BIOLOGY

Chapter 1

The Living World

Introduction:

The living world around us exhibits a vast range of life-forms which make this planet a wonderful and amazing place to dwell. The variety of living organisms flourishing on earth is infinite. Their habitats, habits, behavior are also countless and surprising. Not only this, the habitats in which extreme type of environment is found as in cold mountains, hot deserts, hot-springs, salty lakes, etc. which seem to be challenging for most of the life forms, there also exists some unique kind of life-forms.

WHAT IS LIVING?

Living organisms show some unique and distinctive characteristics which help us in recognizing and differentiating them from other non-living things.

The characteristics which we observe commonly in all living beings are growth, reproduction, sensitivity. There are some other features which are not seen from outside but-we know that they are taking place inside the bodies like metabolic reactions, self-replication, self-organization, etc. These living organisms also have capability to interact and evolve which can be observed and studied in them.

Characteristics of Living Beings

Growth

Growth is a fundamental characteristic of all living organisms. It is regarded as an **intrinsic** property of living organisms through which they can increase both in mass and in number of cells, in their body.

All living organisms whether unicellular or multicellular grow by cell division. The pattern and duration of growth is distinct in different organisms, like in plants, growth can occur throughout their life span whereas animal have only a limited period of growth, in their life span.

In unicellular organisms like bacteria, Amoeba, growth occurs by cell division and such cell division also leads the growth of their population. Although, by such process of cell division reproduction of the individual also occurs Hence, growth and reproduction are **mutually inclusive event,** in unicellular organisms. One can observe, cell division in unicellular organisms like bacteria, in-vitro (outside the body of an organisms), i.e., in a test tube cell Petridis in an artificial medium, under microscope and can even count number of cells, increased during in manually. In higher animals and plants, growth and reproduction are linked but are **mutually exclusive events** However, cell division not only occurs in living organisms at time of growth and reproduction but also during maintenance to replace lost cells due to some injury, etc. from the body. Hence, to maintain original size shape and structure of a body, new cells are formed by division in various living beings.

Hence, growth involves both increase in mass and number of cell which takes place from inside the body of living organisms and is irreversible. On the other hand, non-living objects can also be seen growing like snow mountains grow by addition of snow on them, crystals increase in size by addition of some material from and outside source. So, we can say in non-living objects growth is extrinsic as compared to intrinsic growth in living organisms. Therefore, non-living objects can increase their mass by accumulation of material on surface by any external agency which can be reversed.

Growth, therefore, cannot be taken as defining property of living organisms, though it takes place in all living organisms and is absent in dead organisms. Growth is a characteristic of all living organisms, when all the conditions are well-understood properly examined from a scientific point of view.

Reproduction

Reproduction is one of the fundamental characteristics of living organisms. It can be defined as the production of new individuals of same kind by the grown-up individuals.

It is the characteristic exhibited by living organisms, which can produce new young ones of their own kind. There are two modes of reproduction – asexual and sexual. In asexual mode, new individuals are produced from specialized or any unspecialized part of a single parent (i.e., with or without the involvement of gamete formation). For instance, unicellular organisms like bacteria, algae or Amoeba divide by **fission** to produce new individuals. In such processes, parent body undergoes division to form two or more individuals, i.e., number of cells increases. Hence in unicellular organisms' reproduction is synonymous with growth.

In lower organisms like yeasts and Hydra budding take place in which new individuals are produced by the formation of an outgrowth known as **"bud"**. These buds first grow on parent's body, and then separate from it, to give rise new individual. **Fragmentation** is also a mode of asexual reproduction, as in this, body of an organism (parent body) breaks up into two or more parts (known as fragments) each of which grows into a new individual. It is also quite common in filamentous algae, fungus, bryophytes (at peritonea stage which occurs during life cycle in mosses). Planarian (flat worms) exhibit an extraordinary ability to regenerate new planarians develops by splitting of parent planarian body either lengthwise or transversely. In higher organisms like plants, animal's sexual mode of reproduction is quite common which involves formation of gametes (i.e., sex cells) from two parents of opposite sexes but same species. These gametes then fuse to form Zygote (2n) which develops to form a new organism of same kind.

Hence, reproduction is shown by all living organisms except a few which are either sterile or infertile, like mule, worker-bees, infertile human couples, etc., do not reproduce at all. So, these cannot produce their offspring but show all other characteristics of living organisms. Although, no non-living object can replicate itself by its own, i.e., power of replication or production of new individual of their own kind, is totally absent in them.

Hence, reproduction can be regarded as characteristic of living organisms but it is not their exclusive defining characteristic.

Metabolism

All living organisms are made up of chemicals. These chemicals may be small and large, belonging to various classes, sizes, functions etc. These bimolecular are constantly synthesized and broken down into some other bimolecular in the body of living organisms through various kinds of reactions.

Such thousands of chemical reactions which occur inside living organisms during various processes like photosynthesis, respiration, etc., help them to maintain their living state. The sum total of all the chemical reactions occurring in the body of living organisms is known as **"metabolism",** e.g., synthesis of proteins from amino acid, whereas those metabolic processes in which large molecules are broken down into smaller are known as **"catabolism",** e.g., sugars broken down into molecules of water and carbon dioxide, to liberate energy, i.e., ATP.

On the other hand, non-living objects do not show metabolism. So, metabolism can be regarded as defining feature of all living organisms. Although, some of these reactions can be made to occur outside the body (in-vitro) in cell free system. These reactions occurring outside the body is not living but are living reactions.

Hence, the way cell performs all its functions or processes to organize or constitute the body of an organisms (cellular organization) is unique and that can be regarded as **defining feature** of all life forms.

Consciousness

Most obvious and technically complicated feature of all living organisms. All living organisms are able to detect changes, i.e., sense their surroundings and can also respond to them. This is known as sensitivity which is defined as the ability to detect changes in the environment and to give response towards it accordingly any change that can be detected by an organism is called stimulus. This can be physical (like intensity, duration direction of light, sound, change in temperature, duration of day length, i.e., photoperiod, etc.), chemical (like acids, pollutants, etc.) or biological (like other organisms).

All organisms from the prokaryotes like bacteria to the complex eukaryotes like plants, animals and fungi can sense various changes up to variable degrees in their surroundings. They can also respond by showing movements or behavioral changes in respect to stimuli. For instance, some plants like soyabean, radish etc. or animals like sheep, goat, horse etc. breed or reproduce at specific seasons only, like in winters, summers autumn. Hence, they are known as seasonal breeders as their reproductive behaviour changes with lengths of day i.e., photoperiod. Therefore, they mate or reproduce during their specific breeding season only. Plants are sensitive to external factors like light, water, temperature, pollutants and other organisms etc.

Besides, human being is the only organism, who is aware of himself. He has self-consciousness too with awareness of the surroundings. He can relate his mind to the changes taking place in the world. He is an intelligent animal with thoughts, feelings and self-hood.

Sensitivity or awareness is regarded as **defining property** of living organisms as non-living things do not have power of sensing their surroundings and give response according to it. However, patients lying in coma in hospitals virtually supported by machines which replace heart and lungs are neither living nor dead otherwise brain-dead.

All living phenomena are due to underlying interactions. Properties of tissues are not present in the constituent cells but arise as a result of interactions among the constituent cells. Similarly, properties of cellular organelles are not present in the molecular components the organelle. These interactions result in emergent properties at a higher level of organisation. This phenomenon is true in the hierarchy of organisational complexity at all levels.

Therefore, the living organisms can be said to be self-replicating, evolving and interactive systems capable of responding to external stimuli.

All living organisms - present, past and future are linked to one another by the sharing of the **common genetic material, but to varying degrees.**

DIVERSITY IN THE LIVING WORLD

A large variety of living organisms such as herbs, shrubs, trees, insects, dogs, birds, cats or other animals and plants are easily seen around us. Also, there are many other organisms which are present around us but we cannot see them with naked eyes like viruses, bacteria etc. These are visible only under microscope.

Although, when we consider vast areas like forest, desert, plateau etc. we find that number and kinds of living organisms increase many folds. These different kinds of plants, animals and other organisms are referred to as **'Biodiversity'** of this earth.

Biodiversity is the number and various kinds of organisms found on earth. It stands for the variability found among living organisms inhabiting this world. Diversity differs from place to place as each habitat has its distinct biota (i.e., life). So, every time we explore some new or even old areas, new organisms are found or discovered. It is so because environmental conditions of the area vary with time as well as the range of tolerance of species also varies which determine whether or not a particular species can occur in that area.

Hence, **biodiversity (Greek word bios = life; diversity = forms) or biological diversity** can be defined as the vast array of species of micro-organisms, algae, fungi, plants, animals occurring on the earth either in the terrestrial or aquatic habitats and the ecological complexes of which they are a part.

According to IUCN (International Union of Conservation of Nature and Natural resources), currently known and described species of all organisms are between 1.7-1.8 million. There are millions of plants, animals and other organisms in the world that cannot be recognized, studied or described by an individual on its own. As with recognize the plants or animals in our own area by their local names, which vary from place to place even within a city state or country as the persons inhabiting in different regions have different languages and perspective Hence there is need to standardize the names of all living organisms after proper identification, in order to study such diverse life forms. Therefore, for better understanding of biodiversity scientists have established a definite system of principles, procedures and terms which identifies categories and assigns specific name to each and every organism known to us. Such systems are acceptable to all biologists all over the world.

The scientific need for simple, stable and internationally accepted systems for naming the living organisms of the world has generated, a process called "**Nomenclature**". And, before assigning a specific name to and organism one should determine or know its kind or features correctly, so that one can identify it in each and every part of the world. This is known as **"identification".**

Rules and Recommendations of Nomenclature

Various biologists follow a definite procedure or criteria while studying these variety of organisms which include – **identification nomenclature** and **classification**. Their study is also facilitated by agreed principles and criteria set by biologists all over the world. Likewise, the set of rules and recommendations dealing with the formal names of plants is given or set in **International Code for Botanical Nomenclature (1CBN)**, while the rules of scientific naming of animals is assigned in **International Code for Zoological Nomenclature (ICZN)**. Such names which are kept by consent of scientists under codes set by ICBN or ICZN are known as **scientific names**. These are universally accepted and each species has only one name, i.e., they are unique for every individual species, Also, all the people all over the world are able to correctly identify the name of various living organisms, describes to them so these names avoid any kind of ambiguity in names of variety of organisms. Similarly International Code for Nomenclature of Bacteria (ICNB), International Code for Nomenclature of Cultivated Plants (ICNCP) and International Code for Virus Classification and Nomenclature (ICVCN) also exists.

Binomial Nomenclature

All biologists follow internationally agreed and accepted codes of rules or principles while assigning scientific name to known or newly discovered organisms. Binomial nomenclature for scientific naming of organisms was developed by **Carolus Linnaeus**. This system provides distinct and proper scientific names to variety of organisms. Each name has two parts, i.e., the first part comprises of its **generic name**, while the second part is the specific epithet. This naming system which uses two-word format is universally accepted and used, as it is more convenient to understand and follow.

Rules of Binomial Nomenclature: Some universal rules of Nomenclature framed under codes of ICZN, 1CBN, etc. are as follows:

1. Biological names are generally taken from Latin language irrespective of their origin. New names are now derived either from Latin language or Latinized.
2. Each organism is given only one name consisting of two words. The first word in a biological name represents its genus while the second component denotes the specific epithet.
3. The scientific name is printed in italics or underlined separately when handwritten to indicate their Latin origin.
4. The first word denoting genus starts with a capital letter, while the specific epithet starts with a small letter.
5. The name of the author or discoverer is written after specific epithet in abbreviated form. For example, Mangifera indica Linn, it indicates that this species was first described by **Linnaeus**.
6. All the three words (generic name, species epithet and author citation) collectively form **binomial epithet**.
7. **Principle of priority:** It is the most important of all the rules of ICBN. If first name given to the organism is valid (in terms of rules), that will be considered at the first preference. Any other valid name given after that will be considered as synonym. No names are recognised prior to those used by Linnaeus in 1758 in the 10th edition of **Systema Naturae** for animals and 1753 for plants in Species Plantarum.

Method of writing biological or scientific name can be memorized as

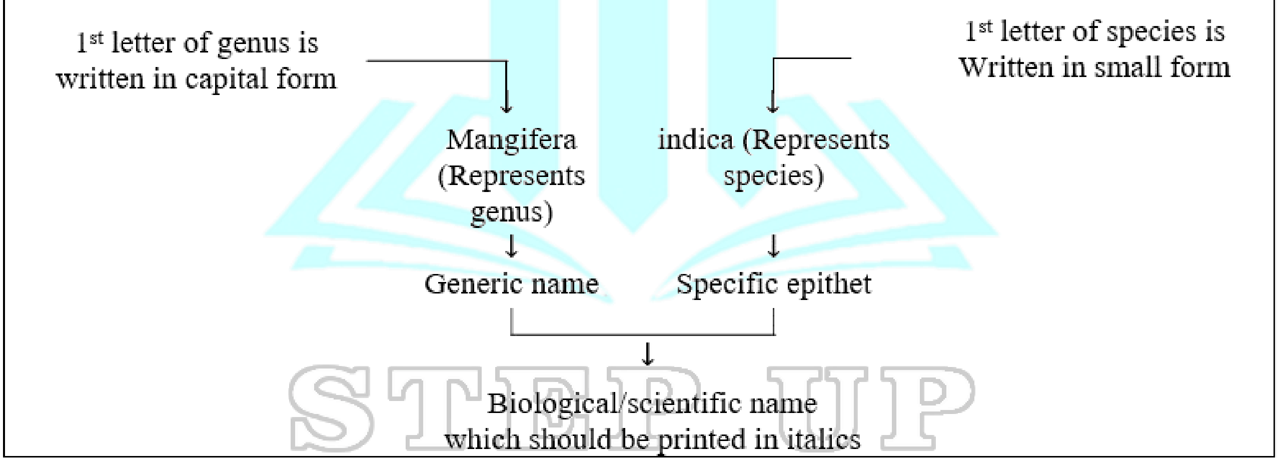


Table shows common and scientific names of different common plants and animal

Common names	Scientific names	Generic names	Specific epithet
Human	Homo sapiens	Homo	Sapiens
Lion	Panthera leo	Panthera	Leo
Dog	Canis familiaris	Canis	Familiaris
Onion	Allium cepa	Allium	Cepa
Wheat	Triticum aestivum	Triticum	Aestivum
Brinjal	Solanum melongena	Solanum	Melongena
Rose	Rosa indica	Rosa	Indica
Pigeon	Columba livia	Columba	livia

Need for Classification

As we know that a huge variety of plants, animals and other organisms with different form and structures exist on this earth. Therefore, it is impossible to study all of these variable creatures individually. Hence, to makes their study easier, simpler, we have divided them into different ranks or categories on basis of some similarities and differences found among them. Thus, in spite of great diversity, organisms are categorised and arranged in hierarchical series of groups and subgroups, on basis of some easily observable characters. Hence, classification categorizes every organism known to us into specific scientific arrangement to make its study easier.

Classification

Once the organism is identified and given a name, it is grouped along with its similar ones, so that its study becomes easier and simpler.

Biological classification is the scientific arrangement of each and every organism, identified and described in a hierarchical series of groups and sub-groups. This is done on the basis of similarities and differences in their traits (or characters) found in them. The process of categorising different organisms, on the basis of some easily observable characters is known as "**Classification**".

When we say, wheat, dog or rat, etc., we recognise each of them with its specific characters and are able to discriminate it from others on the basis of some other characteristics. These specific characteristics shown by the specific organism help us to assign a category to it. The specific term for these categories is "**taxa**", Hence, all living organisms can be classified into different taxa on the basis of specific characteristics exhibited by them. The branch of science which deals with the study of principles and procedures of classification is known as **"Taxonomy".**

The **classical taxonomy** is based on observable morphological characters whereas **modern taxonomic studies** are based on some essential features like study of both external and internal structure of organisms along with cell structure, development process and ecological information of organisms.

Hence, characterization, identification, classification and nomenclature are processes that are basic to taxonomy.

Taxonomic studies are not recently started but are done from very ancient times by humans, as he is curious about nature. So, he is always interested to know more and more about the nature and the variety of organisms found in it. Not only this, he also exploits some organisms vastly studied, for his own benefit. For instance, early human beings need to find sources of food, clothing and shelter for their survival. Later, they classified them on the-basis of their usage. In Vedic literature, 740 plants and 250 animals are being identified and classified. Aristotle (384-322 BC) divided living beings into animals, human beings and plants.

Human beings had not only studied different kinds of organisms but also tried to find out relationships among them. This led to the development of a new branch of study in science field, known as "**Systematics**". The word systematics is derived from Latin word "**Systema**" which means systematic arrangement of organisms. It was first used by Carolus Linnaeus in the title of his book published as "**Systema Naturae**". Systematics is wider field of science as with identification, nomenclature and classification, it also takes into account evolutionary relationships between various organisms. "**Systematics**" is the science which deals with diversity of organisms and all their comparative and evolutionary relationships amongst them.

Taxonomy	Systematics
1. Derived from two Greek words 'taxis and 'nomos'.	1. Derived from Latin word 'systema'.
2. Includes characterization, identification, nomenclature and classification of organisms.	2. Includes characterization, identification, nomenclature, classification of organisms along with their evolutionary study.

TAXONOMIC CATEGORIES

The process of classification of living organisms is not a single step process but it involves a number of steps, i.e., hierarchy of steps in which each step represents a rank or category. Since the category is a part of overall taxonomic arrangement, it is called "**taxonomic category"** and all categories together constitute the taxonomic hierarchy. Therefore, each category is referred to as a unit of classification. It also represents a rank in taxonomic hierarchy.

Taxon (plural: taxa) represents any level of grouping of organisms based on certain easily observable common characteristics like insects represent a group of organisms which share some common features like three pairs of jointed legs, hence insects can be uniquely recognised and classified. So, they were given a definite rank or category in taxonomic hierarchy. Likewise, birds represent that group of organisms which have feathers, beak, hollow bones, etc. due to which they are kept in separate rank or category in taxonomic hierarchy.

We can memories this, by remembering that each rank or taxon represents a group of organisms which share some unique features among members of their group or category which are distinct from organisms kept in various other ranks or taxon. Hence, these taxonomic groups or categories form distinct biological entities and should not be thought as random aggregates of animals based on their morphological features.

Diverse kinds of organisms known to scientists are studied from taxonomical aspect which led to the development of some definite categories. These definite categories or ranks in classification of plants animals and other organisms are:

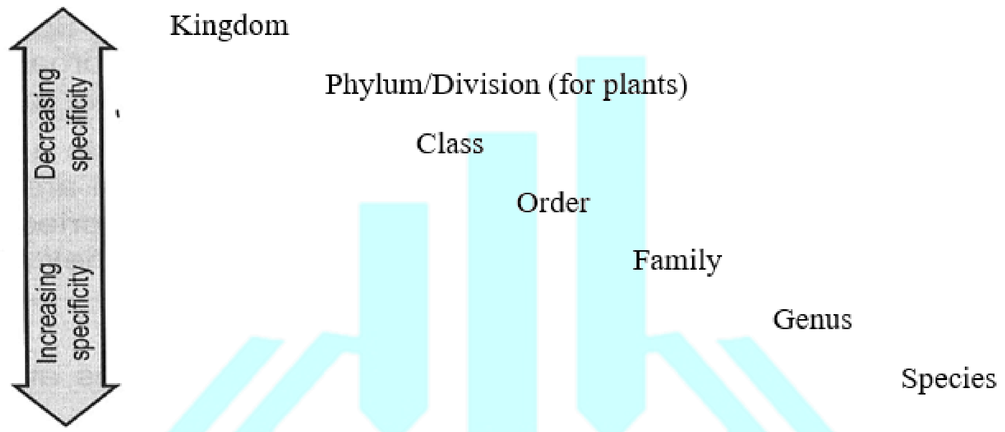
1. Kingdom
2. Phylum (for animals) or division (for plants)
3. Class
4. Order
5. Family
6. Genus
7. Species

These **seven obligate categories** in which all living organisms are classified are arranged in a **descending sequence** starting from kingdom up to species or in an ascending order from species to kingdom the number of similar characters of categories decreases from lowest rank, i.e., species to highest rank, i.e., kingdom.

Specificity decreases when we go from species to kingdom, i.e., the higher the category, lesser will be the number of similar characteristics of organisms belonging to that category, while when we go from kingdom to species, i.e., in a descending order the number of similar characteristics of organisms increases, i.e., specificity increases. In taxonomic hierarchy, taxonomic groups, i.e., taxa are arranged in a definite order, from higher to lower categories and in which s **pieces serves as the basic and lowest category**.

To categories an individual or group of organisms in a definite rank, we should have all the basic knowledge of its characteristics. This would help us in identifying the similarities and dissimilarities among the individuals of the same kind of organisms as well as of other kinds of organisms. Here, we will explain all the seven broad or obligate categories of taxonomic hierarchy.

However, taxonomists have also developed some sub-categories like sub-phylum or sub-division, etc. in this hierarchy to make this arrangement more transparent and scientifically useful.



Taxonomic categories showing hierarchical arrangement in descending and ascending order.

Species

It is a natural population of individuals or group of populations which resemble one another in all essential morphological (i.e., body form, size, shape, etc.) and reproductive characters so that they are able to interbreed freely in nature to produce fertile offsprings. On the basis of taxonomic studies, a group of individuals/populations with fundamental similarities are referred to as **species**. A species can be easily distinguished from other closely related species on the basis of their distinct morphological differences. Let us consider, Solanum tuberosum (i.e., potato), Canis familiaris (dog) and Panthera leo (lion). In all these three names, i.e., tuberosum, familiaris and leo represent the species, while the first words or names Solanum, Canis and Panthera represent the genus, which is next higher taxon than species in the taxonomic hierarchy.

Due to the similarities in some morphological features are kept. In a genus. For example, Solanum has another specific epithets than tuberosum, like nigrum and melongena. Canis has another specific epithets than familiaris like lupus and aureus. Panthera has another specific epithets than leo like tigris and pardus.

All the species represent the different organisms which are kept in the same genus due to some similarities in their morphological features but are assigned to different specific epithet due to some other distinct features like habitat or colour or size, etc.

It is summarised in the given table.

Genus	Specific epithet	Common names
1.Solanum	Tuberosum	Potato
	Nigrum	Black nightshade or Makoi
	Melongena	Brinjal, Eggplant
2.Canis	Familiaris	Dog
	Lupus	Wolf
	Aureus	Jackal
3.Panthera	Leo	Lion
	Tigris	Tiger
	Pardus	Leopard

Biological Concept of Species: Ernst Mayr gave most accepted biological concept of species which defines species as a group of actually or potentially interbreeding populations that are reproductively isolated from other such groups.

Genus

Genus is a group or related species, which characters in common in comparison to species of another genera. For example, potato, makoi and brinjal are three different species but all belong to the same genus Solanum. Species like lupus, familiaris and aureus belong to genus Canis. Likewise, genus Panthera consists of species like Leo, tigris and pardus which have ability to roar as a similar character. The different species of Canis genus resemble to each other in some characters but are different and easily distinguishable from many other species of Panthera genus. So, we can conclude that all the related species in one genus have a common ancestor, so that they have a few differences but many similarities, to be grouped in one genus. Hence, the aggregates of closely related species are a genus.

When we consider human beings, they belong to the species sapiens, which is grouped in genus Homo. Thus, our scientific name is written as Homo sapiens.

Family

The next higher category in the taxonomic hierarchy after genus is family. It includes various groups of related genera, which share less number of similarities as compared to that at genus and species level. As we have already studied that when we move from lower taxon towards higher one in hierarchy, the number of similar characters decreases. For instance, on basis of vegetative and reproductive features of some plant species, they are grouped into three different genera -Solanum, Petunia, Datura and these three different genera are kept in a single family, i.e., **Solanaceae** due to some other common features or correlated characters. They all are distinguishable from the genera of the related family **Liliaceae** which includes two different but related genera, i.e., Allium and Colchicum Similarly, among animals, the genus. Felis of cats and the genus Panthera including lion, tiger and snow leopard are placed under a common family **-Felidae**. At same time, if we observe the features of a cat and a dog, we will find that they both are quite distinct. So, these are kept in separate families - Felidae (cats) and Canidae (dogs).

Order

It is a group of related families that means related families are kept in the same order. For example, the family Felidae of cats and family Canidae of dogs are assigned to the same order **Carnivora.** As they both have canine teeth which is a similar feature found in animals of both the families.

