at anterior side as a pair of ciliated lobes, an arrangement that considerably increases the support given to the larva and makes for a more vigorous and controlled locomotion. This development is explained by the advanced stage of differentation reached by the velliger. It has something like the form of a mollusca i.e. have a shell, a mantle cavity, a beginnings of the foot and sometime bearing an operculum. In the early life of Gastropod there is another complication that is more difficult to explain. This is the torsion which brings the originally posterior mantle cavity to the anterior end and leaves the originally left side of the palial complex on the right. (Fig.22)

Fig.22. Veliger Larva of Aolis

15.2.6.2 Glochidium Larva

Glochidium means the "Point of an arrow". It is a minute larva, 0.1 to 0.4 mm wide, it is found in the development of pelecypoda or Bivalvia. Shell consists of two triangnlar and porous valves, united closely and free ventrally. The ventral free end of each valve is produced into a conspicuous hook (curved) bearing spines. The shell encloses the body with the right and left mental lobes. The mantle lobes are very small and their margins bear on each side, three or four groups of peculiar brush like sensory bristles. The valves close together by the action of a single massive adductor muscle extending transversely between the two valves. The foot is not yet developed but glandular pouch which secretes a long sticky thread called larval byssus. With the help of the byssus it gets attached itself to the skin or gills or fins of a fish and leads a parasitic life for about 15 weeks to get their nourishment from them and live as a ectoparasite on fishes. The closure of valves seems to be due to chemical stimulation by salt escaping from the tissues of the fish. They soon become encysted by a overgrowth of the skin or mucus membrane of the host. The skin of the fish growing around the glochidium and forms the 'black head' and undergoes a peculiar metamorphosis to develop into young adult.

Significance of glochidium larva : -

The life cycle that includes a parasitic glochidium larva on host fishes has many advantages, besides affording protection and a means of nourishment it ensures for wide and more rapid dispersal.

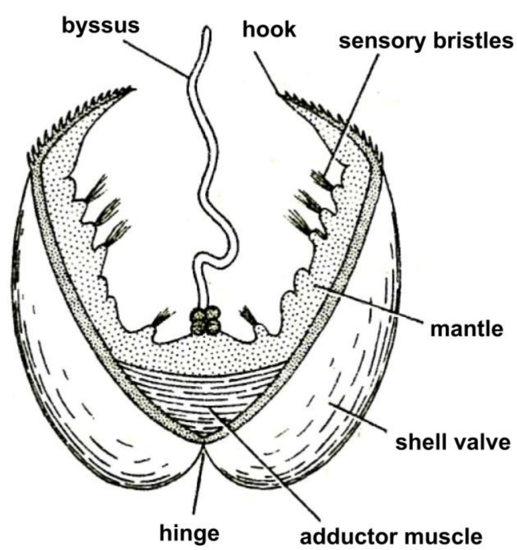


Fig.23. Glochidium larva(Source: Invertebrate by Kotpal)

15.2.7 **Echinodermata**

In the Echinodermata there is a range of modification found in the larval stages and their drastic metamorphosis.

15.2.7.1 Dipleurula Larva or Early Bipinnara : - It is the first laraval stage in all echinoderms. This larva is closely related with a hypothetical dipleurula larva. It is believed that all modern echinoderms have been derived from a dipleurula like ancestor. It is an egg shaped and bilaterally symmetrical. An anterior mid ventral ectodermal invagination called stomodaeum becomes continuous with the archenteron and form a larval mouth. The blastopore becomes anus (deuterostomium). The archenteron is differentiated into a digestive tract which is made up of oesophagus, stomach and intestine. The uniform ciliation of gastrula is replaced in dipleurula by two ciliary bands. A perioral band surrounding the mouth and an adoral band lying inside the mouth. The larvae feed actively on unicellular algae. The food is collected from the currents produced by the stomodaeal cilia. As the larva swims forward, with the help of perioral band of cilia it rotates clockwise.