Therefore, order is assemblage of families which exhibit a few similar characters in spite of many differential features. The similar characters are less in number as compared to different genera included in a single family. Different plant families like Convolvulaceae, Solanaceae are included in the order Polymoniales along with three other related families. The common feature of all different families placed in a single order, *i.e.*, Polymoniales is **similar floral characters** found in them.

Class

A class is a group of one or more related orders. For example, the order Rodentia of rats, Primata of monkey, gorilla and gibbon, and Carnivora of cats and dogs are all placed in the same class **Mammalia.** All these orders are kept under the same class because members of these orders have milk-producing glands and hair on their skin. We can say that class is the assemblage of orders which exhibit a few similar characters.

Phylum / Division

It is a category higher than that of class. The term phylum is used for-animals, while division is commonly used for plants. Phylum or division is a group of related classes, i.e., it is formed of one or more classes. Different classes, comprising animals like fishes, amphibians, reptiles, birds and mammals, together constitute the next higher category known as "**Phylum**". All of these different organisms are placed in the phylum **Chordata** as all of the animals in these classes have some common characters like presence of notochord at least at some stage of their lives, dorsal hollow neural system, etc. In case of plants, classes with a few similar characters are assigned to higher category called division.

Kingdom

It is the highest category in taxonomic hierarchy. It is a group of phyla (in plural) or divisions, which have certain basic common characteristics. Animals present in all phyla lack cell wall and chlorophyll is placed in the kingdom **Animalia**. All plants present in different divisions have rigid cell wall around their cells and synthesize their own food by photosynthesis, are included in the kingdom Plantae. Hence, we can call these two broad categories of plants and animals as plant and animal kingdoms.

So, now we can recall the basis of arrangement of organisms in taxonomic hierarchy. As we go higher from species to kingdom, the number of common characteristics goes on decreasing. Lower the taxa more are the characteristics that the members within the taxon share. Higher the category, greater is the difficulty of determining the relationship to the other taxa at the same level. Hence, the problem of classification becomes more complex.

Table: Organisms with their taxonomic categories

Common names	Biological name	Genus	Family	Order	Class	Phylum OR Division	Kingdom
Man	Homo sapiens	Homo	Hominidae	Primata	Mammalia	Chordata	Animalia
Housefly	Musca domestica	Musca	Muscidae	Diptera	Insecta	Arthropoda	Animalia
Mango	Mangifera indica	Mangifera	Anacardiaceae	Sapinadales	Dicotyledonae	Angiospermae	Plantae
Wheat	Triticum aestivum	Triticum	Poaceae	Poales	Monocotyledonae	Angiospermae	Plantae
Brinjal	Solanum melongena	Solanum	Solanaceae	Polymoniales	Dicotyledonae	Angiospermae	Plantae

TAXONOMICAL AIDS

The systematic study of diverse organisms is beneficial for human kind. As human can exploit this knowledge of various species of plants, animals and other organisms in agriculture, forestry, fishery, industries, etc. and can also exactly understand different bio-resources existing on earth. Therefore, accurate classification and identification of organisms is required which needs field studies and intensive laboratory work. This is done after collection of actual specimens of plants and animal species which is the primary source of all taxonomic studies. This helps in not only studying diverse organisms' morphology etc. but also various relationships present amongst them. It also plays an essential role in systematics training. Hence, these taxonomical studies help in:

1. Fundamental study of different living organisms.
2. Also aid in their systematic study.
3. Information gathered is stored with specimens for future studies.

Therefore, biologists have established certain procedures and techniques to store and preserve the information as well as the specimens. Some of the locations where one can find information with specimen of various plants, animals and other organisms are Herbarium, Botanical Gardens, Museums and Zoological Parks.

Herbarium

It is defined as "store house of collected plant specimens that are dried, pressed and preserved on sheets". Further, these sheets are arranged in the sequence of a universally accepted system of classification.

Fig.: Herbarium showing stored specimens

The sheets having different specimens along with their accurate information form an herbarium. These herbarium sheets are carefully preserved for future use. These sheets carry a label on the right-hand side at lower corner which provides information about:

1. Date on which the specimen was collected.
2. Place from where the specimen was collected
3. English name of the specimen.
4. Vernacular or local name of the specimen.
5. Botanical name of the specimen.
6. Family of the specimen.
7. Name of the collector of that specific specimen.

Such herbaria serve as **quick source of reference** in taxonomical studies. It also provides information about the local flora as well as flora of distant areas. This information is also useful in locating wild varieties and relatives of economically important plants.

List of some Herbaria of the world:

1. Royal Botanical Gardens, Kew (England)
2. Central National Herbarium, Calcutta

Botanical Gardens

Botanical garden is an institution located in an enclosed piece of land which grows numerous kinds of plants obtained from different places for botanical studies. It is ex-situ conservation strategies of plants, each plant is first identified and then labelled indicating its botanical/scientific name and its family.

List of some Botanical Gardens:

1. Royal Botanical Garden, Kew (England)
2. National Botanical Garden, Lucknow
3. Indian Botanical Garden, Howrah
4. Lloyd Botanical Garden, Darjeeling

Museum

Museum is a place used for storing, preservation and exhibition of both plants and animals. All educational institutes and universities maintain museums in their Botany and Zoology departments.

These museums have collection of preserved plants and animals which are used for study and reference. These specimens are kept in the containers or jars in preservative solution. A commonly used preservative solution is "Formalin" Plants and animal's specimen may also be preserved as dry specimens. For instances, insects are collected, killed and pinned before preserving them in special insect boxes while larger animals like reptiles, birds and mammals are usually stuffed and then preserved. Skeleton of some larger animals are also preserved in various museums. Thus, preservation of specimens collected and stored in museum is done by either putting specimens into a condition that checks deterioration or it is protected by other means as no specimens will last forever. National Museum of Natural History (NMNH) in Delhi is important from natural science point of view.

Zoological Parks

Zoological parks commonly known as zoos are the places where live wild animals are kept in protected environment which is made similar to their natural habitats as much as possible. Thus, these are ex-situ conservation of animals. Here, they are provided with protection and care by human beings. These parks serve as ideal means to study and learn different food habits and behaviour of variety of animals. So, students should visit nearby zoos for knowledge and entertainment both. National Zoological Park (Delhi) is one of the finest zoos of Asia.

Key

Key is an important taxonomic aid used for identification of plants and animals based on the **similarities** and **dissimilarities**. Actually, it is a set of alternate characters of different types arranged sequence wise in such a fashion that by selection and elimination one can quickly find out the name of the organism. The keys are based on the set of contrasting characters generally in a pair known as **"couplet"**. Each character of the couplet or statement in the key is called as "**lead**". One has to choose correct option between two statements of characters of definite species so that the animal or plant is identified accurately. **Keys are generally analytical in nature.** There are separate taxonomic keys specific for each taxonomic category such as family, genus and species.

Flora, Manuals, Monographs and Catalogues

These flora, manuals, monographs, etc. are recorded descriptions of plants, animals and other organisms. They provide correct identification and description of variety of living organisms.

(i) **Flora:** It is a book containing information about plants found in a particular area. It gives the actual account of **habitat** and **distribution** of various plants of a given area. These provide the index to the plant species found in a particular area. For example, Flora of Delhi by J.K. Maheshwari.

(ii) **Manual:** It is a book containing complete listing and description of the plants growing in a particular area. They provide useful information for identification of names of various species found in an area.

(iii) **Monograph:** It contains information of any one taxon.

(iv) **Catalogue:** It includes the alphabetical arrangement of species of a particular place describing their features.

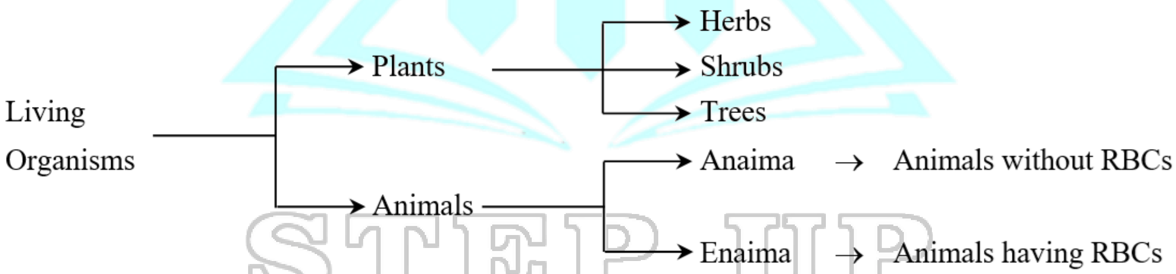
Chapter 2
Biological Classification

Introduction:

Biological classification is the scientific procedure to classify the organisms into different groups on the basis of their similarities and dissimilarities and placing the groups in a hierarchy of categories. Since the starting of civilization, many attempts were made to classify the organisms. The criteria of classification used at that time, were not fit in scientific approach. Just for example, one attempt was to classify organisms on the basis of a need to use organisms for our own use like food, shelter and clothing. Over time, an attempt has been made to evolve a classification system which reflects not only the morphological, physiological and reproductive similarities, but is also phylogenetic i.e., based on evolutionary relationships. In this chapter, we will study, the characteristics of kingdoms Monera, Protista and Fungi of the Whittaker system of classification. We will study Kingdom Plantae and Animalia also but in brief.

KINGDOM SYSTEMS OF CLASSIFICATION

The earlier systems of classification of organisms were simple and based on one or two characters. First scientific attempt for classification was performed by Aristotle in following manner:



Aristotle used simple morphological characters to classify plants into herbs, shrubs and trees. He classified animals into **Anaima** and **Enaima,** on the basis of absence and presence of RBCs respectively.

Linnaeus later classified all living organisms into two kingdom – Plantae and Animalia. The criteria for classification used by him include cell well, locomotion made of nutrition, response to external stimuli and contractile vacuole.

This **two-kingdom classification** system does not distinguish between (i) Unicellular and multicellular organisms, (ii) Eukaryotes and prokaryotes and (iii) Photosynthetic (green algae) and non-photosynthetic (fungi) organisms.

There are few organisms like Chlamydomonas. Euglena and the slime moulds which share the characteristics of both animals and plants. Since there are certain organisms that do not fall naturally into either plant or animal kingdom, it was proposed that a new kingdom is to be established to accommodate such organisms.

Features	Kingdom Plantae	Kingdom Animalia
1. Cell wall	Present	Absent
2. Locomotion	Absent	Present
3. Mode of nutrition	Do not eat	Eat
4. Response to external stimulus	Slow	Fast
5. Contractile system	Absent	Present
6. Organisms	Bacteria, algae, fungi, bryophytes, pteridophytes, gymnosperms, angiosperms	Protozoa, vertebrates, invertebrates

R.H. Whitaker (1969) proposed **five kingdom classification.** He divided organisms into kingdom **Monera, Protista, Fungi, Plantae** and **Animalia,** on the basis of following criteria :

1. Cell structure (either prokaryotic or eukaryotic)
2. Thallus organization (body differentiated or not)
3. Mode of nutrition (autotrophic or heterotrophic)
4. Reproduction
5. Phylogenetic (or evolutionary) relationship

Table : Characteristics of the Five Kingdoms

Characters	Five Kingdoms				
	Monera	**Protista**	**Fungi**	**Plantae**	**Animalia**
Cell type	Prokaryotic	Eukaryotic	Eukaryotic	Eukaryotic	Eukaryotic
Cell wall	Non-cellulosic (Polysaccharide + amino acid)	Present in some	Present (without cellulose)	Present (cellulose)	Absent
Nuclear membrane	Absent	Present	Present	Present	Present
Body organization	Cellular	Cellular	Multicellular/ loose tissue	Tissue/ organ	Tissue/ organ / organ system
Mode of nutrition	Autotrophic (chemosynthetic and photosynthetic) and Heterotrophic (saprophytic/ parasite)	Autotrophic (Photosynthetic) and Heterotrophic	Heterotrophic (Saprophytic/ Parasitic)	Autotrophic (Photosynthetic)	Heterotrophic (Holozoic etc.)

Earlier classification systems included bacteria, blue green algae, fungi, mosses, ferns, gymnosperms and the angiosperms under 'Plants'. The character that unified this whole kingdom was that all the organisms included had a cell wall in their cells. This placed together groups which widely differed in other characteristics. It brought together the prokaryotic bacteria and the blue green algae with other groups which were eukaryotic. It also grouped together under the unicellular organisms and the multicellular ones. Chlamydomonas and Spirogyra were placed together under algae. The classification did not differentiate between the heterotrophic group – fungi and the autotrophic green plants, though they also showed a characteristic difference in their wall's composition – the fungi had chitin in their wall while the green plants had a cellulosic cell wall. When such characteristics were considered, the fungi were placed in a separate kingdom – Kingdom Fungi.

All prokaryotic organisms were grouped together under kingdom Monera and the unicellular eukaryotic organisms were placed in Kingdom Protista. Kingdom Protista has brought together Chlamydomonas, Chlorella (earlier placed in Algae within plants and both having cell walls) with Paramecium and Amoeba (which were earlier placed in the animal kingdom) which lack it. It has put together organisms which, in earlier classifications, were placed in different kingdoms. This happened because the criteria for classification changed. Such kind of changes will take place in future also. This will depend on the improvement in our understanding of characteristics and evolutionary relationship.

Six kingdom classification: Carl Woese proposed six kingdom classification. These six kingdoms are Kingdom–**Archaebacteria,** Kingdom-**Eubacteria,** Kingdom-Protista, Kingdom-**Fungi,** Kingdom-**Plantae** and Kingdom-**Animalia.** He separated the archaebacteria from eubacteria on the basis of some major differences such as the absence of peptidoglycan in the cell walls of the former and the occurrence of branched chain lipids (a monolayer instead of a phospholipid bilayer) in the membrane.

Based on the sequence of 16S ribosomal RNA genes, which is found that the six kingdoms naturally cluster into three main categories. He called these categories as **domains of life**. These domains are **Bacteria, Archaea** and **Eukarya** and are believed to have originated from common ancestor called **progenote.**

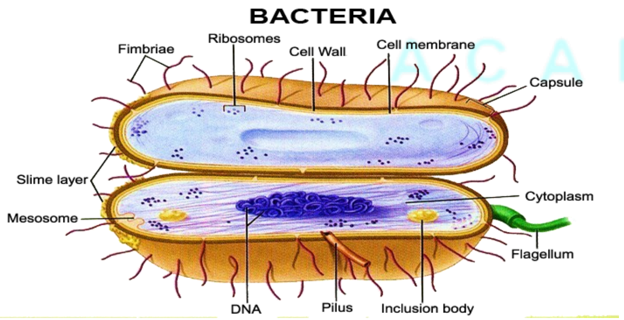
KINGDOM : MONERA

Kingdom Monera includes the most ancient, the smallest, the simplest and the most abundant micro-organisms. These organisms are most primitive. They were the first inhabitants of the earth. And they still continue to flourish.

Bacteria are the sole members of this kingdom. They occur almost everywhere. Hundreds of bacteria are present in a handful of soil. They also live in extreme habitats such as hot springs, deserts, snow and deep oceans where very few other life forms can survive. Many of them live in or on other organisms as parasites.

Characters of Monera

1. They are unicellular, colonial or filamentous, prokaryotic organisms without nuclear, nucleolus, chromatin and histone proteins.
2. Nucleoid or incipient nucleus is composed of naked DNA, RNA and non-histone proteins DNA is circular and double stranded.
3. Cell wall is made up of peptidoglycan (Amino acids + Sugar) except in Archaebacteria and Mycoplasma.
4. Membrane bound cell organelles are absent.
5. Ribosomes are of 70S type.
6. Some of the bacteria are autotrophic but vast majority are heterotrophic.
7. Respiratory enzymes are found associated with plasma membrane.
8. Reproduction is asexual type.
9. Bacteria show both autotrophic and heterotrophic nutrition. Autotrophic nutrition involves synthesis of organic material from inorganic substances with the help of light energy (photosynthetic autotrophic) or chemical energy (chemosynthetic autotrophic). Majority of them show heterotrophic nutrition which involves the obtaining of readymade organic nutrients from outside sources. It is of three types – saprotrophic, symbiotic and parasitic.



On the basis of their shape, bacteria are grouped under four categories :

1. The spherical Coccus (pl.: Cocci),
2. The rod – shaped Bacillus (pl.: Bacilli),
3. The comma-shaped Vibrium (pl.: Vibrio), and
4. The spiral Spirillum (pl.: Spirilla)

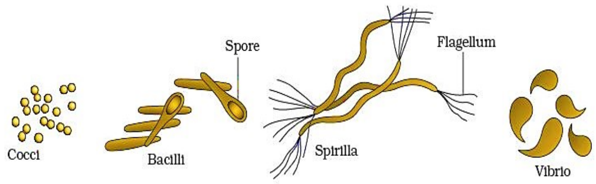


Fig. : Bacteria of different shapes

BACTERIAL LIFE PROCESSES

Discussion of bacterial life processes revolves around the study of the prominent metabolic activities like respiration and nutrition.

A. Respiration : On the basis of mode of respiration, the bacteria are divided into two main groups : i.e., **aerobes** and **anaerobes.** Each group is further of two types i.e., **strict** or **obligate** and **facultative.**

(a) Obligate or strict aerobes : These bacteria can live only in presence of oxygen as they possess the enzyme system for aerobic respiration only. In the absence of oxygen, they cannot respire and thus, die, e.g., Bacillus subtilis.

(b) Facultative anaerobes: They normally respire aerobically. However, they are capable of switching over to anaerobic mode to get energy for their survival, if sufficient oxygen to sustain aerobic respiration is not available in the environment, e.g., Pseudomonas.

(c) Obligate or strict anaerobes : These bacteria respire anaerobically only. The growth of such bacteria will certainly be slower as anaerobic respiration liberates much less amount of energy as compared to aerobic respiration. They lack enzymes necessary for carrying out aerobic respiration e.g., Clostridium botulinum.

(d) Facultative aerobes : They normally respire anaerobically, but are capable of respiring aerobically as well, if oxygen is available. Most of the photosynthetic bacteria are facultative aerobes e.g., photosynthetic bacteria Chlorobium.

B. Nutrition : Bacteria is placed in a particular nutritional class based on their primary source of carbon, energy and electron.

(I) Photolithoautotrophic bacteria :

These bacteria are capable of entrapping solar energy and utilizing it for the synthesis of complex food materials due to the presence of pigments like bacteriochlorophyll (bacteriopurpurin) and bacterioviridin.

Purple sulphur bacteria (e.g., Thiospirillum) and **green sulphur bacteria** Chlorobium limicola are the most familiar example containing pigment **bacteriochlorophyll**, **bacteriopurpurin** and **bacterioviridin** respectively. Bacterial photosynthesis, however, differs from photosynthesis of higher plants. In not liberating oxygen. This type of photosynthesis, characteristic of bacteria, is termed as anoxygenic. Normal photosynthesis, occurring in higher plants, is termed as oxygenic.

In bacterial photosynthesis **water is not the source of electron** that acts as reducing power to convert CO_2 into glucose. The bacteria obtain reducing power from various compounds such as hydrogen sulphide, thiosulphate or even some organic compounds. No oxygen is evolved as it does not involve splitting of water.

Photolithoautotrophic bacteria

Purple sulphur bacteria	**Green sulphur bacteria**
• Bacteriopurpurin pigment	• Bacterioviridin pigment or Chlorobium chlorophyll
• Use inorganic sulphur compounds as e^- and H^+ donor *e.g.*, Chromatium, Thiospirillum	• Use H_2S as e^- and H^+ donor *e.g.*, Chlorobium

Hydrogen released by various compounds mentioned above is picked up by NAD^+ which gets reduced to $NADH_2$ acting as reducing power. $NADH_2$ along with ATP, produced generally by entrapping solar energy are used to reduce CO_2 to glucose. Simple equation for anoxygenic photosynthesis may be written as follows:

$$CO_2 + H_2S \xrightarrow[\text{enzymes}]{\text{Solar energy}} \text{Sugar} +$$

(Sulphur or other oxidised oxidized compound) + H_2O

(Or any other compound acting as e^- donor)

(II) Photoorganoheterotrophic bacteria :

Some photosynthetic bacteria use organic matter as their electron donor and carbon source.

Photolithoautotrophic bacteria

Purple non-sulphur	**Green non-sulphur**
• Bacteriopurpurin pigment	• Bacterioviridin pigment
• Use non-sulphur aliphatic organic compounds as e^- and H^+ donor *e.g.*, Rhodospirillum, Rhodopseudomonas	• Use non-sulphur aliphatic organic compounds as e^- and H^+ donor *e.g.*, Chloronema, Chloroflexus

Most of the photosynthetic bacteria are anaerobes (facultative aerobes).

(III) Chemosynthetic autotrophic bacteria :

Bacteria belonging to this category obtain energy for the synthesis of food by oxidizing certain inorganic substances like ammonia, nitrates, nitrites, ferrous ions, etc. Thus, they do not utilize light as energy source. The chemical energy thus obtained is trapped in ATP molecules. This energy is then used in carbon assimilation with the help of hydrogen from some source other than water, e.g., hydrogen bacteria, nitrifying bacteria, sulphur bacteria, etc. They play a great role in recycling nutrients like nitrogen, phosphorous, iron, sulphur.

(a) **Hydrogen bacteria.** Hydrogenomonas.

(b) **Nitrifying bacteria.** Nitrosomonas, Nitrococcus, Nitrobacter and Nitrocystis

(c) **Sulphur bacteria.** Thiobacillus thioxidans, Beggiatoa

(d) **Iron bacteria.** Ferrobacillus, Leptothrix

(IV) Chemoorganotrophic heterotrophic bacteria :

These bacteria are incapable of synthesizing their own food from simple raw materials. They obtain nourishment either from dead and decaying organic matter or directly from a living host. They are segregated into three main categories, i.e., saprophytic, symbiotic and parasitic forms.

(i) **Saprophytic bacteria :** They are free living bacteria, obtaining nourishment from organic remains such as dead animals, animal excreta, fallen leaves, decaying vegetables, fruits, bread and other products of animal and plant origin.

These bacteria secrete digestive enzymes into the substrate and the complex insoluble substances are converted into simple soluble compounds like water, hydrogen sulphide, ammonia, CO_2 etc. Some of the simpler substances are absorbed and assimilated by the bacteria, whereas the others are added to the soil and atmosphere to complete the nature's material cycle.

(ii) **Symbiotic bacteria :** They are mainly Gram-negative type. A familiar example of symbiotic bacteria is Rhizobium leguminosarum associated with roots of leguminous plants. They are capable of fixing atmospheric nitrogen as ammonia inside the nodule only and not in free state. However, some bacteria like Azotobacter, Beijerinckia, lebsiela are free living aerobic and capable of nitrogen fixation in free state enriching the soil. Clostridium pasteurianum is anaerobic N_2 fixing bacteria.

(iii) **Parasitic bacteria :** these bacteria draw nourishment and obtain special organic compounds required for growth from living organisms either plants or animals called hosts. The disease-causing bacteria are termed and the ones not causing any disease are termed as non-pathogenic.

REPRODUCTION

Bacteria reproduce mainly by asexual method and also show sexual recombination (True sexual reproduction is absent).

A. Asexual Reproduction : Bacteria produce several types of asexual spores like, sporangiospores, conidia and endospores. However, the most common mode of asexual reproduction is binary fission.

Under favorable conditions of nutrient availability, moisture and temperature, daughter cells may repeat binary fission many times and may forms a large population. Fortunately, such a rapid rate is seldom achieved. The process gradually slows down and ultimately stops because of:

(i) Shortage of space.

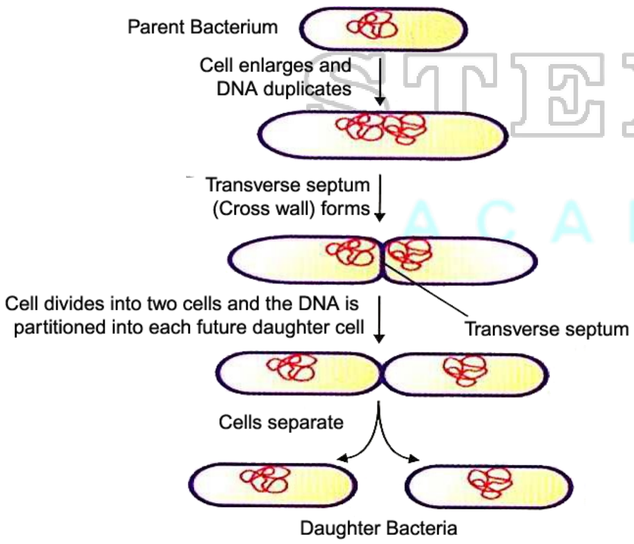
(ii) Lack of nutrient availability.

(iii) Accumulation of waste products (making environmental conditions unfavorable for growth.

(iv) Development of bacteriophages, destroying bacteria.

(a) Binary Fission : It is the most common method under favorable conditions of temperature, moisture and availability of nutrients. Mature bacterial cell divides into two daughter cells. In this process the cell division is amitotic type i.e., not involving the spindle formation

The binary division of a bacterial cell involves mainly 3 steps:



(i) Replication of DNA : The bacterial chromosome divides (replicates) resulting in the formation of two 'circular' chromosomes. Since at one stage, the replicating chromosome appears like the Greek letter θ this mode of replication is called theta model.

(ii) Mesosome division and membrane formation : The parent chromosome is attached to the mesosome. The mesosome begins to divide because of the synthesis of membrane between the DNA-mesosome attachment sites. As a result of the synthesis of the synthesis of cytoplasmic membrane between the mesosomes, each mesosome is pouched to the middle of a daughter cell. Because one chromosome is attached to each mesosome. The two daughter chromosomes get properly partitioned into the daughter cells.

(iii) Cross-wall formation : A peripheral ring of plasma membrane invaginates and continues to grow until the two cells are separated. The cell wall materials are also deposited between the membranes completing the division of the cell. The two events, septum and cross wall synthesis, occur simultaneously.

(b) Endospores : Cells of certain bacteria, e.g., Bacillus, Clostridium etc. form thick-walled, highly resistant bodies within the cell, called endospores. One bacterial cell normally produces only a single endospore. The endospores may be spherical or oval in shape and are terminal or central in position. **Anticoagulant nature** of endospore is due to the presence of **Ca-dipicolinic acid** in cortex layer of wall.

B. Sexual Recombination (Genetic Recombination) : The bacteria exhibit a primitive form of sexual reproduction which differs from eukaryotic sexual reproduction because there is **no gamete formation and fusion.** However, the essential feature of sexual reproduction, i.e., exchange of genetic material does take place and is called **genetic recombination.**

There methods are known by which genetic recombination is achieved by bacteria. In the order of their discovery, there are transformation, conjugation and transduction.

(a) Transformation : Griffith (1928) worked on the effect of Diplococcus or Streptococcus pneumonia bacteria on mice and discovered the process of transformation.

(b) Conjugation : Lederberg and Tatum (1946) demonstrated in E.coli that during conjugation one cell containing F-plasmid acts as donor (F^+ or male) cell and the other lacking F-plasmid as recipient (F^- or female) cell. The plasmid contains fertility factor of F gene which produces protrusions termed **sex pili.** These help the donor F^+ cell in attaching to the recipient cell. The plasmid replicates and a replica is transferred to recipient cell, changing it into F^+. Often the plasmid integrates with bacterial chromosome, converting it into **HFR** (High frequency of recombination) **cell or super male** and a part or whole of bacterial chromosome is transferred to recipient cell through conjugation tube. Such association of episome with the endogenote increases the efficiency of genetic transfer. **The number of genes transferred depends upon the time** for which the two cells remain joined together.

When F^- conjugates with super male, the frequency of recombination increases by 1000 times, that is why it is called as Hfr (super male).

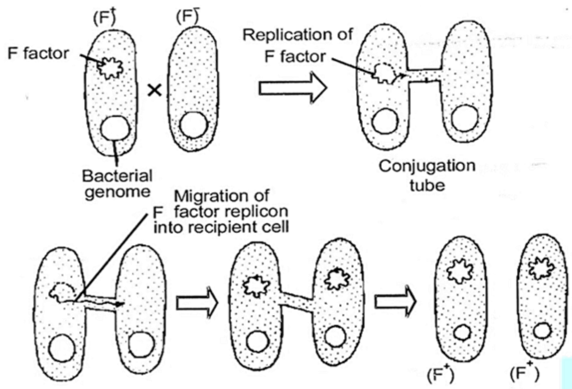


Fig. : Schematic diagram of the conjugation experiment of Lederberg showing conjugation between F^+ and F^- cells

(c) Transduction : During transduction, a small double stranded piece of DNA is transferred from donor to recipient by a bacteriophage. This mode of genetic recombination in bacteria was first demonstrated by **Zinder and Lederberg** (1952) while working with **Salmonella typhimurium.**

Some viruses have the ability to integrate their DNA with bacterial DNA, which is replicated at the same time as the host DNA and is passed from one bacterial generation to the next. Such bacteria carrying phage (viral) DNA with their own DNA are called **isogenic bacteria.** Occasionally, the phage DNA becomes active and codes for the production of new virus particles. A number of phage particles are synthesized followed by the destruction of the host cell and release of phage particles. **Upon release,** the phage particles attack sensitive bacterial cells, multiply and release more phage particles. However, sometimes faulty detachment of phage DNA from bacterial DNA results in the incorporation of a small amount of bacterial DNA into the phage DNA. Subsequent infection of another bacterium with this aberrant phage called **transducing phage,** introduces the piece of foreign bacterial DNA into the recipient's chromosomes, producing a genetic change.

Types of transduction : The ability of the bacteriophage to carry the genetic material from any region of bacterial DNA is called **generalized transduction,** e.g., T_4 – phage. On the other hand, there are bacteriophages such as lambda phage (λ) of E. coli which can carry only a specific region of the bacterial DNA to a recipient. This is called specialized transduction (or restricted transduction). Sometimes, the DNA brought by the phage does not integrate with the genome of the recipient bacterium and is lost after one or two generations. Such a transduction is called absorptive transduction.

ECONOMIC IMPORTANCE

A. Some Useful Bacteria :

I. Soil fertility / biofertilisers

Free-living N_2-fixing bacteria	:	**Azotobacter, Clostridium, Klebsiella, Beijerinckia**
Symbiotic N_2-fixing bacteria	:	**Rhizobium, Frankia, Xanthomonas**
Ammonifying bacteria	:	**Bacillus bulgaris, B. ramosus**

II. Vinegar production : **Acetobacter aceti**

III. Curd, cheese, yogurt production : **Lactobacillus, Streptococcus lactis**

IV. Petroleum pollution control : **Pseudomonas putida**

V. Antibiotics production : e.g., **Bacitracin : Bacillus licheniformis Subtilin : B subtilis**

B. Harmful activities :

(i) Vibrio cholera – Cholera

(ii) Salmonella typhi – Typhoid

(iii) Clostridium tetani – Tetanus

(iv) Xanthomonas citri – Citrus Cankar

Let us Discuss various Monerans in detail:

I. Archaebacteria

These archaebacteria are special since they live in some of the most harsh habitats such as extreme salty areas (halophiles), hot springs (thermoacidophiles) and marshy areas (methanogens).

Archaebacteria differ from other bacteria in having a different cell wall structure and this feature is responsible for their survival in extreme conditions. The cell membrane contains branched chain lipids (phytanyl side chains) which decreases membrane fluidity.

Archaebacteria are divided into three groups – methanogens, halophiles and thermoacidophiles.

(i) Methanogens : These bacteria are of marshy habitats. They are capable of converting CO_2 methanol and formic acid into methane so named methanogens. These methanogens are present in the guts of several ruminant animals such as cows and buffaloes and they are responsible for the production of methane (biogas) from the dung of these animals. These are chemoautotrophs **Examples: Methanococcus Methanobacterium** etc.

(ii) **Halophiles :** These bacteria live in extreme saline environment such as salt lakes, sea, brines etc. In strong light, these halophiles develop a pigmented membrane (purple membrane) composed of a pigment called bacterio-rhodopsin (related to the one found in our own eyes) to harness to sun's energy. The light energy is utilized to carry on ATP production but they cannot use this ATP in food synthesis. Hence, they are heterotrophs. **Examples**: **Halobacterium** and **Halococcus.**

(iii) Thermoacidophiles : These are capable of tolerating high temperature as well as high acidity and hence, the name thermoacidophiles. They often live in hot water springs where the temperature is as high as 80ºC and the pH as low as 2. They oxidise sulphur to sulphuric acid under aerobic conditions and the energy obtained in this reaction is utilized for the synthesis of organic food. Hence, these are chemosynthetic in nature. The medium becomes highly acidic due to the production of sulphuric acid. Under anaerobic conditions sulphur is reduced to H_2S. **Examples: Thermoplasma, Thermoproteus** etc.

II. Eubacteria

There are thousands of different eubacteria or 'true bacteria'. Most of them are characterized by the presence of rigid cell wall, and if motile, a flagellum, Eubacteria include several subgroups like Cyanobacteria, Mycoplasma, Actinomycetes, Rickettsiae, Chlamydiae, Spirochaetes etc. Let us discuss Cyanobacteria and Mycoplasma in detail.

(i) Cyanobacteria : Cyanobacteria are Gram negative photosynthetic prokaryotes, being the most primitive organisms to have **oxygenic photosynthesis.** They added oxygen to the atmosphere, which is indispensable for the existence of aerobic forms of living organisms. They are also known as BGA (Blue green algae) and are classified variously under **cyanophycean** or **myxophyceae.**

(ii) Occurrence : They are mainly fresh forms, though few are marine. **Red sea** is named so because of abundant occurrence of a cyanobacterium richodesmium erythraeum, which imparts red colouration to water. They occur in symbiotic association with almost every group of eukaryotes i.e., green algae, fungi, bryophytes like mosses and Anthoceros, ferms, gymnosperms, angiosperms, sponge, shrimps, mammals etc. Anabaena azollae is associated with Azolla, an aquatic fern. Anabaena cycabeae is associated with coralloid roots of **Cycae.** In many lichens (symbiotic association of algae and fungi), the algal partner may be a cyanobacterium. When they live **endozoically in protozoans they are called cyanelle.**

Structural Organization : These may be unicelled, filamentous and colonial. Filamentous form consists of one or more cellular strands, called **trichomes,** surrounded by mucilaginous sheath. Cyanobacteria are characterized by the **absence of flagellum throughout life cycle.**

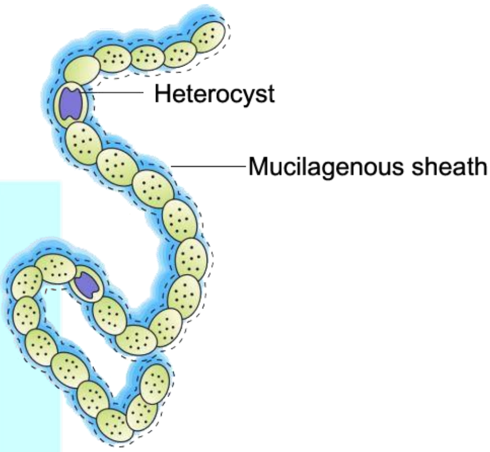


Fig. : A filamentous blue-green algae-Nostoc

Cell Structure : The cell structure in cyanobacteria is typically prokaryotic. The cell lacks a well-defined nucleus and the chromatin material is centrally located, resembling the bacterial chromosome. The cell wall is 4 layered and is invariably covered by mucilaginous sheath, composed largely of mucopeptides.

Protoplasm in cyanobacterial cell can be distinctly divided into two parts the **centroplasm** and **chromoplasm.** The central colorless **centroplasm** contains the chromatic material. The peripheral protoplasm is coloured or pigmented because of the presence of thylakoids called as **chromoplasm.** The protoplast lacks membrane-bound organelles like endoplasmic reticulum, Golgi bodies, mitochondria, lysosomes, plastids and contains 70S ribosomes. Similar to the mesosome of bacteria, a group of coiled membrane called **lamella some** is found which connects nucleoid to the cell membrane. It helps in respiration and replication of DNA. The **cell membrane lack sterols. The sap vacuoles are absent.** Instead, the cell may contain **gas filled vacuoles** which help to regulate the buoyancy of the organism in water. The characteristic feature of cyanobacterium cell is the presence of a system of photosynthetic lamellae called **thylakoids.** The characteristic photosynthetic pigments present in the thylakoids are **chlorophyll a** and **phycobilin's** i.e., phycocyanin (blue coloured), phycoerythrin (red coloured) and allophycocyanin (light blue coloured).

Reproduction : Cyanobacteria reproduce asexually. Typical sexual reproduction is absent.

Asexual reproduction occurs by following methods :

(i) Binary fission : It occurs in unicellular forms. The daughter cells formed by amitotic division separate immediately after the division.

(ii) Fragmentation : It occurs in filamentous forms. The filament breaks up into short pieces or fragments which grow to form new filaments.

(iii) Heterocyst's : Under special conditions, the heterocyst's germinate to form new filaments.

(iv) Hormogonia : Due to the formation of biconcave, mucilage filled dead cells called **necridia,** in between living cells of trichome, the filament breaks into **hormogonia.**

(v) Akinetes : Vegetative cells are transformed into thick walled akinetes due to the deposition of food material followed by the thickening of wall. On the arrival of favourable conditions, they germinate to form new filaments.

Importance of Cyanobacteria

(i) They are the most ancient organisms having **oxygenic photosynthesis** and thus, played a significant role in the evolution of aerobic forms of life.

(ii) They convert atmospheric nitrogen into ammonium compounds and excess of these compounds is excreted cut, enriching the soil. The death and decay of these also increase the soil fertility particularly the nitrogen content of the soil. Tolypothrix and Aulosira N_2 non-symbiotically in rice fields.

(iii) Cyanobacteria are associated in symbiotic relationship with almost every group of plants. They benefit the partner by providing nitrogenous compounds because of their capability of nitrogen fixation.

(iv) Some cyanobacteria serve as food to several aquatic animals. Spirulina is edible, non-toxic, fast-growing cyanobacterium. It is cultivated in tanks as source of protein rich animal food (SCP).

(v) Extract of Lyngbya is used for the manufacture of antibiotic.

(vi) Some cyanobacteria like Microcystis aeruginosa, Anabaena flos-aquae, Aphanizomenon flos-aquae are known to cause **algal blooms** in water bodies. These also secrete toxins into the surroundings, which are harmful to aquatic animals and even to human beings. Water from such sources is harmful and may even prove fatal for organisms drinking it. They also deplete the oxygen from the water reservoir and thereby, cause scale death of the fishes and other aquatic animals.

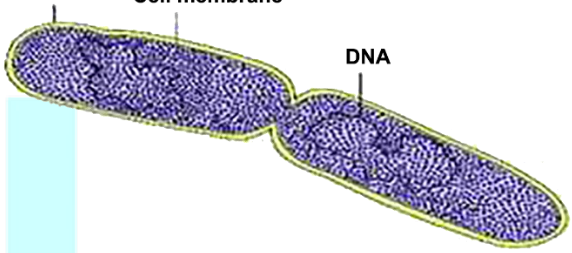


Fig. : A dividing bacterium

III. Mycoplasma

E. Nocard and E.R. Roux (1898) We French Scientists, discovered these organisms from pleural fluid of cattle's suffering from pleuropneumonia. These are pleomorphic and were called **PPLO** (Pleuro Pneumonia Like Organisms) or **Jokers of plant kingdom.** This

KINDGOM : PROTISTA

All unicellular eukaryotes, irrespective of their mode of nutrition, are included in the kingdom **Protista** in Whittaker's system. The term Protista was coined by **Ernst Haeckel.** This kingdom forms a link between kingdom Monera on one hand and other three kingdom i.e., Plantae, Fungi and Animalia on the other hand. Protistans are ancestors of all multicellular eukaryotes (plants, fungi and animals).

Kingdom : Protista includes

Protista
↓

(1) Autotrophic or *e.g.*, Dinoflagellates, Diatoms, Euglenoids

(2) Consumer – Decomposer organisms *e.g.*, Cellular slime moulds Acellular slime moulds

(3) Protozoans *e.g.*, Zooflagellates, Sarcodines, Sporozoans, Ciliates

General Characteristics of Protista :

1. Unicellular, eukaryotic organisms. Some are colonial without much cellular differentiation. Organisation at tissue level is absent.
2. Mostly aquatic organisms.
3. Cell structure is eukaryotic type having all kinds of membrane bound organelles and **80S cytoplasmic** ribosomes and cells may possess cellulosic cell wall.
4. Flagella and cilia have (9+2) pattern of microtubule organization consisting of tubulin protein.
5. Movement by pseudopodia, flagella or cilia where ciliary mode is fastest.
6. Mode of nutrition may be photosynthetic (holophytic), holozoic (ingestive), saprophytic or parasitic (absorptive).
7. Reproduction occurs by asexual and sexual means.
8. Life cycle is of two types – (1) Showing **zygotic meiosis (ii) Showing gametic meiosis.**
9. These are decomposers, photosynthetic or parasites. Parasitic protists may cause diseases like dysentery, malaria, sleeping sickness, etc.

Photosynthetic protists and Slime moulds are described below :

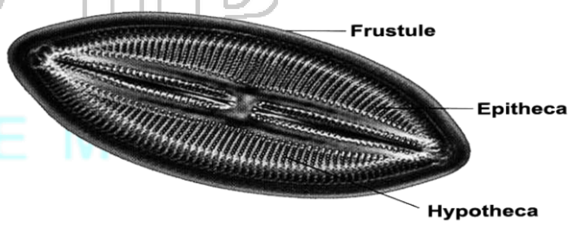
(1) Photosynthetic Protists

These are popularly called protistan algae. Protistan algae constitute the major portion of the phytoplankton.

A. Chrysophytes(Diatoms) : Diatoms are golden brown photosynthetic protists and are called Chrysophytes **(including both diatoms and desmids).** They are both aquatic and terrestrial. Some are marine. They support much of marine life. Their important characters are :

1. These are microscopic organisms possessing varying colours.
2. They are basically unicellular, but may form pseudofilament and colonies, **lacking flagella except in the reproductive stage.** They may be free floating (phytoplanktonic), remaining float on surface of water due to presence of light weight lipids.
3. They cell wall is impregnated with silica to form transparent siliceous shell, known as frustale. Depending upon the symmetry, diatoms may be pinnate type, having bilateral symmetry (e.g., Navivula) and **centric type,** having radial symmetry (e.g., Melosira).
4. The cell wall is characteristic, made up of two halves: one half covering the other **(epitheca** over hypotheca) resembling a **soap box.**
5. The cell wall encloses the peripheral layer of cytoplasm (primordial utricle) surrounding a large central vacuole.
6. Nucleus lies in the central vacuole, suspended with the help of cytoplasmic strands.
7. Mode of nutrition is holophytic (photoautotrophic), photosynthetic pigments are **chlorophyll a, chlorophyll c, β-carotene** and special, carotenoids containing fucoxanthin; **xanthophylls** like **diatoxanthin, diadinoxanthin.**
8. The reserve food is oil and a polysaccharide called leucosin (chrysolaminarin), volutin granules are also present.
9. They are responsible for almost 50% of the total organic matter synthesized in the biosphere.
10. Movement occurs by mucilage propulsion.
11. They mainly undergo asexual reproduction. The common mode of asexual reproduction is binary fission.
12. During binary fission, one-half of the cell wall is retained by each of the daughter cells formed. The other half of the cell wall is secreted fresh.
13. Resting spores are called statospores (centric diatoms).
14. They reproduce sexually as well. Sexual reproduction varies from **isogamy to oogamy.** It involves energetic meiotic as diatoms are generally diploid (diplontic life cycle).

DIATOM



B. Dinoflagellates : Dinoflagellates are **golden brown photosynthetic protists,** belonging to class **Dinophyceae (Pyrophyta).** They are mainly marine though few are fresh water forms. They may appear red, yellow, green, brown or blue depending upon the main pigment present in cell.

General characters of dinoflagellates are as follows :

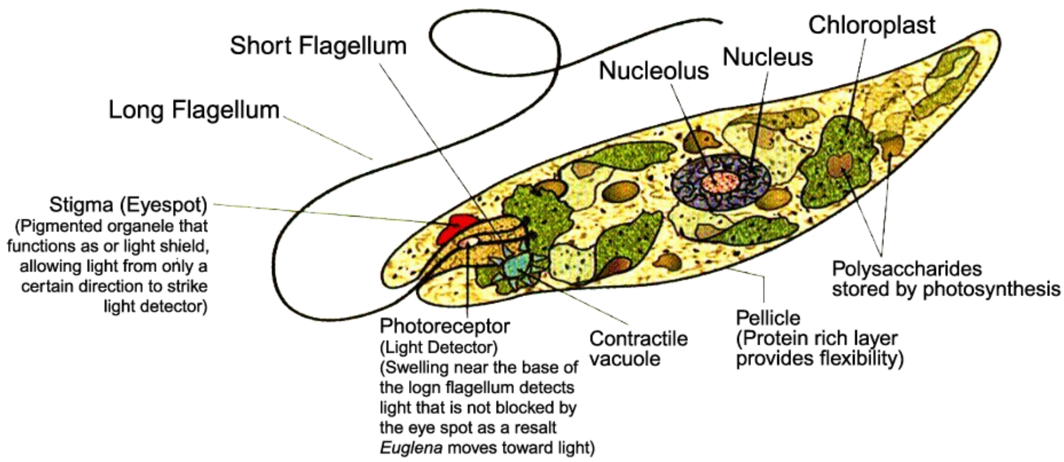
1. Unicellular, motile, biflagellate, golden brown photosynthetic protists (some are non-motile, amoeboid, palmelloid or filamentous).
2. They are mostly marine; some are found in fresh water.

3. The body is enclosed by a rigid coat called **theca or lorica** consisting of 2 to many articulated or sculptured plates of cellulose and pectin, hence are also called **armoured dinoflagellates.**
4. Theca has generally two grooves i.e., longitudinal called **sulcus** and transverse called **cingulum** or annulus **or girdle.**
5. Flagella are heterokont (different). One is longitudinal and other is transverse. The flagella pass out through the pores in the lorica and lie in the grooves. The transverse flagellum lies in the circular groove and the longitudinal flagellum in the longitudinal groove. The longitudinal flagellum is narrow, smooth directed posteriorly and the transverse flagellum is ribbon like.

   Both are oriented at right angle to each other producing spinning movements. Therefore, these protists are also called '**whirling whips'.**
6. Most of the species have brown, green or yellow chromatophores with chlorophyll a, c, **β-carotene and α-carotene, xanthophylls** (e.g., Peridinin). Plastids are generally surrounded by 3-membrane envelope and contain 3-thylakoid lamellae. They are autotrophic or photosynthetic (Ceratium), a few are saprobic or parasitic.
7. **Reserve food** is carbohydrate and oils.
8. Nucleus is relatively larger in size, has condensed chromosomes even in interphase, chromosomes do not have histone. Nuclear envelope and nucleolus remain present even during cell division. This organization is called Mesokaryon (Dodge, 1966).
9. A non-contractile vacuole called pusule is present near the flagellar base. It may have one or more vesicle and takes part in floatation and osmoregulation.
10. Some possess trichocysts and cnidoblasts like those of coelenterates.
11. Reproduction is commonly asexual and occurs through cell division.
12. Isogamous and anisogamous sexual reproduction is reported from some dinoflagellates e.g., Ceratium.
13. Life cycle involves zygotic meiosis (Ceratium, Gymnodinium). Gametic meiosis occurs in Noctiluuca.

C. Euglenoid (Euglena-like) : It is a group of chlorophyllous and non chlorophyllous flagellate protists. Largest genera being Euglena amongst them.

1. Euglenoids are unicellular flagellate protists found in water or damp soil. Majority of them are fresh water organisms found in stagnant water.
2. Body is spindle with blunt anterior end and pointed posterior end.
3. Cell wall is absent but a covering periplast or pellicle is present which is proteinaceous (elastic) in structure.
4. Locomotory organs are flagella.
5. The cell bears a single long tensile type flagellum (stichonematic) arising at the anterior end. Actually, there are two flagella but one of these is reduced. The longer flagellum has two branches at the base each having its own basal granule. **In the area of union of two flagella is present a photosensitive paraflagellar body.**
6. Myonemes are oblique but parallel arranged strips in pellicle. Euglenoids perform creeping movement of contraction and expansion with the help of myonemes which is called metaboly or euglenoid movement.
7. The apical end of the cell bears an invagination with three distinct parts, i.e., mouth (cytostome), canal (gullet or cytopharynx) and reservoir. It helps in the ingestion of solid food particles.
8. Stigma or an eye spot is attached to the membrane of the reservoir at the level of paraflagellar body and along with it seems to be involved in perception of light stimulus. It contains photosensitive red-orange pigment called astaxanthin.
9. A contractile vacuole occurs in the anterior end of the cell just below the reservoir, meant for osmoregulation and excretion.
10. Single large nucleus lies near the centre of the protoplast.
11. Nutrition in Euglena viridis is photoautotrophic. However, it is capable of getting nourishment from dead and decaying organic matter in the substrate by secreting digestive enzymes (saprophytic nutrition) in the absence of light. This dual mode of nutrition is absent in Euglena. Some forms are holozoic (Paranema) or saprobic (Rhabdomonas).
12. Photosynthetic pigments are **chlorophyll a, chlorophyll b**, xanthophylls and β-carotene.
13. Reserve food material is paramylon, stored in cytoplasm in the form of paramylum granules. They are chemically β-1, 3-glucans.
14. Under favourable conditions, they mainly reproduce by longitudinal binary fission. During unfavourable conditions, palmella stage and cysts are formed for perennation. Sexual reproduction is not known to occur in euglenoids, e.g., Euglena and Paranema.