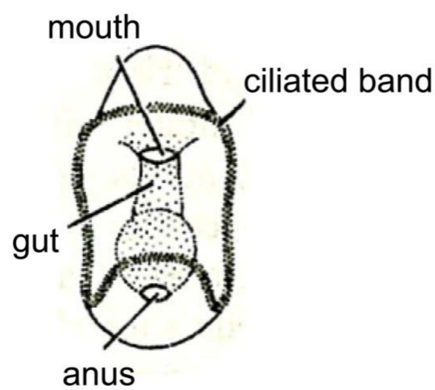


Fig. Dipleurula larva or Early bipinnaria(Source: Invertebrate by Kotpal)

15.2.7.2 Bipinnaria Larva

Bipinnaria larva is bilaterally symmetrical, swims and feeds freely. Dipleurula larva soon develops on its side a large preoral lobe, which becomes bordered by a preoral loop of cilia. Simultaneously, on each lateral side, it forms three lateral lobes which become bordered by a post-oral loop of cilia and gives rise to bipinnaria larva. (Fig.24)

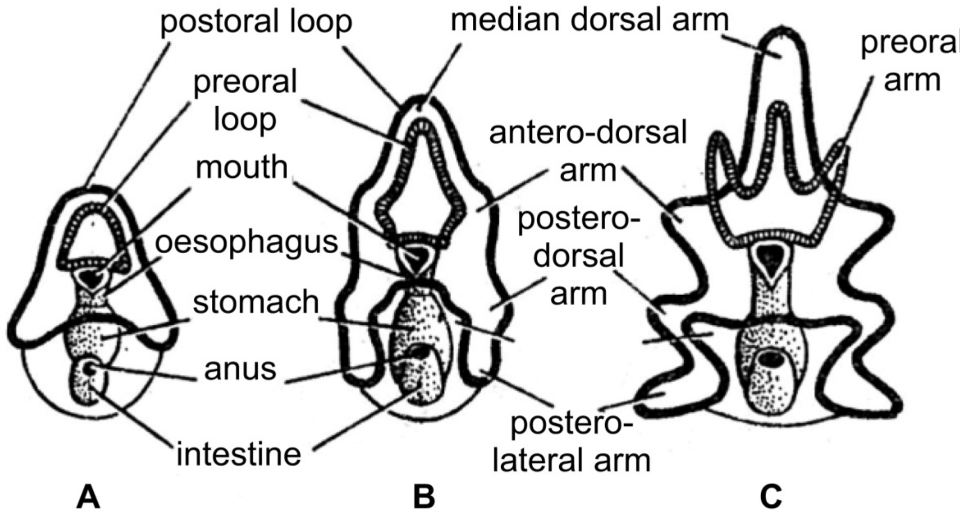


Fig.24. Stage in development of a bipinnaria larva.

(Source: Invertebrate by Kotpal)

15.2.7.3 BRACHIOLARIA LARVA

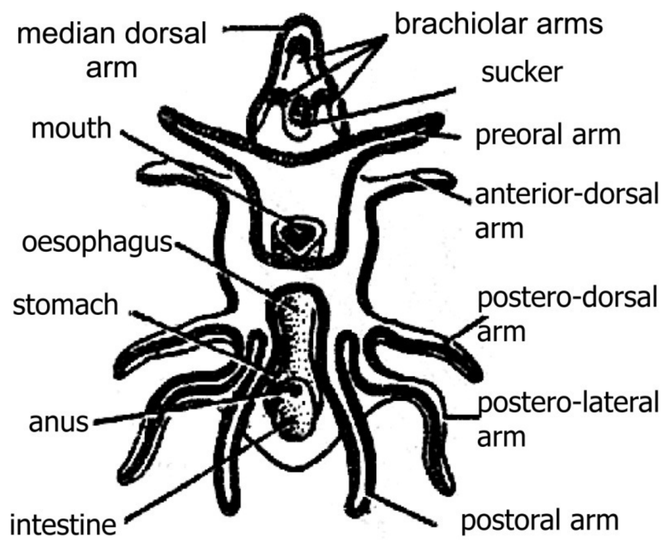


Fig.25. Brachiolaria larva(Source: Invertebrate by Kotpal)

Bipinnaria transforms into brachiolaria larva by conversion of preoral lobes into three short and non ciliated arms known as brachiolarial arms (one median and two lateral), each ending in adhesive disc or sucker. At the anterior and posterior end long, slender, ciliated contractile called as larval arms are also present. Dorso-median, two preoral arms and on lateral side antero-dorsal arms are present at anterior side. At posterior side post-oral arms, postero-lateral arms and postero-dorsal arms are also present. All the arms are supported by calcareous skeletal rods. The locomotion is by ciliated bands. Posterior parts have alimentary canal consisting of mouth, oesophagus, stomach, intestine and anus. The larva after leading a free swimming life for some time, with the help of adhesive disc of branchiolarian arms attaches to the substratum and metamorphoses by detaching the posterior part having gut and convert into a young star. (Fig. 25)

15.2.7.4 Ophiopluteus Larva (Ophiuroidea)

This is free swimming larva of brittle stars and similar to echinopluteus larva with the only difference that the former has fewer arms than the later. The posterolateral arms are longest and directed forward and ciliated bands accompany the edges of arms. Internally the larva contains coelomic chambers and archenteron. There is no attachment stage and starts metamorphosis while freely swimming. (Fig. 26)

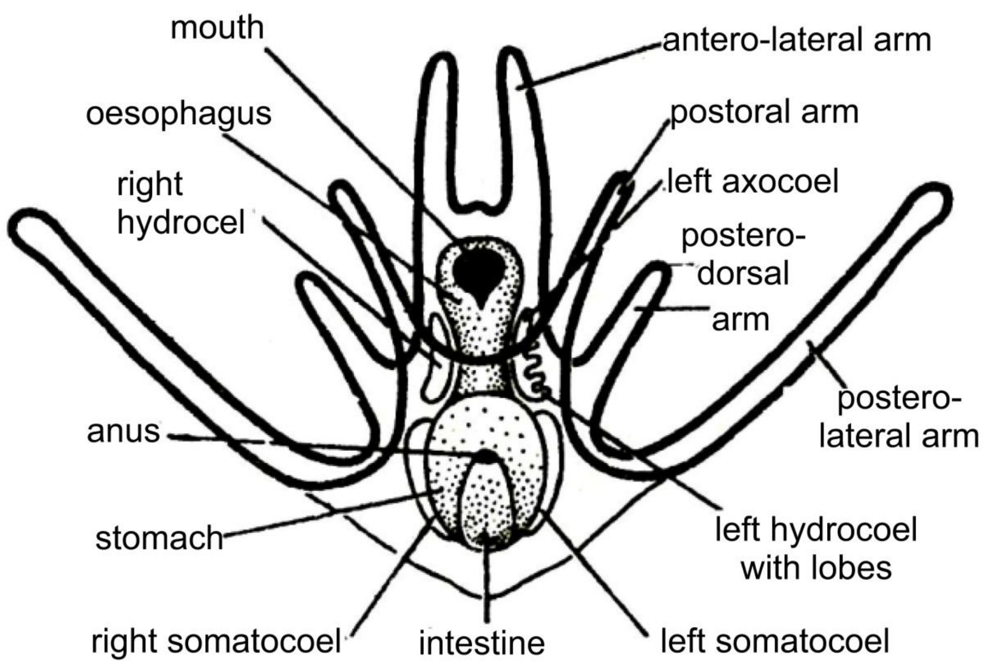


Fig.26. Ophiopluteus Larva(Source: Invertebrate by Kotpal)

15.2.7.5 Echinopluteus Larva (Echinoidea)

There are six arms namely, preoral, anterolateral, anterodorsal, postoral, posterodorasl and posterolateral. Postero-lateral arms are usually very short and directed backward. Tips of the arms are pigmented and supported with calcareous skeletal rods. Internally a vestibule and hydrocoel is formed at the oral side of the adult. Arms and podia are given off by the hydrocoel. Lantern is formed from left somatocoel. The metamorphosis is rapid, taking about an hour and there is no attachment stage. (Fig. 27)