(2) Slime moulds or consumer-decomposer protists

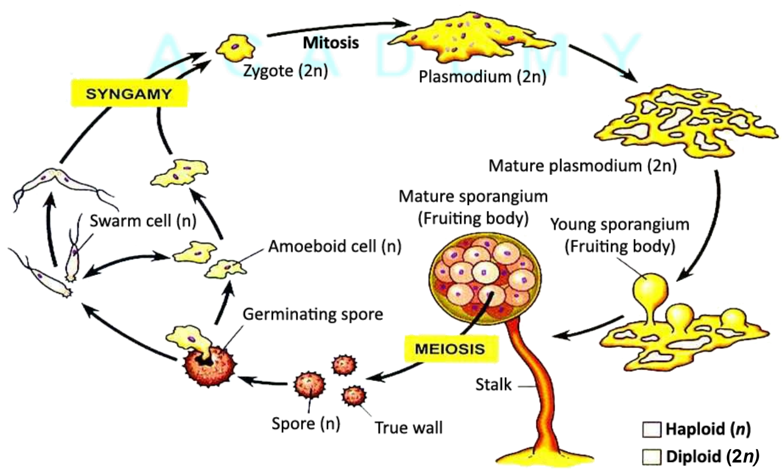
They were included in class myxomycetes of fungi in two-kingdom classification. They were called Mycetozoa by De Bary as they are closely related to animals. Mycologists included them in gymnomycota. Because of their nature they are called protistan fungi.

General characteristics of the slime moulds are :

1. They are usually free-living, creeping over deons like fallen leaves and rotting logs of wood.
2. They have naked protoplast, not covered by any cell wall in vegetative stage.
3. They lack chlorophyll and have saprobic or phagotrophic mode of nutrition.
4. The body moves along decaying called plasmodium which may grow and spread over several feet. During unfavourable conditions, the plasmodium differentiates and forms bodies bearing spores at their tips.
5. During life cycle they are amoeboid and non-cellulosic, but spores have cellulosic wall so that their vegetative phase resembles with animals while reproductive phase resembles with plants.
6. Amoeboid plasmodial stage resembles protozoa and spore forming nature is like fungi.
7. Spores are extremely resistant and survive for many years, even under adverse conditions. The spores are dispersed by air currents.
8. Reproduction is both asexual and sexual.

This group is represented by two separate types of organisms i.e. acellular and cellular.

THE LIFE CYCLE OF A PLASMODIAL SLIME MOLD, SUCH AS *PHYSARUM*



General Characters :

1. Slimy masses found on decaying leaves arid lumber.
2. Somatic body is free living, multinucleate, naked, diploid mass called, **Plasmodium.** Movement occurs by means of **pseudopodia.**

3. During unfavourable conditions, entire plasmodium forms many fructifications/fruiting bodies (polycentric). The fruiting body is called sporocarp which contains a stalk having a sporangium at its tip. The wall of sporangium is called peridium.
4. Sporangium has an intricate network of cytoplasmic threads called capillitium.
5. Diploid protoplast forms haploid spores by meiosis.
6. Spore wall is double, outer wall is spiny and sculptured.
7. On germination, spores produce biflagellate swarm cells or non-motile myxamoebae which act as gametes.
8. Sexual reproduction is isogamous.
9. Diploid zygote directly forms the plasmodium which becomes multinucleate by repeated mitotic divisions of the diploid nucleus.
10. Chief mode of nutrition is saprotrophic.
11. Vegetative reproduction is by fission. e.g., Physarum, Physarella, Fuligo.

Fungi like feature : Formation of fruiting bodies.

Plant like feature : Cell wall around spores.

Animal like feature : Plasmodium is without cell wall.

PROTOZOANS

These are unicellular organisms with heterotrophic nutrition. They are believed to be primitive relatives of animals. These are four major groups of protozoans.

Amoeboid protozoans	Flagellated protozoans	Ciliated protozoans	Sporozoans
1. Habitat and habit Fresh water, sea water or moist soil mostly free living, few parasites.	Free living (aquatic) or parasitic	Fresh water or marine, few parasite.	All endoparasites.
2. Locomotory structure Pseudopodia (false feet)	Flagella	Cilia	Absent
3. Special feature Silica shells in some forms.	Rare sexual reproduction with diverse type of associations – commensal, symbiont, parasitic.	Possess definite region of ingestion (gullet) and egestion.	Infectious spore-like stage is present in life cycle.
4. Example and diseases Amoeba, Entamoeba (Dysentery)	Trypanosoma (Sleeping sickness)	Peramoecium	Plasmodium (Most notorious causing malaria)

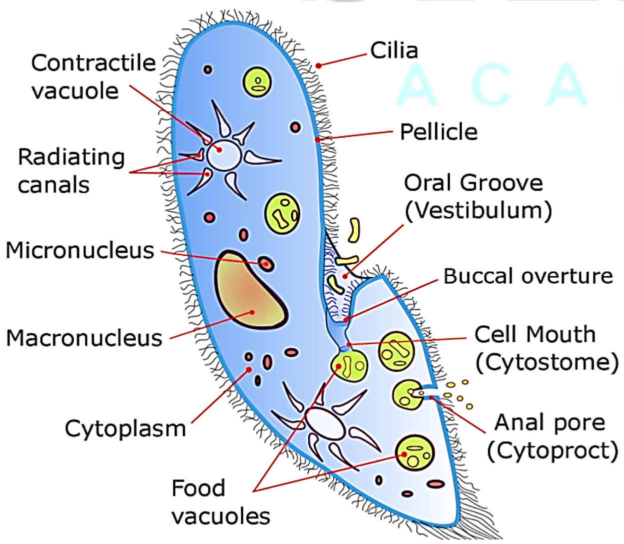


Fig. : Paramecium (a protozoan)

KINGDOM : FUNGI

This kingdom contains achlorophyllous, eukaryotic, heterotrophic, spore producing, thalloid organisms. Fungi include diverse organisms which range in structure from unicellular yeasts to highly complex edible mushrooms, non-edible toad stools. They are cosmopolitan in occurrence being present in air, water, soil and on the animals and plants. They are more abundant in warm and humid areas. So, they show great diversity.

Reproduction in Fungi

Fungi reproduce by all the three modes, i.e., **vegetative, asexual** and **sexual.**

1. **Vegetative reproduction :**

   It occurs by the following methods :

(a) **Fragmentation :** The mycelium breaks up into two or more fragments due to mechanical injury, decay of some other reasons. Each fragment grows into independent mycelium.

(b) **Fission :** Here simple splitting of vegetative cell into two daughter cells takes place by simple constriction.

(c) **Budding :** Some fungi like yeast produce small outgrowths, i.e., buds from their vegetative body. Eventually, the buds are cut off form parent new individuals.

2. **Asexual reproduction :** It occurs through spores. These are single celled specialized structures which separate from the organism, get dispersed and germinate to produce new mycelium after falling on suitable substrate. The spores produced during asexual reproduction in fungi are formed by mitotic division and are thus termed, mitospores.

The various means of asexual reproduction are as follows :

(a) **Zoospore :** Many fungi, especially aquatic members produce these types of spores. Zoospore may be uniflagellate, e.g., Syncytium or biflagellate, e.g., Saprolegnia, Pythium and are naked uninucleate structures formed in zoosporangia. They germinate to give rise to new mycelium. Biflagellate zoospores are of two kinds (e.g., Saprolegnia) **pear shaped or pyriform,** with 2 flagella placed at anterior end (primary zoospore) and **kidney shaped or bean shaped,** bearing two laterally inserted flagella (secondary zoospore). This phenomenon of having two types of zoospores is called **diplanetism**

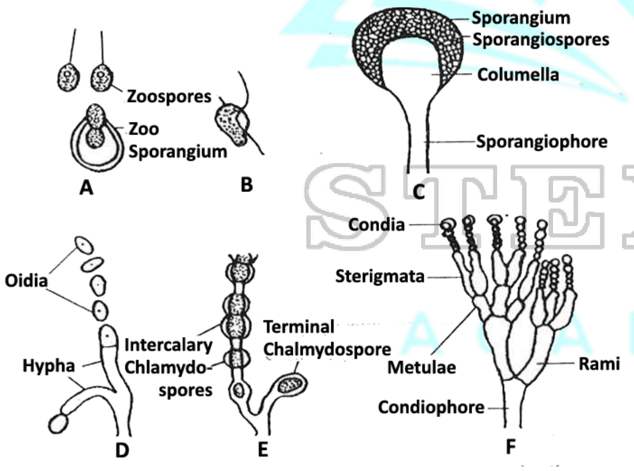


Fig. : A – F Different modes of asexual reproduction

(b) **Sporangiospore :** Sporangiospores are thin-walled non-motile spores produced **endogenously** in a sporangium during favourable conditions, which after liberation give rise to new mycelium, e.g., Rhizopus, Mucor.

(c) **Conidia :** Conidia are non-motile, thin-walled exogenous spores produced at the tips of erect hyphae called **conidiophores.** They are arranged in chains upon the conidiophores, e.g., Aspergillus and Penicillium.

(d) **Chlamydospore :** In some fungi the hyphae under unfavourable conditions, forms **thick-walled resting resistant spores** which later get separated from each other. They may be terminal or intercalary. They may remain viable for several years. On return to favourable conditions, they germinate to give rise to new individuals. Thus, chlamydospores are structures for perennation also, e.g., Rhizopus.

(e) **Oidia :** Non-motile thin-walled spores developing under sugar rich conditions in medium. Their budding condition is called **torula stage.**

3. **Sexual reproduction :** It occurs through **oospores, ascospores and basidiospores.** The various spores are produced in distinct structures called fruiting bodies. The fruiting bodies are ascocarps and basidiocarp which contain asci and basidia respectively. The ascospores are a type of non-motile spores which are produced inside special sacs called asci (singular-ascus). Basidiospores are non-motile which are formed exogenously (i.e. outside the body) on short outgrowths of club-shaped called basidium.

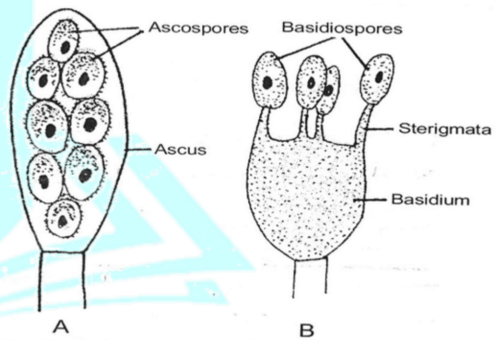


Fig. : A. Ascospores, B. Basidiospores

Sexual cycle involves three steps :

1. **Plasmogamy :** There is union protoplasm between two haploid hyphae of compatible mating type or gametes.

Plasmogamy occurs by the following methods :

(a) **Plan agametic copulation/Gametic fusion :** This is the simplest form of sexual reproduction. In this process fusion of two gametes of opposite sex or strains takes place. One or both of the fusing gametes are motile. It results in the formation of a diploid zygote, e.g., Allomyces.

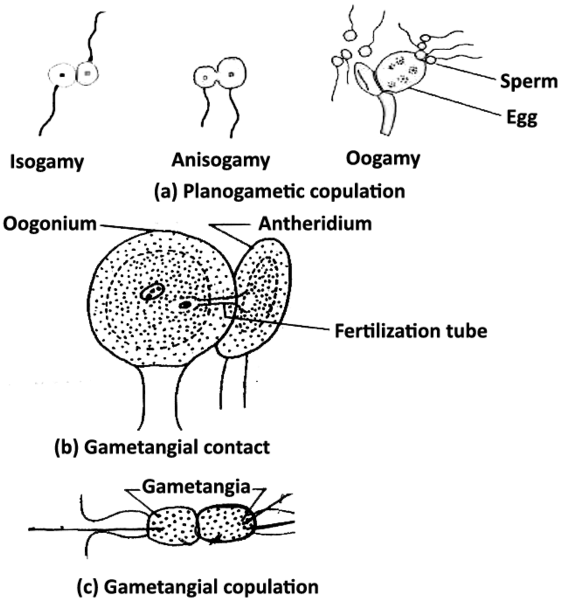


Fig. : Different modes of plasmogamy in fungi

This process is usually of three types : Isogamy, Anisogamy, Oogamy.

(b) Gametangial contact : In this process two gametangia come in contact with one another. A **fertilization tube** is developed to facilitate the migration of entire contents of male gametangium into the female gametangium. Both the gametangia never fuse together losing their identify, e.g., Pythium Albugo (**Oomycetes).**

(c) Gemetangial copulation : In this process, direct fusion of entire contents of two gametangia is accomplished by dissolution of their common walls resulting in the formation of a single cell in which protoplasts of two gametangia fuse.

(d) Spermatization : Some fungi produce many minute spore like - single celled structures called spermatica (non motile male gametes) on spermatophores (hyphae). These structures are transferred through agencies like water, wind and insects to special female receptive hyphae (Basidiomycetes). The contents migrate into receptive structure. Thus, dikaryotic condition is established, e.g., Puccinia.

(e) Somatogamy : This takes direct fusion of somatic hyphal cells occur to establish dikaryophase, e.g., Agaricus.

2. **Karyogamy :** Fusion of two nuclei is called karyogamy. In some fungi, the fusion of two haploid cell immediately results in diploid cells (2n). However, in some fungi (e.g., Agaricus, Aspergillus) an intervening dikaryotic stage (n + n i.e. two nuclei per cell) occurs such a condition is called a dikaryon and the phase is called dikaryophage. Later, the parental nuclei will fuse and the cells become diploid in karyogamy.

3. **Meiosis :** The fungi form fruiting bodies in which reduction division (meiosis) occurs leading to the formation of haploid spores.

Kingdom fungi is classified on the basic of **Morphology of the Mycelium, Mode of Spore Formation and Fruiting Bodies** into various classes.

Fungi
- Phycomycetes
  - Oomycetes
  - Zygomycetes
- Ascomycetes
- Basidiomycetes
- Deuteromycetes

I. Oomycetes : The Algal Fungi

1. Hyphal wall **contains cellulose** and the glucans in many members.
2. The mycelium is **ceonocytic** (multinucleate and aseptate).
3. Asexual reproduction involves the formation of spore containing sacs or **sporangia.** In aquatic forms, the sporangia produce zoospores.
4. Zoospores generally have two laterally inserted flagella with **heterokont condition,** in which one flagellum is **smooth** (whiplash) while the other is of **tensil type** (having fine surface outgrowths called mastigonemes).
5. Sexual reproduction is by planogametic fusion or **gametangial contact.**
6. The product of sexual reproduction and **site of meiosis is oospore.**

II. Zygomycetes : The Conjugation Fungi

1. It is class of terrestrial fungi which are mostly saprotrophic and rarely parasitic.
2. Hyphal wall contains **chitin** or fungal cellulose.
3. The mycelium is **coenocytic** (multinucleate, aseptate) like the one found in Oomycetes.
4. Motile cells (zoospores or plasmogametes are absent.
5. Mitospores are non-motile. They are called **sporangiospores** as the spores are formed inside **sporangia** that are born at the tips of special hyphae called **sporangiophores.**

6. Sexual reproduction occurs through **gametangial copulation** or **conjugation**. Because of it zygomycetes an also called **conjugation fungi.**
7. The gametes a commonly multinucleate and are called **coenogametes.**
8. Sexual reproduction produces a **resting diploid spore called zygospore.** Because of the presence of zygospore the group of fungi is called zygomycetes. **Zygospore differs from oospore** in that, for its formation a distinct food laden, non-motile, large female gamete is not produced.
9. Zygospore is the **site of meiosis** and does not give rise to new mycelium directly. Instead, it produces a new sporangium called **germ sporangium** (previously called zygosporangium). Germ sporangium forms meiospores called germ spores.
10. Sometimes gametangia fail to fuse. Gametangia become surrounded by a thick wall resulting in formation of **a zygospore** (parthenogenetically produced zygospore).

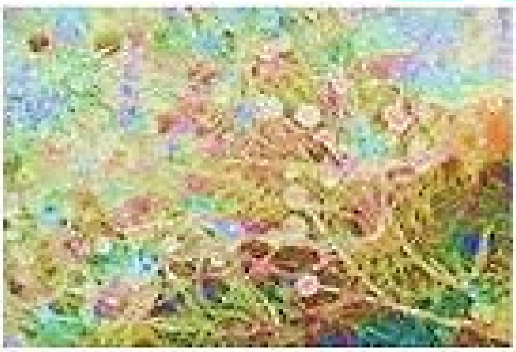


Fig. : Mucor

III. Ascomycetes : The Sac Fungi

1. The mycelium consists of **septate** hyphae. (Yeast are an exception in that they are basically unicellular).
2. They are saprophytic, decomposers, parasitic or coprophilous (growing on dung).
3. The septa possess central pores **septal pores.** The pores allow communication and transport between adjacent cells.
4. Cell wall contains **chitin.**
5. **Motile structures do not occur in the life cycle.**
6. In majority of ascomycetes, the common mode of asexual reproduction is through the formation on **conidia.** Conidia are born on branched or unbranched hyphae called **conidiophores,** e.g., Penicillium Aspergillus.
7. Female sex organ is called ascogonium.
8. Plasmogamy occurs by means of :
   (i) Gametangial contact (e.g., Pyronema)
   (ii) Conjugation (e.g., Yeast)
   (iii) Spermatization (e.g., Ascobolus)
   (iv) Somatogamy (e.g., Peziza)
   (v) Autogamy (e.g., Morchella).
9. Karyogamy is delayed after plasmogamy. A new transitional phase appears in the life cycle. It is called **dikaryotphase.** The cells of dikaryophase are called dikaryotic cells. Each such cell possesses two different nuclei (Dikaryon). **This forms a shorter phase of life cycle.**
10. Once a cell becomes dikaryotic, it transfers the nucleus to other cells by the **crozier method** (method of dikaryotization) to make them dikaryotic.
11. Some dikaryotic cell function as **ascus mother cells.** This converts the cells into **asci** (singular-ascus). Ascus is a sporangial sac peculiar to Ascomycetes. **Ascus is the site of karyogamy and meiosis. 4 to 8** haploid meiospores named **ascospores** are produced **endogenously** in each ascus. In most of the cases half the number of ascospores belong to one mating type (+) while the other half belong to the second mating type (-).
12. Ascospores may be arranged linearly (Neurospora) or unorderly (yeast).
13. The asci may occur freely or get aggregated into specific fructifications called **ascocarps.** Ascocarps are of many types : cup-like (**apothecium,** e.g., Peziza), flask-shaped (**perithecium,** e.g., Neurospora, Claviceps), elongated with a slit **(hysterothecium),** closed (**cleistothecium,** e.g., Penicillium) cushion like chambered (**Ascostroma,** e.g., Pleospora). The fructifications of some ascomycetes are edible, e.g., morels truffles.

IV. Basidiomycetes : The Club Fungi

1. They are the **most advanced and most commonly seen fungi.** Their fructifications are often large and conspicuous, e.g., mushrooms, toadstools, puff balls, bracket fungi etc.
2. Basidiomycetes are among the best **decomposers of wood.** They are able to decompose both cellulose and lignin. Lignin is not metabolized by most other fungi and even bacteria. Ganodermatic species causes decay of wood even on standing trees.

3. **Motile structures or cells are absent.**
4. Mycelia are of two types primary and secondary. Primary mycelium contains monokaryotic cells and is short lived.
5. Monokaryotic phase or primary mycelium may multiply by oidia, conidia-like spores and pycniospores.
6. Secondary mycelium is long lived and **dominant phase of life cycle.** It is represented as **dikaryophase.** It consists of profusely branched septate hyphae.
7. Septa possess **dolipores** or central pores with barrel-shaped outgrowths (except rusts and smuts).
8. Handle like outgrowths are found on the sides of septa. They are called **clamp connections.** Clamp connections are meant for proper distribution of dikaryons at the time of cell division.

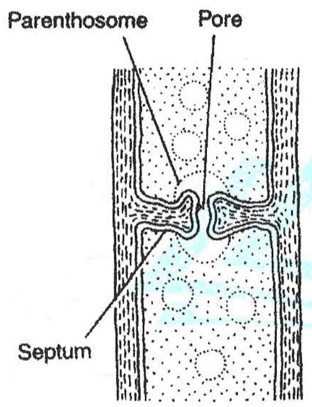


Fig. : Dolipore septum

9. Secondary mycelium can perennate in the soil or wood by means of **sclerotia or** rhizomorphs.
10. Dikaryophase or secondary mycelium may multiply by different types of spores-**chamydospores aecidiospores, uredospores, teleutospores** etc.
11. There is often differentiation of two mating types (+) and (-) in thallus.
12. Sexual reproduction does not involve sex organs. Instead, fusion occurs between basidiospores and other monokaryotic spores, between a spore or spermatium and hypha or between two hyphal cells of primary mycelia.
13. **Karyogamy and meiosis** occur in club-shaped structures known as **basidia** (singular – basidium). The name of the class is based after them.
14. A basidium commonly produces four meiospores or basidiospores exogenously at the tips of fine outgrowths called sterigmata or directly on the basidium.
15. The fungi may or may not produce fructifications called basidiocarps. The basidiocarps vary from microscopic forms to large macroscopic structures. Some puff balls and brackets can be over 50 cm in diameter.

V. Deuteromycetes : The Fungi Imperfect

There is only asexual and vegetative phase known so these are commonly regarded as imperfect fungi. It is also possible that the asexual and vegetative stage have been given one name (and placed under deuteromycetes) and the sexual stage another (and placed under another class).

By the establishment of linkages, the perfect stage (or sexual form) discovered in these fungi, they are moved out of deuteromycetes to ascomycetes and basidiomycetes. The deuteromycetes reproduce only by asexual spores known as conidia. The mycelium is septate and brancher in these fungi. Some of them are saprophytes or parasites while a large number of them are decomposers of litter (organic matter) and help in mineral cycling.

Example : Alternaria, Colletotrichum and Trichoderma.

After this discussion, we can easily differentiate between various classes of fungi.

Features	Phycomycetes	Ascomycetes	Basidiomycetes	Deuteromycetes
1. Mycelium	Aseptate/coenocytic	Septate, branched	Septate, branched	Septate, branched
2. Asexual spore	Zoospore (Aplanospore)/ Sporangiospore	Conidia	Generally absent	Conidia
3. Sexual spore	Zygospore/Oospore	Ascospore	Basidiospore	Absent
4. Fruiting bodies	Absent	Ascocarp	Basidiocarp	Absent

MYCORRHIZA (FUNGAL ROOTS)

The mutual beneficial or symbiotic association of a fungus with roots of higher plants (gymnosperms and angiosperms) represent mycorrhiza.

Benefits to fungi	Benefits to plant
1. Nourishment from root cortical cells. 2. Shelter	1. Surface area for absorption increases. 2. Enhanced supply of H_2O, N, P,S.

The mutually beneficial or symbiotic association of a fungus with the roots of higher plants is termed **mycorrhiza**. Mycorrhizal roots differ in shape from normal roots and often show a wooly covering. **These root slack, root cap and root hairs**. A fungus may get associated with roots of a number of plants and a particular plant may form association with a number of fungi. Depending upon the location of the fungus, the mycorrhiza is of two types, i.e., **ectomycorrhiza** and **endomycorrhiza**.

In **ectomycorrhiza,** the fungal hyphae are mainly external, forming a wooly covering intercellularly and intracellularly. The fungus is able to break the cell wall in a limited way and is restricted to cortical region of the root. Some hyphae send small projections into cortical cells without destroying them. Such fungi are termed **VAM (Vesicular Arbuscular Mycorrhiza),** e.g., Orchid roots.

Mycorrhizal association is a **symbiotic relationship** as both the partners are mutually beneficial to each other. The fungal partner obtains nourishment from the cortical cells of the root and depends upon the plant for shelter. The root cells excrete sugars and other soluble gradients which are used by fungal hyphae spreading in intercellular spaces. The hyphae may get nourishment from the cells directly and also by sending small projections into cortical cells. The fungus seems to be essential for the growth of the plant having mycorrhiza. The plant also gets benefit from the association at the fungal hyphae spreading in soil substantially increases the surface area of absorption, thereby **enabling the plant to get enhanced supply of water, nitrogen, phosphorus and other minerals** from the soil. Orchids seldom occur without mycorrhiza. Certain forest trees like pines birches show stunted growth if their roots are not associated with fungus.

KINGDOM : PLANTAE

All eukaryotic chlorophyll containing organisms commonly called plants are included under kingdom plantae. Few of them are partially heterotrophic such as insectivorous plants (e.g., Bladderwort and Venus fly trap) or parasites (e.g., Cuscuta). The plant cell have a eukaryotic structure with prominent chloroplasts and cell wall which is mainly up of cellulose.

Kingdom **Plantae** includes algae, bryophytes, pteridophytes, gymnosperms and angiosperms. In plants, life cycle has two distinct phases i.e. the diploid sporophytic and haploid gametophytic that alternate with each other. This phenomenon is called alternation of generation. The lengths of haploid and diploid phases and whether these phases are free living or dependent on others vary among different groups in plants.

KINGDOM : ANIMALIA

The members of this kingdom are multicellular and their cells lack cell walls. They directly or indirectly depend on plants (autotrophs) for nutrition. In these members, the digestion of food takes place in an internal cavity and they store their food reserves in the form of glycogen or fat. Their mode of nutrition is holozoic by ingestion of food. They follow a definite growth pattern and grow into adults that have a definite shape and size. Most of them are capable of locomotion. Higher forms of kingdom animal in a show elaborate sensory and neuromotor mechanism.

VIRUSES, VIROIDS AND LICHENS

In the five-kingdom classification of Whitaker, there is no mention of some a cellular organisms like viruses, viroids and lichens. These are briefly introduced here.

VIRUSES

Viruses are infectious agents with simple, a cellular organization. They are exception to the cell theory. The study of virus is called virology. Viruses are connecting link between living and non-living entities. They have the properties of both living and non-living things. Viruses can reproduce only within living cells and are obligatory intracellular parasites.

Non-living Nature of Virus :

1. Lacking protoplast.
2. Ability to get crystallized, e.g., TMV, poliomyelitis virus.
3. Inability to live independent of a living cell. (Lack functional autonomy)
4. High specific gravity which is found only in nonliving objects.
5. Absence of respiration.
6. Absence of energy storing system.
7. Absence of growth and division.

Living Nature of Virus :

1. Being formed of organic macromolecules.
2. Presence of genetic material.
3. Ability to multiply.
4. Occurrence of mutations.

5. Occurrence of certain enzymes like, neuraminidase (first discovered), transcriptase and lysozyme in certain viruses.
6. Infectivity and host specificity.
7. Viruses can be 'killed' by autoclaving and ultraviolet rays.
8. They take over **biosynthetic** machinery of the host cell and produce chemicals required for their multiplication.
9. Viruses are responsible for a number of infectious disease like common cold, epidemic influenza, chicken pox, mumps, poliomyelitis, rabies, herpes, AIDS, SARS etc.

Discoveries of Virology :

- Term virus (means venom or poisonous fluid) was coined by **Pasteur** (1880).
- **D.J. Ivanowsky** (1892) recognized certain microbes as causal organism of the mosaic disease of tobacco. These were found to be smaller than bacteria because they passed through bacteria proof filters.
- **M.W. Beijerinck** (1898) demonstrated that the extract of the infected plants of tobacco could cause infection in healthy plants and called this fluid as Contagium virus fluidum (infectious living fluid).
- **W.M. Stanley** (1935) crystallized TMV (Tabacco mosaic virus) for the first time. He showed that viruses could be crystallized and crystals consists largely of proteins.

Viruses did not get place in classification because they are not truly living. To understand living organisms, they should have cell (fundamental unit of life) but viruses does not follow it. Viruses do not have their own cellular machinery. When they enter (or infect) a cell then these take over the cellular machinery of host to replicate themselves.

Structural Components of Viruses

The Structural components of viruses are envelope, capsid and nucleoid :

1. **Envelope :** It is the outer thin loose covering composed of proteins (from virus), lipids and carbohydrates (both from host). This layer may or may not be present. Envelope is present in HIV, Herpes virus.
2. **Capsid :** It is the outer protein coat made up of small subunits called capsomeres for the protection of nucleic acid (their genetic material).
3. **Nucleoid :** Viruses contain either DNA or RNA :
   (a) DNA containing viruses are called deoxy viruses. These are of two types :
      (i) Double stranded DNA (dsDNA) virus e.g. Pox virus, Cauliflower mosaic virus, Herpes virus.
      (ii) Single stranded DNA (ssDNA) e.g. Coliphage $\phi \times 174$, M13 phage.
   (b) RNA containing viruses or riboviruses are of two types :
      (i) Double stranded RNA (dsRNA) virus e.g. Retrovirus, Wound tumor virus.
      (ii) Single stranded RNA (ssRNA) virus e.g. TMV, Influenza virus, Foot and Mouth disease virus, Retroviruses (HIV).

On the basis of host specificity viruses are divided into three groups :

Group	Common type of genetic material
1. Phytophagineae/Plant viruses	1. ssRNA
2. Zoophagineae/Animal viruses	2. Ss or dsRNA or dsDNA
3. Bacteriophages/Bacterial viruses	3. dsDNA

Structure of Some Viruses

1. **Tobacco Mosaic Virus (TMV)** is elongated rod like 3000A long. 180 Å in diameter with molecular weight 39.4×10^6 Dalton. 2130 capsomeres are arranged helically to form the capsid. RNA strand is helical. ssRNA consists of 6400 nucleotides. Thus, the ratio of nucleotides : capsomeres: : 3 : 1

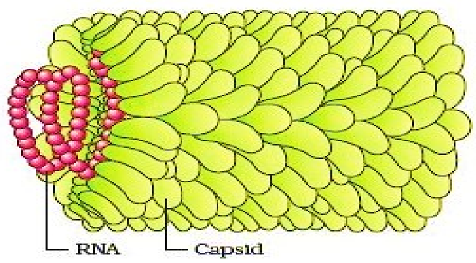


Fig. : Tobacco Mosaic Virus (TMV)

2. **Bacteriophage** (or bacterial viruses) are the infect the bacteria. Bacteriophages usually have double stranded DNA. **T_4 Bacteriophage** has a tadpole like structure with polyhedral head connected to a helical tail. The head consists of nucleic acid surrounded by a protein coat or capsid. Nucleic acid is double stranded DNA. Tail is proteinaceous tube-like core surrounded by sheath. At one end tube is joined to the head by thin collar. At the other end it has a hexagonal base plate with six small tail pins and six tail fibres which help in attachment of the phage to the host cell.

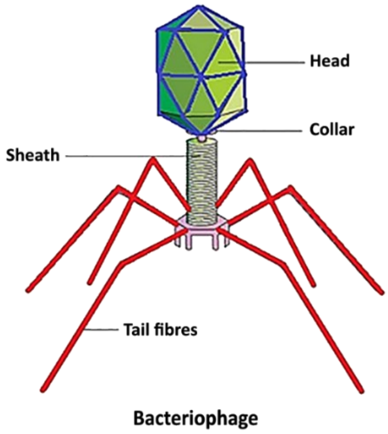


Fig. : Structure of T_4 bacteriophage

Reproduction

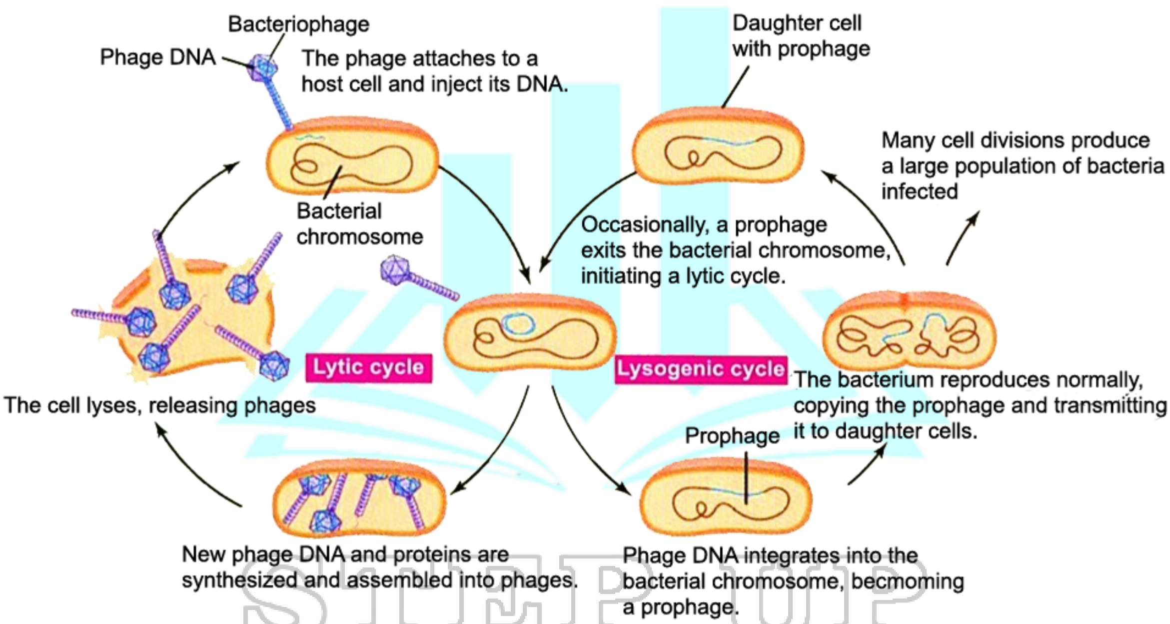
It is of two main types : **Phagic** and **Pinocytic**

(a) Phagic Reproduction : Only nucleic acid of virus enters the host cell. It is further of two types :

- **(i) Lytic cycle :** Occurs in virulent phages, e.g., T_4 bacteriophages.
- **(ii) Lysogenic cycle :** Occurs in temperate viruses such as λ phage.

(b) Pinocytic Reproduction : It is found in viruses like TMV, HIV, Hepatitis B etc., in which of virus particle enters host cell except envelope (if present).

VIRUS MULTIPLICATION CYCLE



Life of some Diseases caused by viruses

Table : Viral diseases of Man

Name of the disease	Causal agent
1. Influenza	1. Influenza virus
2. Small pox	2. Variola virus
3. Mumps	3. Paramyxovirus
4. AIDS	4. Retroviruses
5. Poliomyelitis	5. Polio virus
6. German measles	6. Rubella virus
7. Measles	7. Measles virus

Table : Viral disease of Plants

Name of the disease	Causal agent
1. Tobacco mosaic	1. TMV
2. Cucumber mosaic	2. Cucumber mosaic virus
3. Potato leaf roll	3. Potato leaf roll virus
4. Bunchy top of banana	4. Banana bunchy top virus

Sub-viral Agents :

These are viruses which lack one of the essential component, e.g., viroids, virusoids, prions :

(1) Viroids (L. virus – poison, eidos diminutive): They are the smallest self-replicating particles which were discovered by **Diener** (1971). Viroids are infectious RNA particles which are devoid of protein coat. They are obligate parasites. Molecular weight of a viroid is low. The RNA is tightly folded to form circular of linear structures. Viroids are known to cause diseases (some 20) in plants only, e.g., Potato spindle tuber disease (PSTD), Chrysanthemum stunt and Citrus exortis.

(2) Prions : Discovered by **Alperetal.**

Proteinaceous infectious particles, causing certain diseases like

(i) Kuru disease (laughing death disease in humans)

(ii) Bovine spongiform encephalopathy (BSE or Mad cow disease)

(iii) Scrapie disease in sheep

(iv) Creutz Feldt Jakob disease

LICHENS

Lichens are **dual (composite) organisms** or entities which contain a permanent association of a fungal partner or **mycobiont** and an algal partner or **photobiont. Mycobiont** is dominant partner and mostly belongs to ascomycetes (Ascolichens –e.g., Graphis, Caledonia, Parmelia, Usnea, etc.) or sometimes basidiomycetes, Trebouxia, Protococcus, Plamella, etc. or can be a BGA (e.g., Nostoc, Chlorococcus, Scytonema etc.). The term lichen was coined by **Theopharastus** (370 – 285 B.C.), also **called Father of Botany.** Lichens often grow in most inhospitable and uninhabited places like barren rocks (saxicolous), soil (terricolous), icy tundra or alpines, sand dunes, roofs, walls, wood (lignicolous), tree (corticolous), leaves, etc. They commonly live under humid and exposed conditions but can tolerate extreme desiccation. However, **lichens cannot tolerate air pollution especially due to sulphur dioxide** (so are considered indicators of SO_2 pollution).

Lichens are perennial. Their growth is slow. Lichens have greyish, greenish, orange, dark brown or blackish coloration.

Structure

Based upon external morphology, the lichens are of their types :

(i) Crustose. Crust like closely appressed to the substratum and attached to it at several places, e.g., Graphis, Lecanora, Rhizocarpon.

(ii) Folilose : The body of the lichen is flat, broad, lobed and leaf-like, which is attached to the substratum at one or a few places with the help of rhizoid like structures called **rhizines,** e.g., Parmelia, Peltigera.

(iii) Fruticose : The lichen is branched like a bush and attached to the substratum by means of a disc, e.g., Cladonia, Usnea, Evemia, Bryonia.

Chapter 3
Plant Kingdom

Introduction:

In this chapter we will study in detail the classification within the plant kingdom. Earlier, Fungi and members of the Monera and Protista having cell walls were put under the kingdom Plantae. But now they have been excluded from the kingdom. So, the cyanobacteria that are also referred as blue green algae are not 'algae' any more. The plant kingdom has been classified in various ways by different scientists. Here, we will describe Plantae under **Algae, Bryophytes, Pteridophytes, Gymnosperms and Angiosperms.**

CLASSFICATION SYSTEM

There are three main types of systems of classification i.e., artificial natural and phylogenetic.

Artificial System of Classification

(a) **Basis :** The earliest systems of classification were **artificial** and involves usage of one or few morphological characters for grouping of organisms. For example, classification within the angiosperms was based only on gross superficial morphological characters such as habit, color, number and shape of leaves etc. Such systems were based mainly on vegetative characters or on the androecium structure (system given by Linnaeus).

(b) **Proponents :** Scientists who gave artificial system : **Aristotle, Linnaeus.**

(c) **Drawbacks :** They separated the closely related species as they were based on few characteristics. Also, equal weightage to vegetative and sexual characteristics were given. Since the vegetative characters are more affected by environment so this was not acceptable. Looking into these drawbacks the natural classification system was developed.

Natural System of Classification :

(a) **Basis :** Organisms in this system are classified on the basis of natural affinities and consider not only external but also internal features like ultrastructure, anatomy, embryology and phytochemistry.

(b) **Proponents : George Bentham** and **Joseph Dalton Hooker** gave such classification for angiosperms.

Phylogenetic System of Classification

(a) **Basis :** At present phylogenetic classification systems are acceptable which are based on evolutionary relationships between the various organisms assuming that organisms belonging to the same taxa have common ancestor. The fossils play important role in elucidation of evolutionary relationships.

(b) **Proponents :Engler and Prantl, Hutchinson, Takhtajan**

We now use information from many other sources too, to help resolve difficulties in classification. These become more important when there is no supporting fossil evidence.

BRANCHES OF TAXONOMY

Numerical Taxonomy (Phenetics) : It involves usage of numerical methods for the evaluation of similarities and differences between species with the help of computers.

Steps involved in numerical taxonomy :

1. Numbers and codes are assigned to all the observable characters like plus (+), minus (-), data not available (0).
2. All possible characters are compared by computers by giving equal importance.
3. The organization and analysis of data forms core of this taxonomy.

One of the major benefits of this taxonomic method is that hundreds of characters can be considered at the same time.

Cytotaxonomy/karyotaxonomy : It is based on cytological information like chromosome number, structure, behavior etc.

Chemotaxonomy : It is based on the chemical constituents of the plant. For example DNA sequence, chemical nature of proteins, crystals (Calcium oxalate or calcium carbonate) and aromatic compounds are used by scientists to resolve confusions in classification.

ALGAE

Algae are chlorophyll containing, simple, thalloid (plant body not differentiated into root stem and leaf) and autotrophic organisms.

The main characteristics of algae are :

1. Algae are largely aquatic, either marine or fresh water. They also occur in habitats like moist stones, soils and wood. Some of them also occur in association with fungi (lichen) and animals (e.g., on sloth bear).
2. Algae are of variable size and forms. The size ranges from the microscopic **unicellular** forms like Chlamydomonas to **colonial** forms like Volvox. Each mature Volvox colony is composed of numerous flagellate cells. They may be **filamentous** also like Ulothrix and Spirogyra. A few of the marine forms such as **kelps** forms massive plant bodies.
3. Vascular tissues are absent. Being aquatic, water conduction is not required even in giant forms.
4. Algae reproduce by vegetative, asexual and sexual methods.
5. **Vegetative reproduction** is by fragmentation. In fragmentation, the parent body breaks into two or more fragments. Each fragment develops into a thallus.
6. During the **asexual reproduction** different types of spores are produced. Spores are released from the parent body which on germination give rise to new plants. The most common spores produced are the **zoospores.** They are flagellated (motile) spores and on germination give rise to new plants.
7. Sex organs are non-jacketed and unicellular. Sexual reproduction takes place through the fusion of two gametes. Sexual reproduction can be :
   - **(i) Isogamous :** Fusion of two gametes which are similar in size either flagellated or non-flagellated is termed as isogamous. e.g., Chlamydomonas (gametes are flagellated and similar in size). Spirogyra (gametes are non-flagellated and similar in size).
   - **(ii) Anisogamous :** Fusion of two gametes which are dissimilar in size is termed as anisogamous. e.g., some species of Chlamydomonas.
   - **(iii) Oogamous :** When a small, motile or non-motile male gamete fuses with a large non-motile female gamete such type of reproduction is known as oogamous. e.g., Volvox, Fucus, Polysiphonia (both gametes non-motile)

Algae are mainly classified on the basis of their pigments. Flagellation, storage products and chemistry of cell wall are also taken into account. The three classes of algae are **Chlorophyceae** (green algae), **Phaeophyceae** (brown algae) and **Rhodophyceae** (red algae).

Chlorophyceae

1. The members of chlorophyceae are commonly called green algae. The pigments, chlorophyll-a, chlorophyll-b, carotene and xanthophylls are present in them. They are usually grass green in color due to the dominance of pigments i.e., chlorophyll a and b.
2. These pigments are present in definite chloroplasts. Chloroplasts are greenish plastids (cell organelle).
3. The shape of chloroplast varies in different species. It can be discoid, plate-like, reticulate, cup-shaped, spiral or ribbon-shaped.
4. The plant body may be unicellular, colonial or filamentous.
5. Most of the green algae have one or more storage bodies called pyrenoids located in the chloroplasts. Pyrenoids contain **protein and starch (protein beside starch).**
6. In some green algae, food is stored in the form of **oil droplets.**
7. Green algae usually have a rigid cell wall made up of an inner layer of cellulose and an outer layer of pectose.
8. Vegetative reproduction usually takes place by fragmentation.
9. Asexual reproduction takes place by flagellated zoospores produced inside the zoosporangia (cells in which the zoospores are produced).
10. Sexual reproduction shows considerable variation in the type and formation of sex cells and it may be isogamous, anisogamous or oogamous.
11. Some commonly found green algae are Chlamydomonas, volvox, Ulothrix, Spirogyra and Chara.

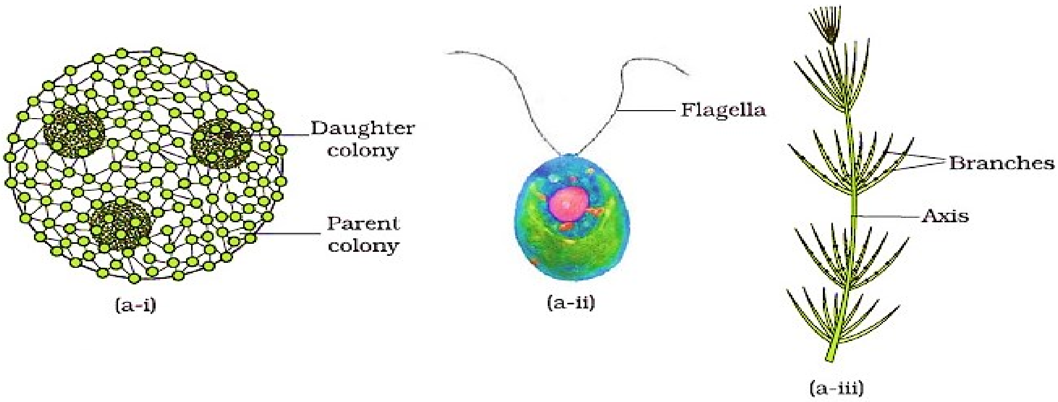


Fig. : Green algae : (a) Volvox, (b) Chlamydomonas, (c) Chara

Phaeophyceae

1. The members of phaeophyceae are commonly called **brown algae.** Brown algae are found primarily in marine habitats.
2. They possess the pigment chlorophyll a and c, carotenoids and xanthophylls.
3. They vary in color from olive green to various shades of brown depending upon the amount of the xanthophylls called **fucoxanthin.**
4. They show great variation of size and form. In Ectocarpus the body is simple branched and filamentous whereas in **kelps** the body is profusely branched e.g., Laminaria, Macrocystis. Kelps may reach a height or 100 meters.
5. Food is stored as complex carbohydrates which may be in the form of **laminarin** or **mannitol** (alcoholic sugar).
6. Brown algae have cell wall made up of cellulose which is usually covered on the outside by a gelatinous coating of algin. Algin is a hydrocolloid which has good water holding capacity.
7. Their protoplast (the living contents of a cell enclosed by the plasma membrane i.e., the cytosol, organelles and nucleus) contains plastids, a centrally located vacuole and nucleus.
8. The plant body is often differentiated into **holdfast** for attachment to substratum, **stipe** (stalk) and leaf-like photosynthetic organ called **frond.**
9. The large forms often possess **air bladders** for providing **buoyancy.**
10. Vegetative reproduction takes place by fragmentation.
11. Asexual reproduction occurs with the help of biflagellate zoospores that are pear-shaped and have two unequal laterally attached flagella.
12. Sexual reproduction may be **isogamous, anisogamous or oogamous.** Fusion of gametes takes place in water but in oogamous species, gametes fuse in the **oogonium.** Oogonium is the female reproductive structure, usually a rounded cell or sac containing egg cell or **oosphere** (the non-motile female gamete).
13. The gametes are pyriform i.e., pear-shaped and bear two laterally attached flagella.
14. The common forms of brown algae are Ectocarpus, Dictyota, Laminaeria, Sargassum and Fucus.

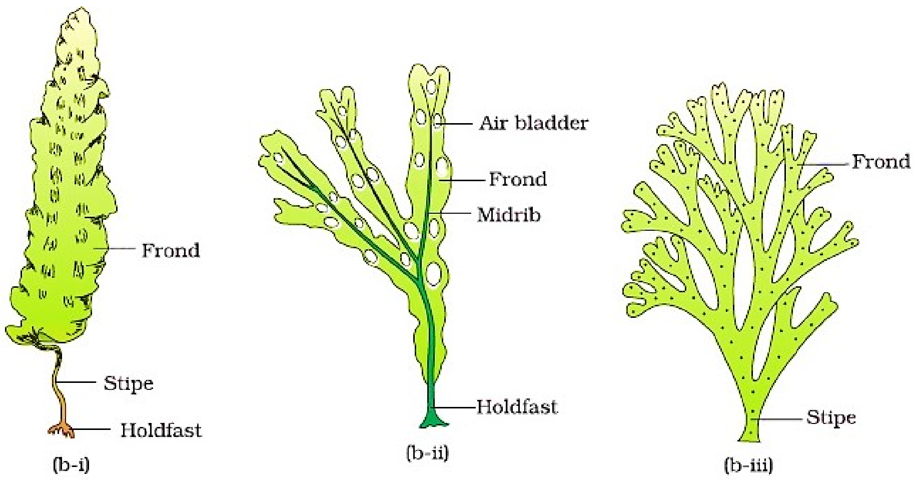
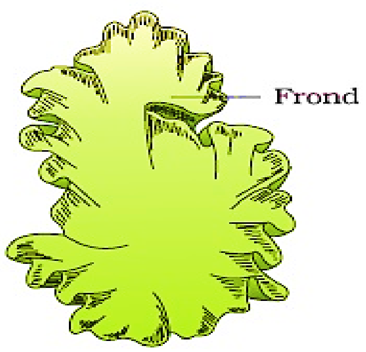


Fig. : Brown algae : (a) Laminaria, (b) Fucus, (c) Dictyota

Rhodophyceae

1. The members of Rhodophyceae are commonly called **Red Algae.** The pigments present in them are r-phycoerythrin, r-phycocyanin, chlorophyll-a and chlorophyll-d. The characteristic red color is due to the predominance of the red pigment, **r-phycoerythrin.**
2. They are mostly found in marine habitats with abundance in the warmer areas.
3. They occur in both well-lighted regions close to the surface of water and also at regions where relatively little light penetrates i.e., at great depths in oceans.
4. Most of the red algae are multicellular. Some of them have complex body organization.
5. Cell wall is composed of cellulose, pectin and hydrocolloids like **agar, carrageen and funori** (hydro colloids).
6. Food is stored in the form of **floridean starch.** Structurally, it very similar to amylopectin and glycogen.
7. They reproduce vegetatively of fragmentation.
8. Red algae reproduce asexually by non-motile spores.
9. Sexual reproduction is oogamous and the gametes are non-motile.
10. Complex post-fertilisation developments occur.
11. The common members are : Polysiphonia, Porphyra, Gracilaria and Gelidium.