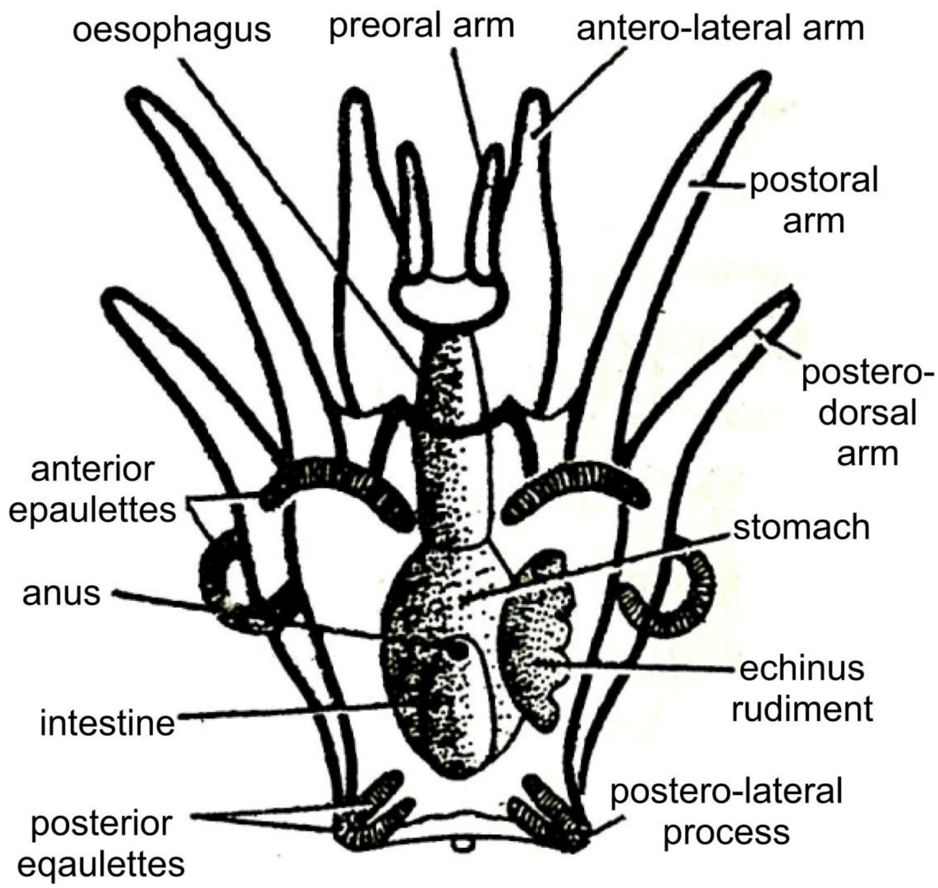


Fig.27. Echinopluteus Larva(Source: Invertebrate by Kotpal)

15.2.7.6 Auricularia larva (Holotothuria)

It is free swimming, transparent, pelagic, about 0.5 to 1 mm in length with preoral loop and anal loop of ciliated band. Internally, it has curved gut with sacciform stomach, hydrococel and stomocoels. (Fig. 28)

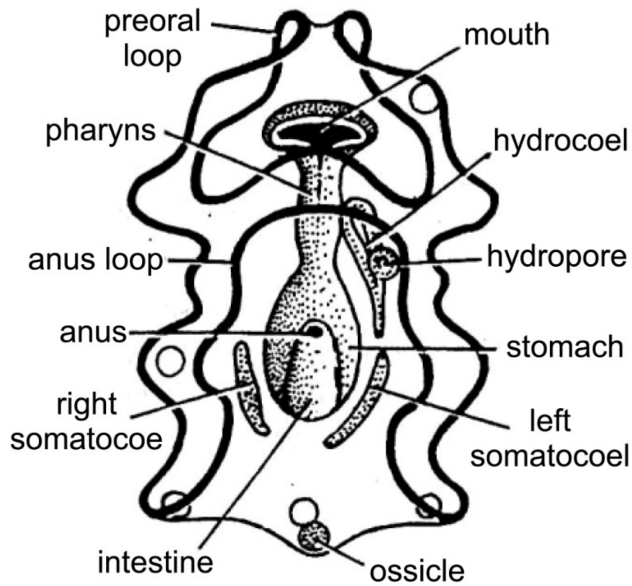


Fig.28. Auricularia larva(Source: Invertebrate by Kotpal)