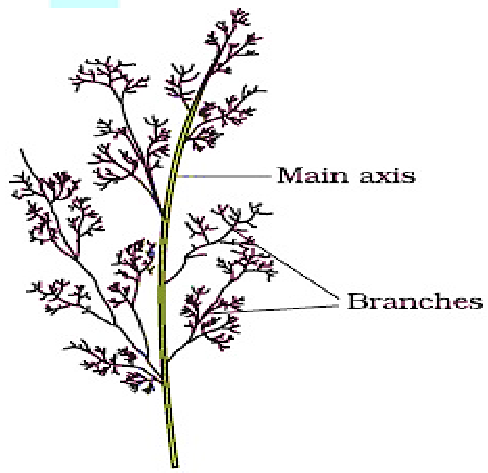


Fig. : Red algae : (a) Porphyra, (b) Polysiphonia

Table : Divisions of Algae and their Main Characteristics

Classes	Common Name	Major Pigments	Stored Food	Cell wall	Flagellar Number and Position of Insertions	Habitat
Chlorophyceae	Green algae	Chlorophyll a, b	Starch	Cellulose	2-8, equal, apical	Fresh water, brackish water, salt water
Pheophyceae	Brown algae	Chlorophyll a, c, fucoxanthin	Mannitol, laminarin	Cellulose and algin	2, unequal, lateral	Fresh water (rare) brackish water, salt water
Rhodophyceae	Red algae	Chlorophyll a, d, phycoerythrin	Floridian starch	Cellulose, pectin & poly sulphate esters	Absent	Fresh water (some), brackish water, salt water (most)

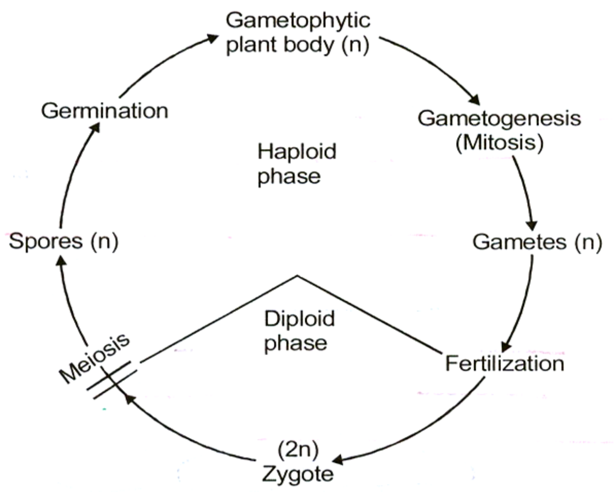


Fig. : Common life cycle in most of the algae (Haplontic life cycle)

Economic Importance :

(i) Photosynthesis : At least a half of the total carbon dioxide fixation on earth is carried out by algae through photosynthesis. Being photosynthetic they increase the level of dissolved oxygen in their immediate environment (as during photosynthesis oxygen is released). It is essential for respiration of aquatic life.

(ii) Primary producers.

(iii) Food supplements : Many species of Porphyra (Red algae), Laminaria and Sargassum (Brown algae) are among the 70 species of marine algae used as food. Certain unicellular algae like Chlorella and Spirullina are rich in proteins and are used as food supplements even by space travelers.

(iv) Hydrocolloids : Hydrocolloids are water-holding substances. Certain marine brown and red algae produce large amounts of hydrocolloids which are used commercially. Algae and carrageen are hydrocolloids obtained from Gelidium and Gracilaria and used to grow microbes and in preparations of ice-creams and jellies.

(v) Iodine : Fucus and Laminaria are rich sources of iodine.

BRYOPHYTES

Bryophytes are non-vascular terrestrial plants of moist habitats in which a multicellular diploid lives as a parasite on an independent multicellular haploid gametophyte.

Bryophytes include the various mosses and liverwort that are found commonly growing in moist shaded areas in the hills.

The main characteristics of bryophytes are :

1. They are found commonly in damp, humid and shaded localities.
2. The plants are small. They seldom attain great length of height.
3. They are also called **amphibians** of the plant kingdom because these plants can live in soil but are dependent on water for sexual reproduction.
4. The plant body of bryophytes is more differentiated than that of algae. It is thallus-like and may be prostrate or erect. They lack true roots, stems or leaves but possess root-like, leaf-like or stem-like structures. The plant body is attached to the substratum by root-like structures called rhizoids. The rhizoids may be unicellular or multicellular.
5. Vascular tissues i.e. xylem and phloem are absent.
6. The dominant phase or the main plant body is a free-living gametophyte and the sporophyte is born on the gametophyte.
7. Gametophyte is the haploid stage of a plant that generates gametes by the process of mitosis hence is called as gametophyte.
8. The gametophyte of bryophyte consists of multicellular sex organs. The male sex organ is called **antheridium** and the female sex organ is flask-shaped called **archegonium.**

   Antheridium is surrounded by a sterile jacket which encloses mass of sperm mother cells/androcytes which produce two biflagellated antherozoids (motile male gametes). Archegonium is flask-shaped with tubular neck and swollen venter. Just like antheridium, female sex organ is also surrounded by a jacket. Venter cavity possesses a sterile venter canal cell and a fertile egg. Neck encloses a few sterile neck canal cells.

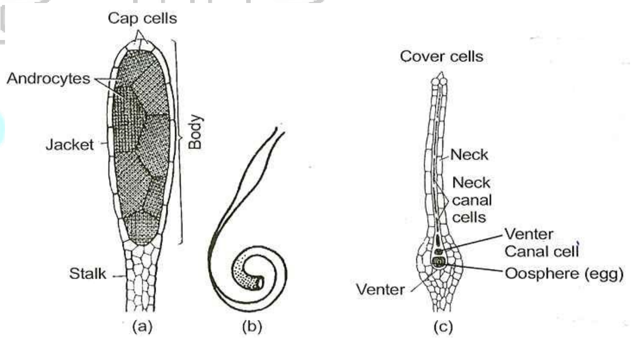


Fig. : (a) An antheridium (b) One antherozoid (c) An archegonium

9. An external layer of water is essential for the swimming of antherozoids to the archegonia.
10. Fertilisation produces zygote that is formed inside the archegonia. Zygotes do not undergo reduction division (meiosis) immediately instead they undergo mitotic division to form the embryo which develops further into diploid sporophyte. They are first **embryophytes.**

11. The sporophyte is riot free-living but attached to the photosynthetic gametophyte and derives nourishment from it
12. The sporophyte of bryophytes consists of three parts namely **capsule, seta** and **foot.** inside the **capsule**, the **spore mother cells** undergoes meiosis to produce haploid spores (sporic meiosis).
13. Bryophytes are **homosporous** i.e., they produce only one type of spores.
14. The spores get disseminated by wind. As the air shakes the capsule the spores come out and are dispersed. Spores have the ability to germinate immediately after falling on the suitable substratum.
15. When the spores fall on a suitable substratum, they germinate either directly into the thalloid gametophyte (as in liverworts) or through a filamentous stage called protonema (as in mosses).
16. Vegetative reproduction occurs through fragmentation, gemmae and budding.

The bryophytes are divided into liverworts and mosses.

Liverworts

1. Liverworts grow usually in moist, shady habitats such as banks of streams, marshy ground, damp soil, bark of trees and deep in the woods.
2. The plant body of liverwort is thalloid as in Marchantia. The thallus is dorsiventral and closely appressed to the substratum. The leafy members like Porella have tiny leaf-like appendages in two rows on the stem like structure.
3. Asexual reproduction occurs by means of fragmentation or by the formation of specialised structures called **gemmae** (sing. - gemma). Gemmae are green, multicellular asexual buds which develop in small receptacles called gemma cups located on the thalli. Mature gemmae become detached from the parent body and germinate to form new individual.
4. During sexual reproduction the sex organs antheridia (male) and archegonia (female) are produced either on the same (Riccia) or on different thallium (Marchantia). In Marchantia sex organs are present on stalked receptacles. The male sex organs are present on **antheridiophore** and female sex organs are borne on the **archegoniophore.**

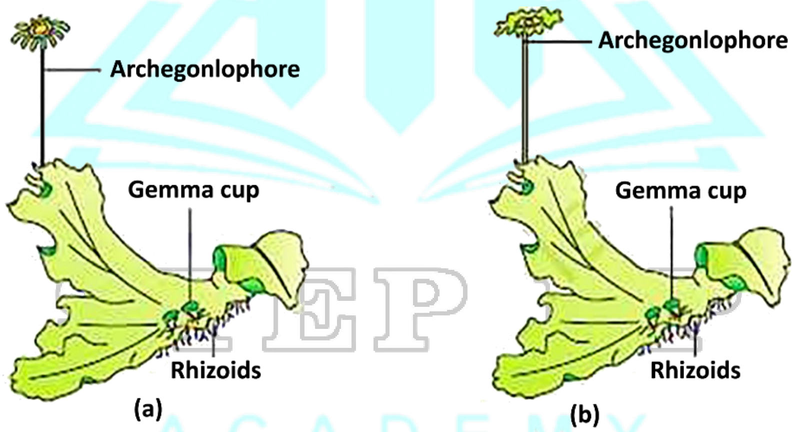


Fig. : Bryophytes : A liverwort – Marchantia : (a) Female thallus, (b) Male thallus

5. Fusion of gametes results in the formation of zygote which develops into an embryo. The embryo in turn develops into sporophyte (diploid).
6. The sporophyte is differentiated into foot, seta and capsule. Within the capsule, the spore mother cells undergo meiosis to produce the haploid spores. Spores on liberation germinate into the haploid free-living gametophyte.

Mosses

1. The predominant stage of life cycle of a moss is the gametophyte which consists of **protonema** and leafy stages.
2. The plant body is a leafy gametophyte which has multicellular and branched rhizoids. They consist of upright, slender axis bearing spirally arranged leaves. This stage bears the sex organs.
3. In sexual reproduction, the sex organs antheridia and archegonia are produced at the apex of the leafy shoot. The sex organs are present on the same plant but on different branches.
4. Each antheridium produces a number of biflagellate antherozoids.
5. Each archegonium produces a fertile egg.
6. Fusion of gametes with the help of water leads to the formation of zygote. The zygote develops into a sporophyte which is differentiated into foot, seta and capsule.

7. The capsule encloses two spore sacs, where spores are formed by meiosis. The mosses have an elaborate mechanism of spore dispersal.
8. The spores on liberation germinate into a creeping, green, branched and frequently filamentous stage called protonema (juvenile stage).
9. Vegetative reproduction in mosses is by fragmentation and budding in the secondary protonema. Leafy stage develops from the secondary protonema as a lateral bud.
10. Common examples of mosses are Funaria, Polytricum and Sphagnum.

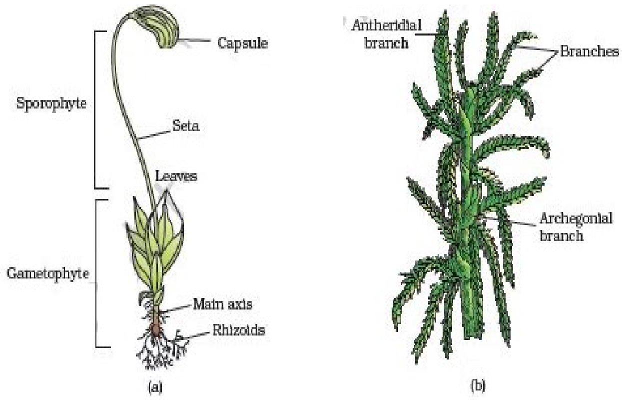


Fig. : Mosses (a) Funaria, Gametophyte and Sporophyte, (b) Sphagnum Gametophyte

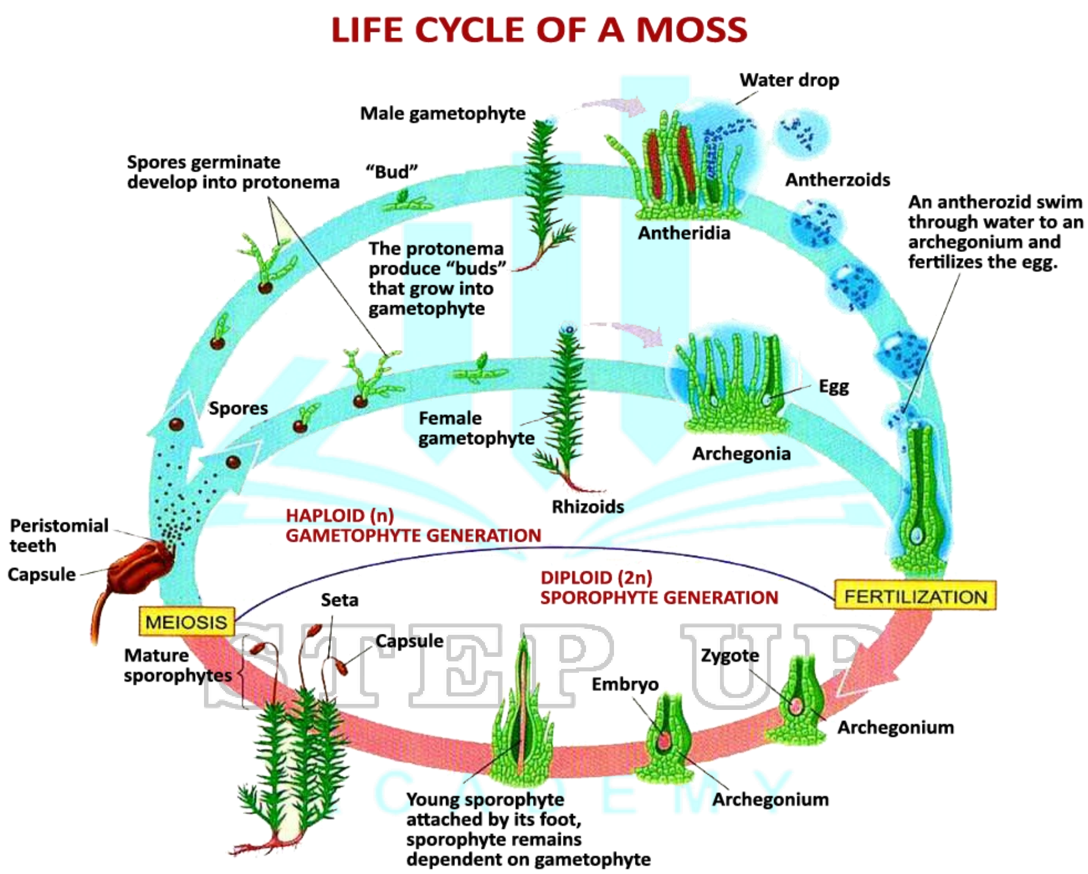


Fig. : Graphical Representation of Life Cycle of Moss

Economic importance :

(i) Prevention of soil erosion: Bryophytes, especially. mosses form dense mats over the soil and prevent soil erosion against falling rains.

(ii) Soil formation: Mosses are an important link in plant succession on rocky areas. They take part in building soil in rock crevices formed by lichens. Growth of Sphagnum (Bog moss) ultimately fills ponds and lakes with soil

(iii) Water retention: Dry Sphagnum has great water absorbing capacity. This characteristic is employed by gardeners to keep seedlings and cut-plants moist during transportation and propagation. Sphagnum moss was used in place of absorbent cotton, so it is also called cotton moss.

(iv) Peat: Sphagnum often grows in acidic marshes. The older dead parts of moss and other marshy plants got slowly carbonised, compressed and fossilised over thousands of years and have produced a dark spongy mass called peat. Peat is dried, compressed and cut to form blocks. The peat blocks are used as fuel. Peat is also a good manure. It overcomes soil alkalinity and increases its water retention as well as aeration.

(v) **Other uses:** In rocky and ice-cold areas mosses are a good source of food for certain animals like birds. A decoction of Polytrichum commune employed in removing kidney stones.

PTERIDOPHYTES

They are seedless vascular plants including horsetails and ferns.

The main characteristics of pteridophytes are:

1. The pteridophytes are found in cool, damp, shady places though some may flourish well in sandy-soil conditions.
2. Evolutionarily they are the first terrestrial plants to possess vascular tissues- xylem and phloem. Xylem transports water and minerals while phloem conducts organic food.
3. The dominant phase or independent plant is a sporophyte.
4. Main plant body is differentiated into true stem, leaves and roots.
5. The leaves in pteridophyta may be small (microphylls) as in Selaginella or large (macrophylls) as in ferns.

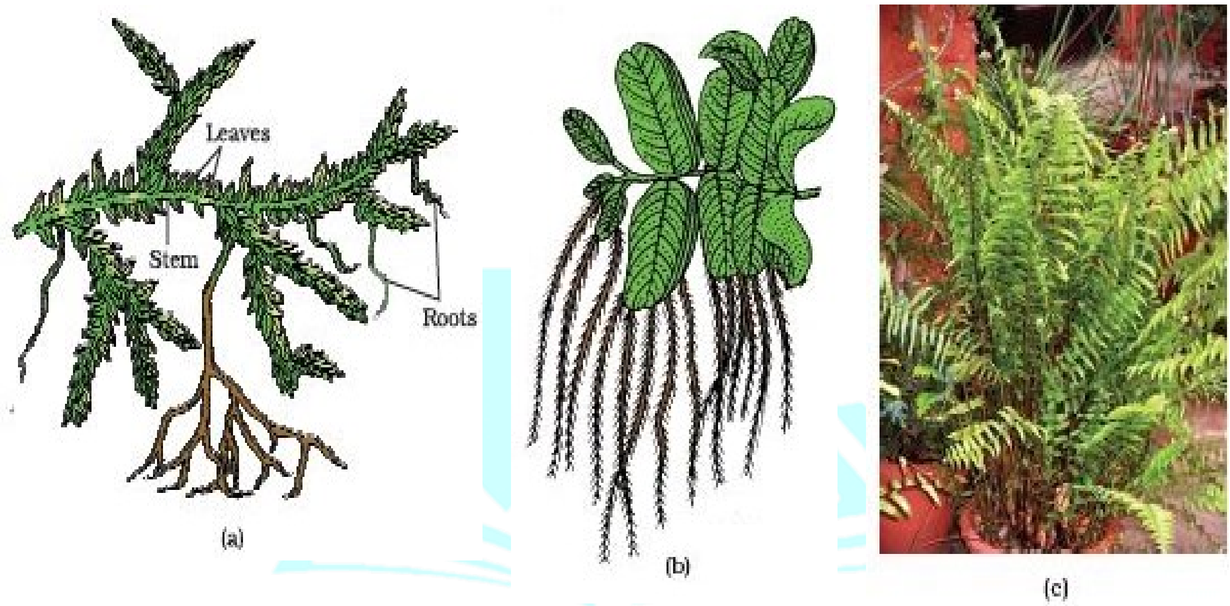


Fig. : (a) Selaginella, (b) Salvinia (aquatic fern), (c) Terrestrial fern

6. The leaflets and leaves having sporangia are called sporophylls.
7. The sporangia contain sporogenous tissue where spore mother cells undergo sporic meiosis to produce spores.
8. In some pteridophytes Selaginella and Equisetum the sporophylls may be compactly arranged into structures called strobili or cones.
9. Plants like Lycopodium, Dryopteris etc. produce a single kind of spores and are known as **homosporous** whereas plant is like Selaginella, Salvinia etc. produce two kinds of spores, macro (large) and micro (small) spores. They are known as **heterosporous**.
10. The spores germinate to give rise to inconspicuous, small but multicellular free living and mostly photosynthetic thalloid gametophytes called **prothallus.**
11. The megaspores and microspores germinate and give rise to female and male gametophytes respectively.

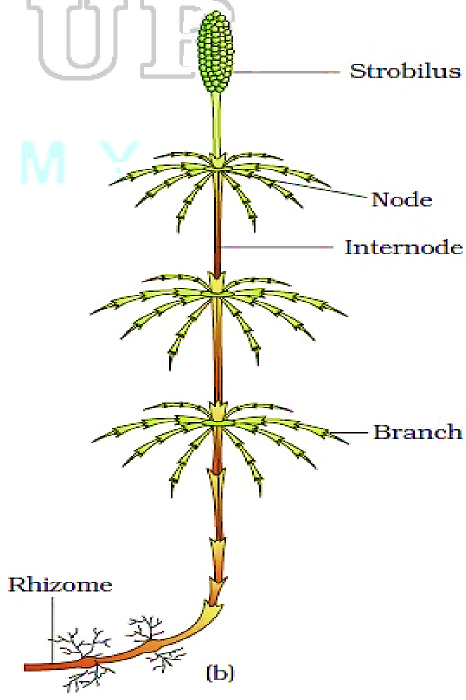


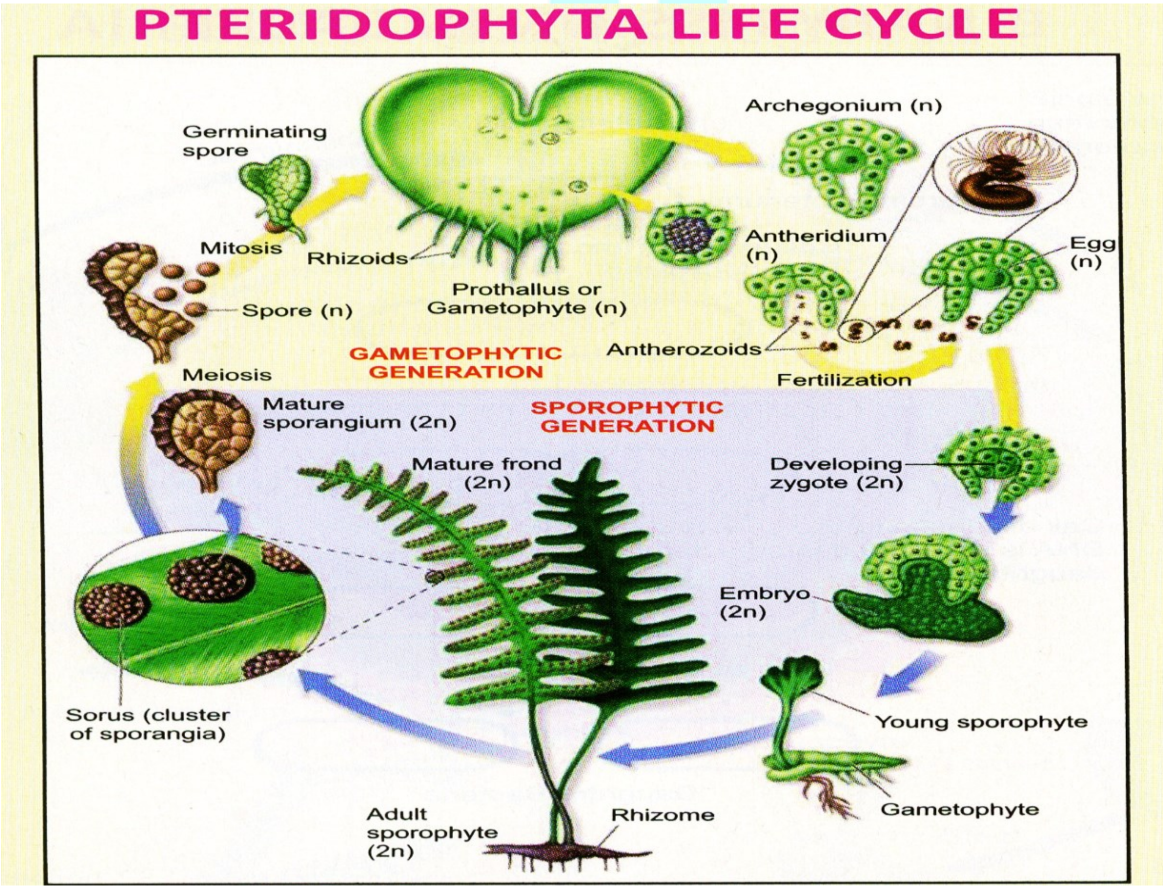
Fig. : Equisetum

12. The gametophytes bear male and female sex organs called antheridia and archegonia respectively.
13. The gametophyte that develops in homosporous species is monoecious (having male and female reproductive structures on the same individual) while those of heterosporous species is dioecious (plants having the male and female reproductive structures on different individuals).
14. These gametophytes require cool, damp, shady places to grow. Because of this specific restricted requirement and the need for water- for fertilisation, **the spread of living pteridophytes is limited and restricted to narrow geographical regions.**
15. Sperms are flagellated (antherozoids). They require an external supply of water for swimming to the mouth of archegonium.
16. Fusion of gametes results in the formation of zygote which develops into embryo. The embryo develops into a multicellular well-differentiated sporophyte.
17. In the heterosporous species the female gametophyte remains on the parent sporophytes for variable periods. The development of the zygotes into young embryos takes place within the female gametophytes. **This event is a precursor to the seed habit (tendency towards seed formation) considered an important step in evolution.** Hence, heterospory leads to seed habit in plants.
18. Heterosporous vascular cryptogams like Selaginella and Marsilea fail to develop seeds because :

(a) They have no protective structure like the integuments surrounding the megasporangia.