15.2.7..7 Doliolaria or Vitellaria larva (Crinoidea)

It's subsequent history differentiates it from that of the bipinnaria, for it breaks up into sections that become arranged and extended to form three to five transverse ciliated bands that are thrown into anterior and posterior folds. There is an adhesive pit over the first ciliated band,near the apical plate in the mid ventral line. Between second and third ciliated band lies the stomodaeum or vestibule. Larva attaches and metamorphoses into cystidean or pentachrinoid larva. (Fig. 29)

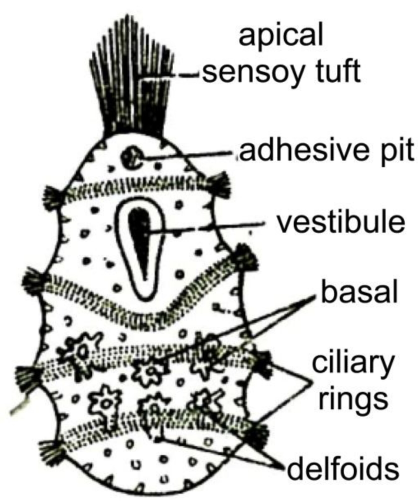


Fig.29. Doliolaria or Vitellaria larva(Source: Invertebrate by Kotpal)

15.2.7.8 Pentachrinoid Larva: When doliolaria larva attaches with the substratum, internal organs rotate at an angle of 90 degrees from ventral to posterior position. Now the larva with a stalk is known as pentachrinoid larva. This larva is also called as cystidean larva as it has resemblance with the extinct cystids. At first it can't feed for the stomodaeum is closed but within a few days it opens up. Finally after some further months of sessile life it breaks away from the stalk and begins the free swimming life characteristic of Antedon and most living crinoids.

15.3 Evolutionary significance of larval life

Larvae represent one of the classic problems of evolutionary biology and may explain how new body plans originate. It has often been suggested that many entirely unique body plans first originated as retained larvae of ancestral organisms. There is firstly the need of a delicate young organism to grow in conditions which satisfy its special requirements and avoid unnecessary competition with the adult, secondly there is the need to provide for dispersal of the species and thus to avoid over crowding. Finally there is the need to select its habitat that is suited to the requirements of the adults. Because of these varied functions larvae often become very highly specialized and all of them undergo some degree of metamorphosis.

According to the biogenetic law or recapitulation theory of Haeckel, every organism during its development (ontogeny) repeats to some extent its evolutionary history (Phylogeny). In other words, successive stages of individual development correspond with successive adult ancestors in the line of evolutionary descent. Due to its occurrence in the development of all Crustacean, the nauplius was previously regarded to be representing the ancestral form of Crustacea. It was presumed that from this ancestral form the present day crustaceans are evolved phylogenetically. In other words the other larval forms (Zoea, megalopa etc.) show stages of evolution of the higher crustacean from nauplius like Crustacean ancestors. But the old idea of recapitulation stands greatly modified now a days and the crustacean larval forms are now regarded to be the larval reversion to the types much simpler than the crustacean ancestors. The larval stages are helpful to determine the homologies and the affinities among various groups. The animals which pass through similar stages are closely related.

The trochophore larva is of great phylogenetic significance. Many animals such as polychaetes, sipunculans, bryozoans, molluscs, develop a trochophore larva, of course, with certain modifications. This has led some embryologists (e.g., Hatscheck, 1878) to suggest a theory (the so-called trochophore theory) that these animal groups have descended from a common hypothetical ancestor called trochozoon having trochophore-like features. The animal groups thought to have common ancestry may also include other phyla (Platyhelminthes and Arthropoda) which may have lost the trochophore somewhere in the evolution. There is a striking resemblance between certain rotifers and the trochophore larvae of some annelids, molluscs and others. This indicates that the rotifers and the animals closely related to the ancestors of the annelids, molluscs and the other groups.