(b) The retention of megaspores permanently within the megasporangia has not become established.

19. The pteridophytes are further classified into four classes. Psilopsida (Psilotum), Lycopsida (Selaginella, Lycopodium), Sphenopsida (Equisetum) and Pteropsida (Dryopteris, Pteris, Adiantum).



Economic importance :

(i) Soil binding: Pteridophytes bind the soil even along hill slopes. The soil is protected from erosion.

(ii) Medicines: An antihelmintic drug is obtained from a pteridophyte called Dryopteris.

(iii) Ornamentals: Ferns are grown as ornamental plants for their delicate and graceful leaves.

(iv) Food: Marsilea, a water fern yields starch that constitutes a good source of food for certain tribals.

(v) Scouring: Equisetum stems have been used in scouring (cleaning of utensils) and polishing of metals.

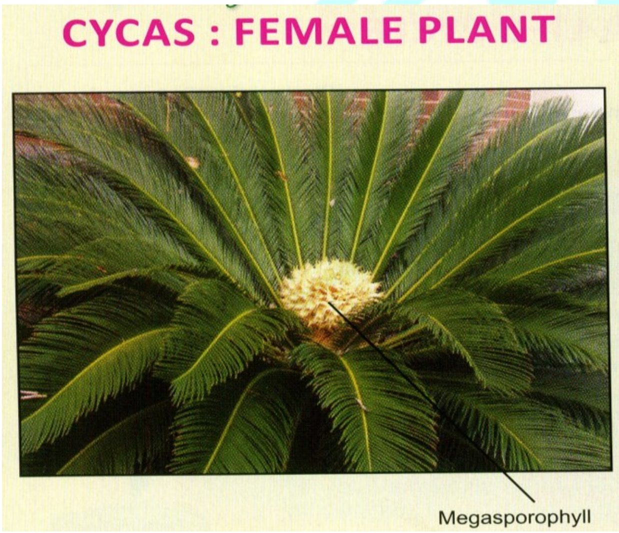
GYMNOSPERMS

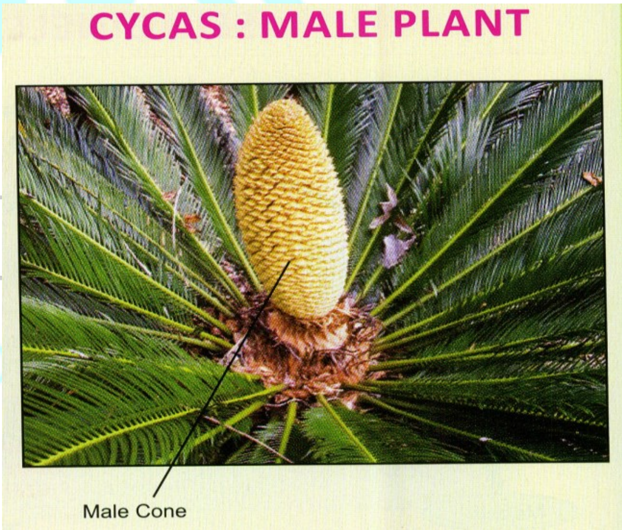
The gymnosperms (gymnos: naked, sperma: seeds) are plants in which the seeds are not enclosed within fruit wall, i.e., they bear naked seeds. These are seeded plants without fruits.

The main characteristics of gymnosperms are :

1. They include medium-sized trees or tall trees and shrubs. The Sequoia (red wood tree) is one of the tallest tree species.
2. Unlike bryophytes and pteridophytes, in gymnosperms the male and female gametophytes do not have an independent free-living existence.
3. The plants represent the diploid sporophytic phase in the life cycle.
4. Plant body is differentiated into roots, stem and leaves.
5. The **roots** are generally **tap roots.** The direct elongation of the radicle leads to the formation of primary root which grows inside the soil. The primary roots and its branches constitute the tap root system. Roots in some genera (Pinus) have fungal association in the form of **Mycorrhiza**. Mycorrhiza is symbiotic association of a fungus and the root of a higher plant. While in some others (Cycas) small specialised roots called coralloid roots are associated with nitrogen-fixing cyanobacteria. Coralloid roots are irregular that do not possess root hairs and root caps.
6. The **stems** are unbranched (Cycas) or branched (Pinus, Cedrus).
7. The **leaves** may be simple or compound. In Cycas the **pinnate leaves** persist for a. few years. In simple leaf, there is a single lamina which is usually entire. In compound leaf incision of lamina reaches up to the midrib or petiole due to which lamina is divided into several small parts known as leaflets.

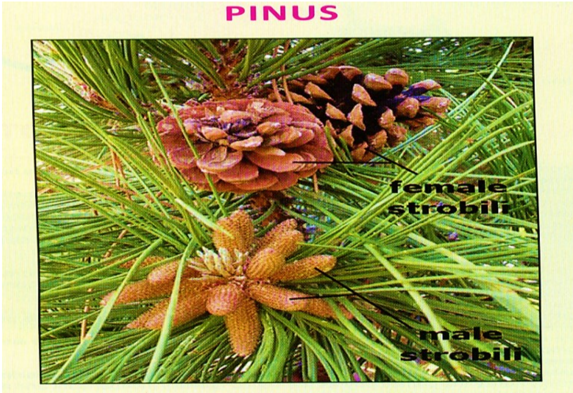
Fig: Cycas





8. The leaves in gymnosperms are well-adapted to withstand extremes of temperature, humidity and wind. In conifers, the needle-like leaves reduce the surface area. Their thick cuticle and sunken stomata also help to reduce water loss) Leaves of Ginkgo biloba are fan-shaped.
9. They have well-developed vascular tissues - xylem and phloem.
10. Gymnosperms are heterosporous and produce smaller microspore and larger megaspore. The two kinds of spores are produced within sporangia that are borne on sporophylls which are arranged spirally along an axis to form lax or compact strobili or cones.
11. Sporophylls are of two types: microsporophylls and megasporophylls.
12. Microsporophylls are compactly arranged on a central axis to form a **male strobili** or

microsporangiate/pollen cone. They bear microsporangia where microspore mother cells undergo meiosis to form microspores. The microspores develop into a male gametophytic generation which is **highly reduced** (haploid) and is confined to only a limited number of cells. This reduced gametophyte is called a **pollen grain**. The development of pollen grains takes place within the microsporangia.



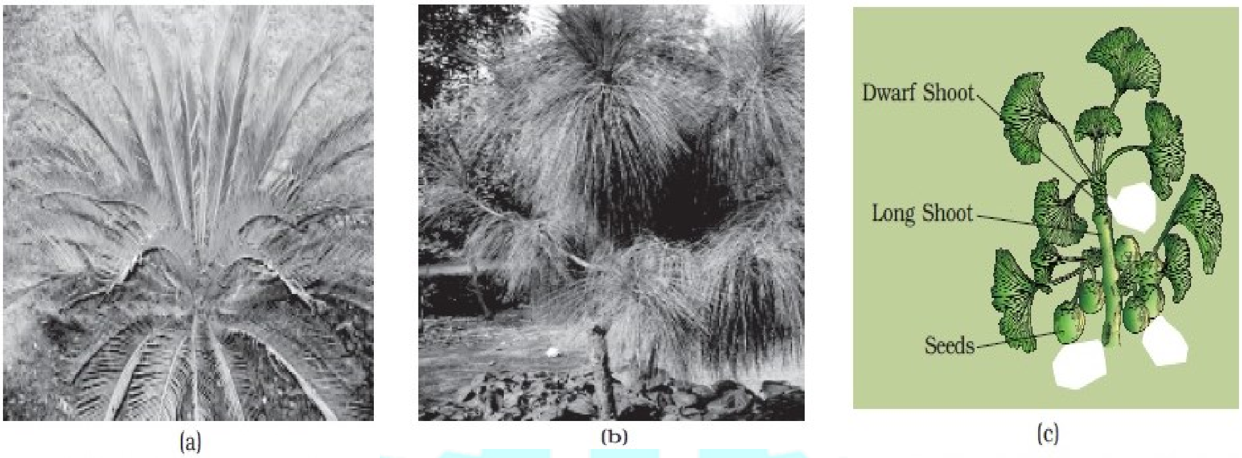


Fig: Some Gymnosperms: (a) Cycas, (b) Pinus, (c) Ginkgo

13. Megasporophylls are compactly arranged to form female strobili or macrosporangiate/seed cone. They bear the integumented megasporangia (ovules). The ovule or the integumented megaspprangiurn. Mainly consists of a body called nucellus protected by envelope or integument.
14. The male or female reproductive bodies may be borne on the same tree (Pinus) or different trees (Cycas).
15. One of the cells of the nucellus differentiates as megaspore mother cell which undergoes meiosis to form a tetrad of megaspores of which three degenerate.
16. The functional megaspore enclosed within the megasporangium (nucellus) undergoes repeated mitosis and develops into a multicellular female gametophyte that bears two or more **archegonia** (female sex organs). The multicellular female gametophyte is also retained within megasporangium.
17. During pollination the grains are carried in **air currents** and reach the opening of the ovules (micropylar end) borne on megasporophylls.
18. Each pollen grain germinates and the resulting pollen tubes discharge the male gametes near the mouth of the archegonia.
19. Fertilization results in the formation of zygote, which develops into an embryo.
20. Ovules become transformed into seeds as the female gametophyte is retained within ovule on the sporophyte plant and embryo development also continues on the parent plant. These seeds are not covered.

PINUS LIFE CYCLE

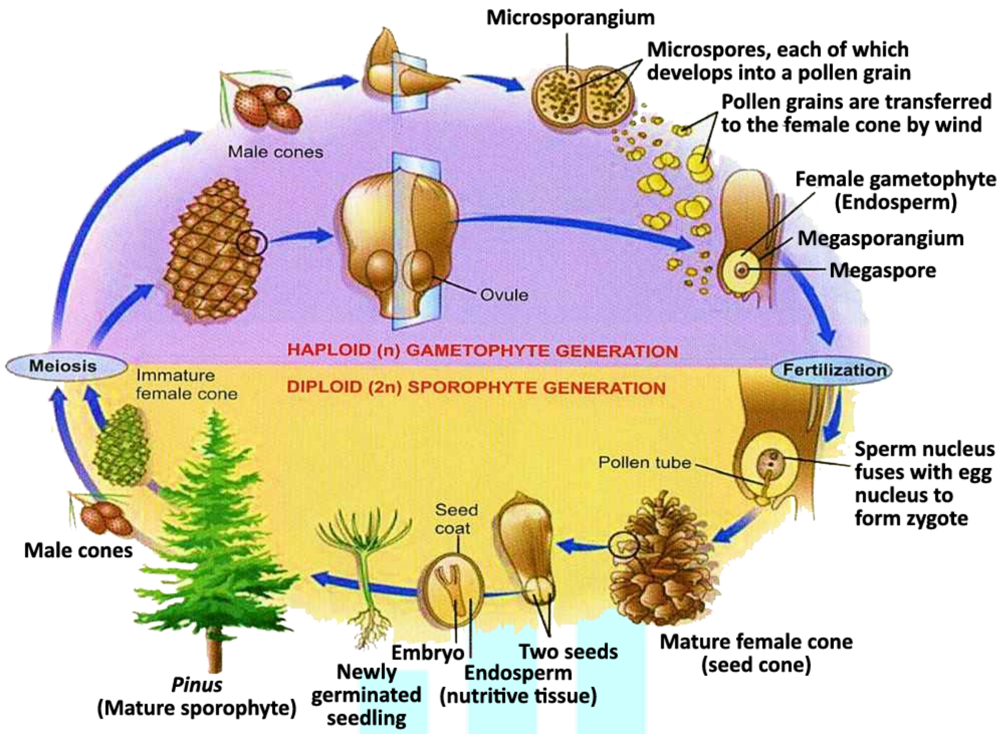


Fig. : Life cycle of gymnosperm (Pinus)

Economic importance :

(i) Edible seeds: Seeds of Pinus gerardiana called chilgoza are edible. They are eaten after roasting.

(ii) Timber: Gymnosperms possess softwood. It is used in preparation of light furniture, plywood, packing cases, match-sticks, railway sleepers, etc.

(iii) Paper: A number of gymnosperm woods are used in the manufacture of paper.

(iv) Fiber board's: Needle of Pinus and other conifers are used in making fibre boards that are used in making packing cases.

(v) Ephedrine: Drug ephedrine is obtained from Ephedra a gymnosperm. The drug is used in curing respiratory ailments including asthma.

(vi) Taxol: An anticancerous drug called Taxol is obtained from the bark of Taxus.

ANGIOSPERMS

Angiosperms (Gk. angion - vessel, sperma - seed) are those plants in which seeds are formed inside fruit and the sporophylls are organised into **flowers**.

The main characteristics of angiosperms are:

1. These are the flowering plants where ovules are enclosed in the ovary and hence seeds are enclosed in the fruit.
2. This is the largest group of plants occurring in a wide range of habitats.
3. They range in size from tiny almost microscopic Wolffia (smallest angiosperm) to tall trees Eucalyptus (over 100 meters).
4. Angiosperms are divided into two classes - on the basis of number of embryonic leaves or cotyledons: the **dicotyledons** and the **monocotyledons**. The two are commonly spoken as dicots and monocots respectively. Dicots are flowering plants which are characterised by the presence of two cotyledons in the seed e.g., Pea, Rose, Eucalyptus, Mustard, Cotton, Acacia, Sunflower. Monocots are angiospermic or flowering plants which are characterised by the presence of a single cotyledon in the seed e.g., Banana, Cereals, Palms, Grass, Bamboo, Orchids.


(a)


(b)

Fig. Angiosperms: (a) A dicotyledon, (b) A monocotyledon

5. A flower is the shoot modified for reproduction. The male and female sex organs of a flower are stamen and pistil/carpel respectively.
6. Each stamen consists of a slender filament with an anther at the tip. Anther is the pollen bearing part of a stamen. The anther encloses microsporangia, where the microspore mother cells undergo sporic meiosis to form microspores. Microspores develop into pollen grains.
7. **Pistil or the carpel** is the female sex organ in a flower. A pistil has three parts - **stigma, style** and **ovary**. Stigma is the terminal receptive part of the pistil which functions as landing platform for the pollen grains. Style is elongated narrow stalk that connects the ovary with the stigma. Ovary is the basal swollen part of the pistil. It may have one to several ovules.
8. Inside the ovary is the ovarian cavity where the placenta (the part of the ovary of flowering plants which bears the ovules) is located. Arising from the placenta are the megasporangia commonly called ovules. The number of ovules in an ovary may be one (wheat, mango) to many (papaya, watermelon). Each ovule has one or two protective envelops called integuments. Enclosed within the integuments is a mass of cells called the nucellus.
9. A single megaspore mother cell of the nucellus undergoes sporic meiosis to produce four haploid megaspores. Out of the four only one is functional while the other three degenerate. The functional megaspore develops into the female gametophyte or the **embryo sac.** Thus embryo sac formation is preceded by meiosis.

   Let us study the formation of embryo sac in a little more detail. The functional megaspore divides mitotically forming 2-nucleate embryo sac. Two more sequential mitotic nuclear divisions results in the formation of the 4-nucleate and ultimately 8-nucleate stage, leading to the organisation of the typical female gametophyte or embryo sac. Each cell of the embryo sac is haploid.
10. Each embryo sac has a three-celled egg apparatus - one egg cell and two **synergids,** three **antipodal** cells and two **polar nuclei**. The polar nuclei eventually fuse to produce a diploid **secondary nucleus**.

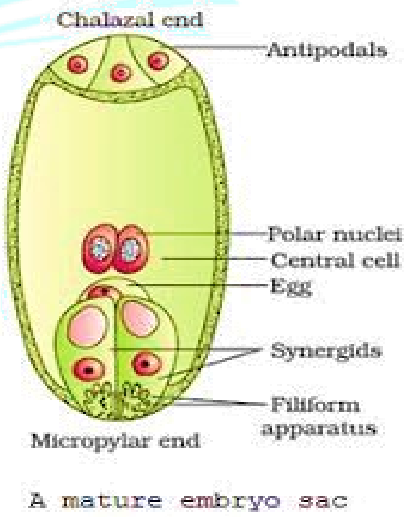


Fig.: A diagrammatic representation of the mature embryo sac.

11. After the dispersal from the anthers, pollen grains are carried by wind or various other agencies to the stigma of a pistil. This transfer of pollen from anther to stigma is known as **pollination**.
12. The pollen grain germinates on the stigma and the resulting pollen tube grows through the tissues of stigma and style and reaches the ovule. The pollen

tube enters the embryo sac through the micropylar end and discharge the two male gametes present in the pollen grain. One of the male gamete's fuses with the egg cell to form the zygote. This is known as **syngamy**. The other male gamete fuses with the diploid secondary nucleus to produce the triploid **primary endosperm nucleus (PEN). Thus, double fertilisation occurs, an event unique to angiosperms.**

13. After fertilization the synergids and antipodal cells degenerate. The zygote develops into an embryo and the primary endosperm nucleus (PEN) develops info endosperm which provides nourishment to the developing embryo. **The synergids and antipodals degenerate after fertilisation.**
14. Thus, the zygote develops into embryo and the fertilized ovules into seeds and ovaries develop into fruit. Thus, seeds are covered by fruit wall. A fruit is technically a ripened ovary.

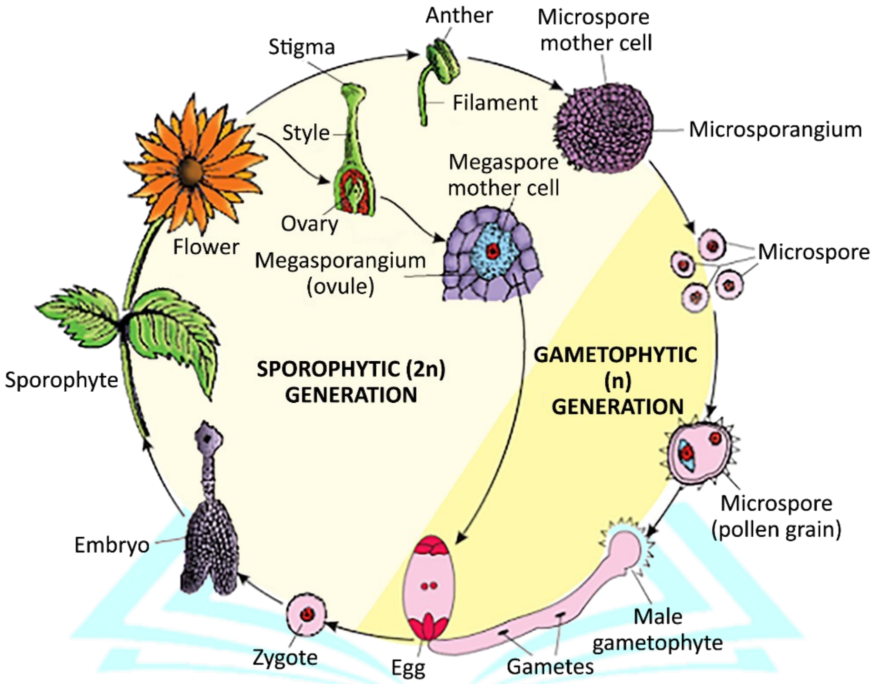


Fig. : Life cycle of an angiosperm

Economic Importance :

(i) **Food**

(ii) **Edible oils**

(iii) **Spices**

(iv) **Beverages**

(v) **Medicines**

(vi) **Timber**

(vii) **Fibres**

Differences between various plant groups having embryo

Features	Bryophyta	Pteridophyta	Gymnosperms	Angiosperms
Dominant phase	Gametophyte	Sporophyte	Sporophyte	Sporophyte
Ploidy of main plant body	Haploid	Diploid	Diploid	Diploid
Differentiation of body	Thallus or foliose Structures and rhizoids	Root, stem and leaves	Root, stem and leaves	Root, stem and leaves
Vascular bundles	Absent	Present	Present	Present
Nature of spores	Homospores	Homospores and Heterospores	Heterospores	Heterospores
Seed and its coverings	Seed absent	Seed absent	Seed naked (without covering)	Seed with covering
Flower and fruit	Absent	Absent	Absent	Present

PLANT LIFE CYCLES AND ALTERNATION OF GENERATIONS :

In plants, formation of haploid and diploid bodies occurs because both the haploid and diploid cells are able to divide by mitosis. The haploid plant body known as gametophyte produces gametes by mitosis. After the fertilisation the diploid zygote also divides by mitosis to produce a diploid sporophytic plant body. The diploid sporophytes undergo meiosis to produce haploid spores which in turn divide by mitosis to form a haploid plant body once again. Thus, during the life cycle of a sexually reproducing plant, there is an alternation of generations between gamete producing haploid gametophyte and spore producing diploid sporophyte. Let us try to understand life cycles patterns of different plant groups.

1. Haplontic Life Cycle

(i) The dominant phase in the life cycle is a free-living photosynthetic haploid gametophyte.

(ii) The diploid or sporophytic generation is represented only by the single-celled zygote.

(iii) The zygote undergoes meiosis (zygotic meiosis) and forms haploid spores. The spores on germination give rise to gametophyte. This pattern is represented by many algae such as Volvox, Spirogyra and some species of Chlamydomonas.

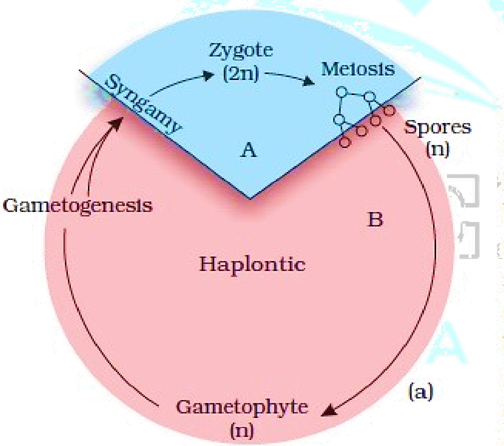


Fig: Haplontic Life cycle

2. Diplontic Life Cycle

(i) The dominant phase in the life cycle is the photosynthetic independent diploid sporophytic plant.

(ii) Meiosis occurs in the spore mother cells (diploid) and the gametophytic phase is represented by the single to few celled haploid gametophyte which is short-lived and is dependent on the photosynthetic sporophyte. This pattern of life cycle is followed by all seed-bearing plants i.e., gymnosperms and angiosperms.

Fucus: a brown alga is diplontic.

In Fucus, meiosis occurs during gametogenesis.

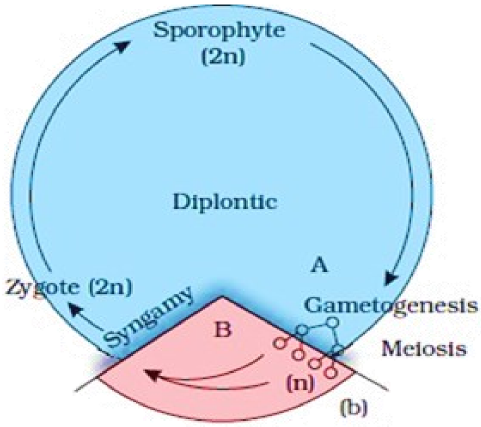


Fig: Diplontic Life Cycle

3. Haplo-diplontic Life Cycle

(i) It is an intermediate type of life cycle, where both the sporophyte and gametophyte are multicellular, equally dominant and often free-living. Bryophytes and pteridophytes exhibit this pattern.