Trochophore larva (theory) accounts satisfactorily in many ways for a common ancestor of the coelomate prostomia but not for the acoelomate groups. Many authorities, however, believe that the resemblance of trochophore larvae may be coincidental, the result of adaptive radiation and not of evolutionary significance or actual relationship.

A cladistic analysis of spiralian taxa (with special reference to polychaete annelids), based on a suite of adult and larval characters, is used to assess several hypotheses: (1) that the trochophore (in a strict sense) is a plesiomorphic form for the Spiralia; (2) that the strictly defined trochophore is plesiomorphic for members of the Spiralia such as the Polychaeta. The homology of each of the various separate ciliary bands of spiralian larvae, and features such as the apical tuft and protonephridia is also assessed. The results favour the conclusion that the trochophore, if defined as a feeding larval form using opposed bands, should not be regarded as an ancestral (= plesiomorphic) type for the Spiralia, or any other large taxon such as the Polychaeta or Mollusca. The evidence suggests that the various ciliary bands have differing evolutionary histories, and only the Echiura (possibly an annelid group) has members with the classical trochophore. The trochophore is re-defined as a larval form with a prototroch. This broad definition covers a wide variety of larvae, and matches the current usage more accurately than the restricted term. Features such as the neurotroch, telotroch and opposed-band feeding show convergence and reversals. The nature of the metatroch requires further investigation. The presence of a prototroch (and hence trochophore larvae) is used to identify an apomorphy-based taxon, Trochozoa, that includes the first ancestor to have evolved a prototroch and all its descendants.

Molluscs share a distant common ancestor with the annelid worms, an evolutionary heritage suggested by their larval form, called a **trochophore larva**, found in all molluscs and in certain marine annelids called polychaete worms. It's hard to imagine that a clam could be a close cousin to the earthworm, because most familiar molluscs have a highly modified body type. The ancestral mollusc probably resembled a chiton, a flattened worm like animal protected by a dorsal shell.

The bilateral symmetry of Auricularia of Echinoderm is similar to the Tornaria of Balanoglossus of Hemichordate in respect to their cleavage pattern, looping bonds enterocoelic origin of coelom and body cavity. The general likeness between Auricularia and Tornaria is so great that it can only be accounted for on the ground of genetic affinity. All the larval of echinoderms have a bilateral symmetry. Hence it is believed that the ancestor of echinoderms was a bilaterally symmetrical animal. According to Bather(1900), this ancestor was called dipleurula. But according to Semon(1988), this ancestor was called Pentaetulla. The pentaetulla ancestor was universally accepted. The radial symmetry of exhibited by Coelenterate and Porifera is primary. The radial symmetry in Echinoderm is superficial, concealing the true bilateral symmetry. The adult Echinoderms are more primitive than larvae because they possess the features of lower animals like Porifera and Coelenterala. The primitive characters are radial symmetry, absence of head, lack of anterior and posterior ends. Hence during Metamorphosis the advanced larva becomes a primitive adult. Hence the Metamorphosis is Retrogressive.

The larvae are helpful in the wide distribution of species particularly in those organisms which are sessile and less active and having the food reserves of eggs to a minimum. In addition, larval stages also help in finding common origin of classes, taxonomic and phylogenetic affinities.

15.4 Importance of Planula larva

The alternation of a sessile polyp and a planktonic medusa represents the phylogenetically primary mode of life cycle in the medusozoa. The polyp is involved in asexual reproduction, whereas the medusa generates planula larva by reproducing sexually. Thus planula larva and medusa both contribute to species dispersal. In many Hydroida, however free swimming medusa has been lost during evolution and planula are released from sessile gonophores. In these cases –provided the hydroid is benthic-, the larva represents the main dispersive stage. In addition to distribution planula also shows zooxanthellae symbiosis and photoaccimilation as coral. Planula larva also provide support to Lankester’s colonial theory. According to Lankester, the ancestral metazoan was a morula like solid colony named as planula.

15.5 Summary

Various larval forms like amphiblastula and coeloblastula in Porifera; Planula, Scyphistoma, Ephyrae in Coelenterata; Miracidium, Sporocyst, Redia, Cercaria, Metacarcaria, Hexacanth and Onchosphere, Cysticercus or Bladderworm Larva in Platyhelminthes; Trochophore Larva in Annelida; Nauplius**,** Metanauplius, Protozoaea, Zoaea, Cypris, Mysis or Schizopod, Megalopa, Phyllosoma, Alima larva in Crustacea; Oligopod, Protopod, Polypod, Apodous in Insecta; Veliger Larva, Glochidium larva in Mollusca, Dipleurula or Early Bipinnara, Bipinnaria, Brachiolaria, Pentachrinoid, Echinopluteus, Auricularia, Doliolaria or Vitellaria, Ophiopluteus Larva in Echinodermata. Their significance in lifecycle of an organism is to provide different habitat, distribution of sessile forms and taxonomic and phylogenetic affinities of different forms.

15.6 Glossary

- **Acoelomate:** Animal without body cavity (coelom).
- **Appendages:** A movable projecting part of the body.
- **Bivalve:** Possessing two shell valves.
- **Blastocoel:** Fluid-filled cavity of the blastula.
- **Blastopore:** Mouth like opening of the gastrula.
- **Choanocytes:** Known as collar cells that line the interior of sponges.
- **Cilia:** Numerous small hair like projections from the cell surface that beat in coordinated fashion.
- **Deuterostome:** Animals in which anus is developed from blastopore during development.
- **Diploblastic:** Possessing two germ layers ectoderm and endoderm.
- **Endoparasite:** A parasite living within the host’s body.
- **Enterocoelomate:** Animals having coelom formed by the outpouching of a mesodermal sac from the endoderm.
- **Flagella:** Long whip like cytoplasmic organelle.
- **Flame cells:** specialized excretory cell in invertebrates.
- **Gastropoda:** Taxonomic class of Phylum Mollusca known as snails and slugs.
- **Manubrium:** An extension from the subumbrellar surface of jelly fish.

- **Metamorphosis:** A marked structural change from a larva into an adult.
- **Oviparous:** Egg laying animals.
- **Ovovivparous:** Production of eggs that are retained and hatched within mother's body.
- **Protostome:** Animals in which mouth appears before the anus from blastopore during development.
- **Prototroch:** The ciliated band or ring characteristic of Trocophore larvae.
- **Rostellum:** a small protruberance of the scolex of a tapeworm which bear hooks.
- **Schizocoelomate:** animals with coelom formed by the splitting of embryonic mesoderm.
- **Trploblastci:** Possessing three germ layers, endoderm, ectoderm and mesoderm.
- **Viviparous:** An animal whose female gives birth to young.
- **Yolk:** Nutritive substance present in embryo.

15.7 Self- learning Excersise

Section -A (Very Short Answer Type)

1. Name the Scypha's larva.
2. Young stage of *Leucosolenia* is _______.
3. Bivalvia have _________ larva.
4. Echinopluteus larva belongs to the class _______ of echinodermata.
5. The sequence of larval stages in *Fasciola hepatica* is redia, cercaria, metacercaria and sporocyst. (T/F)
6. Cysticercus and bladderworm are two different larval stages present in *Taenia solium* .(T/F)

(Ans. 1. Amphiblastula; 2. Parenchymula; 3. Glochidium; 4. Echinoidea; 5. False; 6. False)

Section -B (Short Answer Type)

1. Give the significance of planula larva.
2. Write short notes on
   (i) Bladder worm
   (ii) Sporocyst
   (iii) Nauplius

(iv)Trocophore

(v) Ephyra

Section -C (Long Answer Type)

1. Discuss the evolutionary significance of invertebrate larval forms.
2. Give a detail account on crustacean larvae.

15.8 References

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