(ii) In bryophytes, the dominant phase is the independent, photosynthetic, thalloid or erect haploid gametophyte and it alternates with the short-lived multicellular sporophyte totally or partially dependent on the gametophyte for its anchorage and nutrition.

(iii) In pteridophytes, the dominant phase is represented by the sporophyte which is diploid, independent, photosynthetic vascular plant body. It alternates with multicellular, independent but short-lived haploid gametophyte.

Algae exhibit haplontic life cycle but some of them such as Ectocarpus, Polysiphonia, kelps are haplo-diplontic.

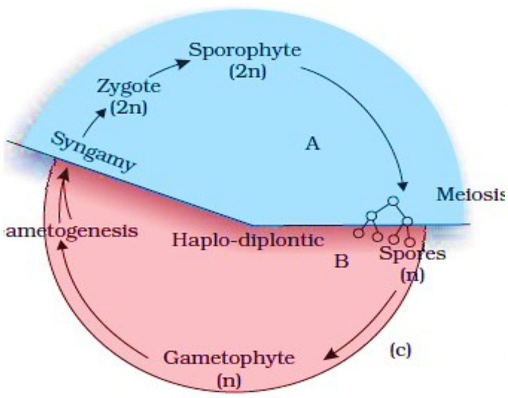


Fig: Haplo-diplontic Life

Chapter 4
Animal Kingdom

Introduction:

Every day you come across a number of animals. Have a look at your surroundings, you can see a diverse range of animals. You see parrots, Cockroaches, dogs, cats, horses, fishes, monkeys, cows, houseflies, mosquitoes, frogs, ants, butterflies, etc. and last but not the least human beings. Some fly, some creep, some jump, some walk and some swim. Just observe them how different they look, how differently they behave, their habits, their habitats, everything is so diverse and different and yes amazing too.

KINGDOM ANIMALIA : BASIC FEATURES OF ALL ANIMALS

The Kingdom animalia is characterized by **heterotrophic eukaryotic organisms** that are multicellular and their cells lack cell walls. Let's elaborate this statement to understand completely the various features of animals.

(i) **Heterotrophic Nutrition:** All animals are heterotrophs. They directly or indirectly depend on plants for food. Now what is the meaning of directly or indirectly depending on plants as we know animals can be **herbivores, carnivores** on the basis of their nutritional requirements. Those animals which are herbivores, depend directly on plants as they eat only plant products like fruits, vegetables, cereals, pulses etc. Whereas the animals which are carnivores or omnivores eat other animals which obtained their nutrition from either plants or other animals. For e.g., lions eat deers and deers eat grass. Hence lions indirectly depend on grass. Here lions are carnivores and deers are herbivores. Hence all animals directly or indirectly depend on plants for food and cannot survive without them.

(ii) **Holozoic Mode of Nutrition:** Nutrition involving engulfment of the whole or part of plant or an animal either in solid or in liquid state is called as animal like or holozoic nutrition. Holozoic mode of nutrition involves the **ingestion, digestion** (i.e., breakdown by enzymes), **absorption** and **assimilation** to properly utilize the food. This food 'taken in' and is stored in the body in the form of 'food reserves'. Glycogen and fat are the common food reserves in body of animals.

(iii) **Multi cellular:** No animal is unicellular. All are multi cellular. Their body is made more than one cell. Now some can have hundreds of cells and some others billions or trillions of cells. But they all are said to possess multi cellularity.

(iv) **Growth:** The animals show a definite growth pattern from birth to death. All of them grow into adults that have a definite shape and size. Sometimes the adult forms are remarkably different from their young ones about which we will study later in the metamorphosis.

(v) **Locomotion:** Most of the animals are capable of locomotion. Animals move from place in search of food, shelter, protection, mates, etc. some animals that cannot move from one place to another and are said to be sessile e.g., sponges. They remain attached permanently to any solid support which is called substratum.

(vi) **Nervous and Sensory Control:** Higher animals show elaborate sensory and neuro motor mechanism and are aware of their surroundings. Their nervous, sensory and endocrine systems fully control and coordinate the body. Nervous system controls all other systems of the body. Sensory system makes an organism aware of all the changes in the environment. The endocrine system provides chemical integration through hormones. But lower animals do not possess that much specialized controlling systems.

(vii) **Reproduction:** Sexual reproduction is the major of reproduction which includes copulation of male and female followed by embryological development. Although some lower animals also undergo asexual modes of reproduction like fragmentation, budding, etc.

BASIS OF CLASSIFICATION

In spite of differences in the structure and form of different animals, there are certain fundamental features which are common to various individuals in relation to :

(1) **Levels of organization** also called grades of organization.
(2) Patterns of **digestive, circulatory or reproductive system,**
(3) **Body symmetry.**
(4) Number of **germ layers** during embryonic development.
(5) Nature of **coelom** or body cavity.
(6) Presence or absence of **segmentation** in the body.
(7) Presence or absence of **notochord.**

These features are used as the basis of animal classification:

(1) Levels of Organization

Organization means an orderly arrangement. We know that cell is the building block of body of all living organisms. Many specialized cells organized to form a tissue, many tissues an organ, many organs, an organ system and finally many organ-systems an organism.

On the basis of how cells are arranged in the body of animals following four levels of organization seen in animals are:

(i) Cellular level of organization
(ii) Tissue level of organization
(iii) Organ level of organization
(iv) Organ-system level of organization

(i) Cellular level of organization: Cells are the basic unit in this level and perform vital functions of organism. The cells are arranged as loose cell aggregates but they do not form any tissue.

Some division of labour (activities) occur among the cells.

This level is exhibited by **poriferans** (members of phylum porifera) whose body are made up of loose aggregates of cells.

(ii) Tissue level of organization: This level is somewhat higher and complex to cellular level in which the cells performing the same function or structure and are arranged to form tissues. The tissues perform the various basic functions of animals. This level of organization is present in **coelenterates** and **ctenophores**.

(iii) Organ level of organization: When tissues are grouped together to form organs this level is called organ level of organization. Here each organ is specialised for a particular function. This level is exhibited by **platyhelminthes**.

(iv) Organ-system level of organization: In higher animals, organs are associated to form functional systems and each system concerned with a specific physiological function. For example, various organs like stomach, intestine, gall bladder, pancreas etc. unit to form the digestive system.

Different organ systems depend upon each other to maintain the functioning of an organism. This level is exhibited by **aschelminthes to chordates.**

(2) Patterns of Complexities of Various Organ Systems

Organ and organ system levels began in lower animals like platyhelminthes and aschelminthes but their complexity kept on increasing from lower to higher phyla. These complexities are quite obvious and can be used as a basis of classification of animals.

(i) Digestive System: The digestive system of animals can be of two types on the basis of complexity :

(a) Incomplete digestive system: When the digestive system has only a **single** opening to the outside of the body that serves as both mouth and anus it is called an incomplete digestive system. **Coelenterates, Ctenophores and Platyhelminthes** possess incomplete digestive system.

(b) Complete digestive system: When the digestive system has **two** openings mouth and anus it is called complete digestive system. Hence the entry of food and exit of waste takes place from separate openings. **Aschelminthes to chordates** all possess complete digestive system.

(ii) Circulatory System: Similarly the circulatory system may be of two types :

(a) Open circulatory system: In open type the body cells and tissues are directly bathed in the blood pumped out of the heart as the blood flows in open spaces. Hence there is a direct contact and exchange of materials between the blood and body cells.

e.g., Arthropods, non cephalopod molluscs, hemichordates and tunicates.

(b) Closed circulatory system: In this system, the blood circulates through a series of the blood vessels of varying diameters, i.e., arteries, veins and capillaries without ever coming in direct contact with the body cells. A series of these vessels maintain the continuous flow of blood. The exchange of materials between blood and body cells takes place in the capillaries.

e.g., Annelids, Cephalopod, mollusks, Chordates.

(iii) Reproductive system: Lower animals like sponges, coelenterates- undergo asexual reproduction along with the sexual reproduction while in higher animals, sexual reproduction becomes the predominating mode of reproduction.

(3) Body Symmetry

(i) Asymmetric: When any plane passing through the centre does not divide the body into equal halves, the organism is said to be asymmetric, e.g., sponges. Most of the sponges are asymmetrical although some are radially symmetrical also.

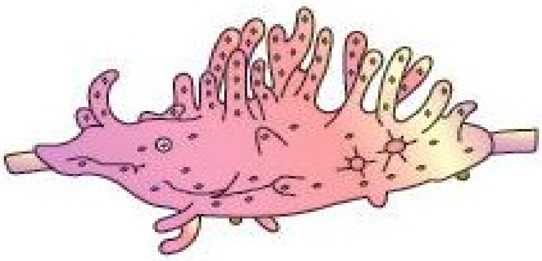


Fig: Spongilla (Asymmetrical)

(ii) Radially symmetric : When any plane passing through the central axis of the body divides the organism into two identical halves, it is called radial symmetry and the organisms possessing it are called radially symmetric. For e.g., some sponges, coelenterates, ctenophores, adult echinoderms.

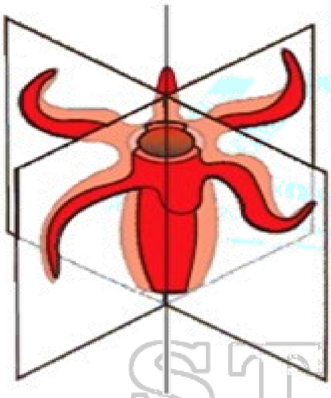


Fig. : Radial symmetry

(iii) Bilaterally symmetric : When the body can be divided into identical left and right halves in only one plane, it is called bilateral symmetry and the animals possessing this type of symmetry are called bilaterally symmetric.

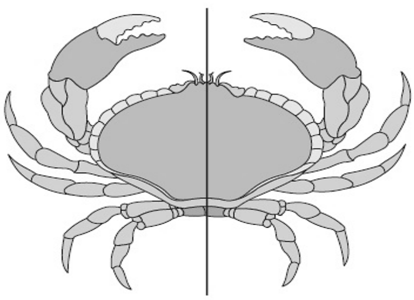


Fig. : Bilateral symmetry

First phylum of animal kingdom to exhibit bilateral symmetry is platyhelminthes. it is characteristic of the most successful and higher animals including platyhelminthes, aschelminthes, annelids, arthropods, molluscs, hemichordates and chordates.

(4) Germ Layers

Ectoderm, mesoderm and endoderm are the germ layers which arise during the embryo formation. These layers give rise to all the tissues/organs of the fully formed individuals. Depending upon the number of germ layers in the embryo, the animals can be

(i) Diploblastic: Those animals in which the developing embryo has only two germinal layers, i.e., an external ectoderm and an internal endoderm, are called diploblastic animals e.g., coelenterates and ctenophores.

Mesoderm layer is not present between ectoderm and endoderm, rather an undifferentiated, jelly-like layer mesoglea, is present in between them. This mesoglea is called undifferentiated because this layer is not specialized to form any particular tissue/organ of the body. See figure (a).

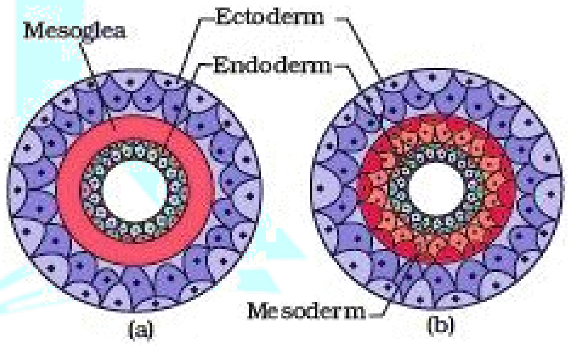


Fig.: Showing germinal layers : (a) Diploblastic (b) Triploblastic

(ii) Triploblastic: Those animals in which the developing embryo also has third germinal layer i.e., mesoderm, in between the ectoderm and endoderm are called triploblastic animals. See figure (b).

e.g., Platyhelminthes to chordates all animals are triploblastic.

(5) Coelom or Body cavity

A body cavity can mean any internal space or a series of spaces present inside the body. Whereas coelom or true body cavity generally refers to a large fluid-filled space (cavity) lying between the outer body wall and the inner gut wall (wall of digestive tube).

The coelom contains most of the visceral organs and is lined by mesoderm on all sides. Absence or presence of coelom in body is a very important classifying feature of animals and on this basis they can be divided as

(i) Eucoelomate: The true coelom is a body cavity which arises as a cavity in embryonic mesoderm, In this case the mesoderm of the embryo provides a cellular lining called coelomic epithelium or peritoneum to the cavity. The coelom is filled with coelomic fluid secreted by the peritoneum. True coelom is found in **annelids, echinoderms and chordates** (Figure-a). True coelom is of two types:

(a) Schizocoelom: It develops by the splitting up of mesoderm. It is found in annelids, arthropods and molluscs. Body cavity of arthropods and non-cephalopod molluscs is called haemocoel.

(b) Enterocoelom: The mesoderm arises from the wall of the embryonic gut or enteron as hollow out growths or enterocoelomic pouches. It occurs in echinoderms and chordates.

(ii) Pseudocoelomates: In some animals the body cavity is present but it is not completely lined by mesoderm instead the mesoderm is present as scattered pouches in between the ectoderm and endoderm. Such a body cavity is called pseudocoelom (pseudo-false, coelom-body cavity) and the animals possessing them are called pseudocoelomates, e.g., aschelminthes (Figure-b)

(iii) Acoelomates: Those animals in which the true body cavity or coelom is absent are called acoelomates. For e.g., sponges, coelenterates, ctenophores and platyhelminthes. Figure (c) is the diagrammatic representation of a section of body of a platyhelminth (triploblastic acoelomate) showing three germ layers outer ectoderm, middle mesoderm and inner endoderm and innermost is the lumen of digestive tube (gut). But there is no coelom or cavity between the body wall and gut wall.

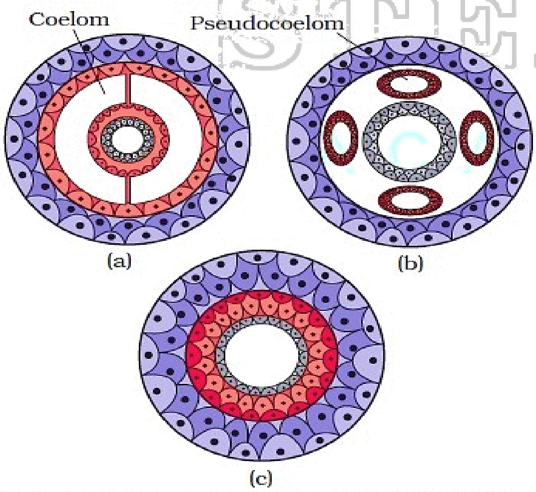


Fig.: Diagrammatic sectional view of:
(a) Coelomate (b) Pseudocoelomate
(c) Acoelomate

(6) Segmentation

Segmentation is defined as the division of body into parts or segments. In some animals the body is externally and internally divided into segments and these body segments have a serial repetition of at least some organs. This kind of segmentation in which there is linear series of body segments fundamentally similar to one another in structure is called **metameric segmentation** and this phenomenon is known as metamerism the body segments are called metameres. Segmentation is seen in **annelids, arthropods** and **chordates.**

(7) Notochord

It is an elongated rod-like, flexible, structure formed during the embryonic development in some animals. It is composed of the cells derived from the mesoderm. Notochord is formed on the dorsal or upper side of body of embryo and defines its primitive axis. It serves as an internal skeleton (endoskeleton) and provides support to the body. It is not present in all animals. Animals with notochord are called chordates and those animals which do not form this structure are called non-chordates. e.g., porifera to echinodermata.

Hence all chordates possess this mesodermally derived notochord during their embryonic life as support of the body. However in some chordates, notochord is replaced by the vertebral column and these chordates are called vertebrates.

CLASSIFICATION OF ANIMALS

We just discussed that we are surrounded by a vast range of animals. Now we cannot study these animals haphazardly without any classification. So for a systematic study of animals, they are divided into various minor and major groups on the basis of similarities and differences and each group is given a particular name depending upon its characteristics. There are various levels of classification like kingdom, phylum, class, genus etc. which in the decreasing order of complexity can be shown as:

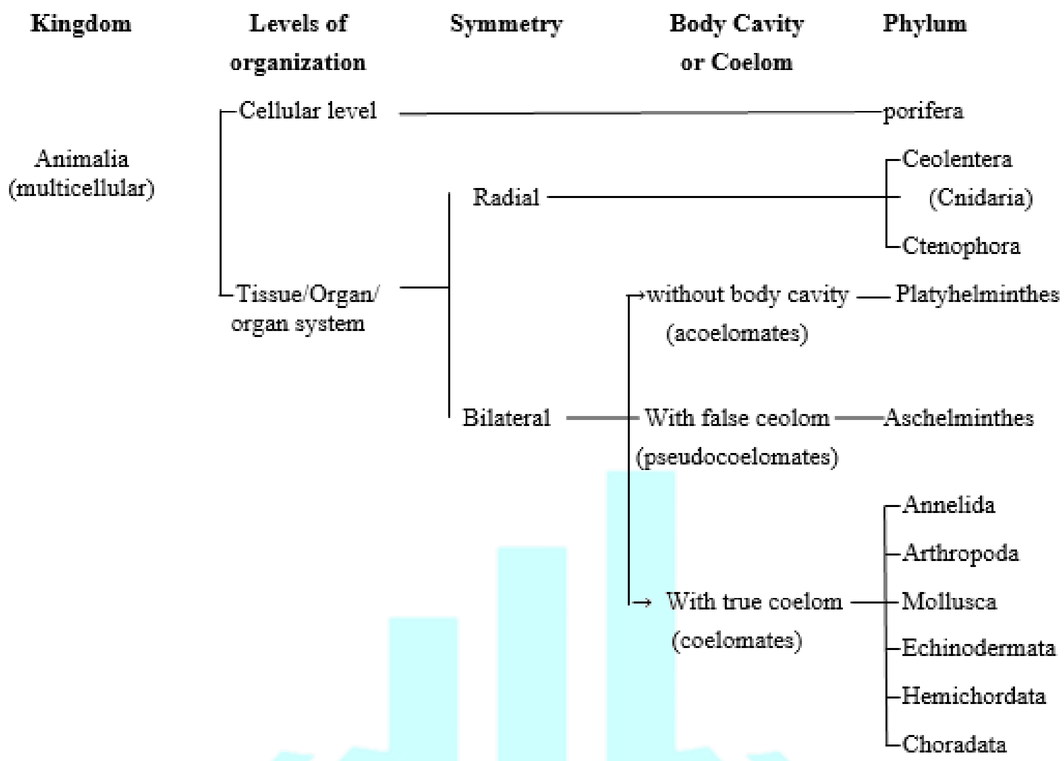
Kingdom → Phylum → Class → Order → Family → Genus → Species

Basically the Kingdom Animalia is divided into following eleven phyla:

(1) Porifera
(2) Coelenterata (Cnidaria)
(3) Ctenophora
(4) Platyhelminthes
(5) Aschelminthes
(6) Annelida
(7) Arthropoda
(8) Mollusca
(9)' Echinodermata
(10) Hemichordata
(11) Chordata

Animal Classification

The broad classification of Animalia based on common fundamental features is given in the following figure.



The important characteristic features of the different phyla are described on next page.

PHYLUM - PORIFERA

About 5,000 species of sponges are known.

General Characteristic features of animals of Phylum - Porifera

Introduction : Members of this phylum are commonly known as sponges. They are also known as 'pore bearers' as their body walls possess numerous tiny pores.

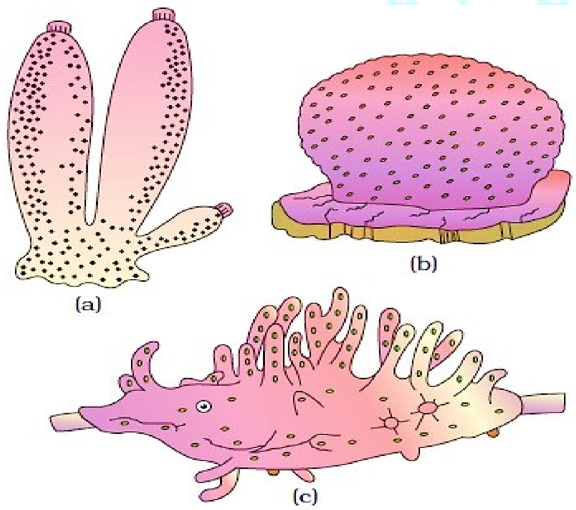


Fig. : Examples for Porifera : (a) Sycon (b) Euspongia (c) Spongilla

(1) Habitat: All sponges are aquatic. Most of them are marine but a few sponges live in fresh water also. For example, Spongilla is a fresh water sponge. It is found in lakes and slow streams. Sponges are sessile organisms and remain attached to an underwater object called substratum. They cannot move about here and there. Then how do they obtain their food? They obtain their food and other substances through the water entering their body.

(2) Body symmetry : Sponges are the primitive multicellular animals. Most of them are asymmetric as any plane passed through their body centre cannot divide them into equal halves.

(3) Level of organization : They have cellular level of organization. The cells in their body do not form the tissues. All cells act more or less independently and show little coordination. However, some division of labour is present among the cells.

(4) Body form : It is the distinguishing feature of all the sponges. These numerous pores are meant for the entry and exit of water current. Minute pores present in the body wall through which the water enters into the body are called ostia (singular- ostium).

These ostia lead into the single, central and spacious cavity called **spongocoel** or paragastric cavity either directly or through other small canals. The water entering through the ostia brings the food and oxygen inside the body of sponge. From spongocoel this water exits outside through a large opening the **osculum**. The canals (if present) and the spongocoel are internally lined by **characteristic flagellated cells called choanocytes** (see figure).

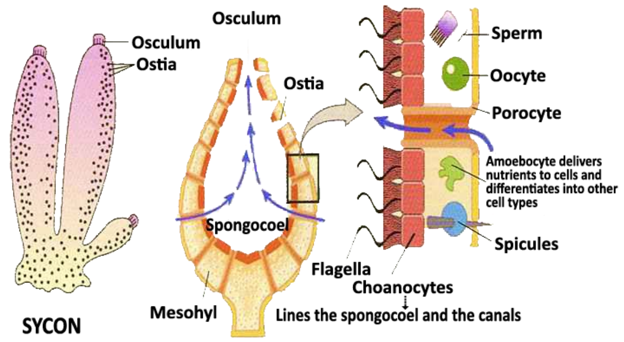


Fig. : Water canal system

Functions of canal system or water transport system: All sponges are sessile i.e., they remain permanently attached with the substratum and cannot move about. That's why they rely on a constant water flow through their body to obtain food, oxygen and to remove wastes. The canal system ensures this constant water flow in the body of sponges. Following are the functions of canal system in the sponges:

(i) **Food gathering :**

(ii) **Respiratory exchange**.

(ii) **Removal of waste :** The undigested residue and the metabolic waste ; chiefly ammonia (NH_3) are eliminated out with the water through oscula (sing : osculum).

(iii) **Transfer of sperms :**

(7) **Skeleton :** Almost all sponges possess an internal skeleton also called the endoskeleton. This internal skeleton provides the support to the body of sponge and comprises of **spicules or spongin** fibres or both Spicules and spongin fibres are the structural elements of skeleton in the sponges. Further the spicules may **be calcareous** (made of calcium) or **siliceous** (made up of silica).

(8) **Reproduction :** All sponges are **hermaphrodite** i.e. sexes are not separate in them. Male gamete (sperms) and female gametes (ova) both are produced by the same individual. Hermaphrodite animals are also called **monoecious** and **bisexual**.

Types of reproduction in sponges : Both **asexual** and **sexual** reproduction occur in them. They reproduction asexually by **fragmentation** whereby the organism splits into the fragments. Each of these fragments development into mature, fully grown individuals that are the clones of the original organism. Asexual reproduction also occurs by budding and gemmule formation.

Sexual reproduction occurs by the formation of haploid male and female gametes. The sperms leave this body of one sponge and enter that of another with the water current to fertilise the ovum (egg) in situ. Hence the fertilisation takes place inside the body of another sponge. This type of fertilization which involves sperms of one and ova of other individual is called cross fertilization and as the fertilisation occurs within the body of sponge it means they undergo internal fertilisation. It results in the formation of a diploid zygote.

(9) **Development:** In sponges the development of adult sponge from diploid zygote is indirect which mean it is mediated by an intermediate free swimming flagellated larval stage for dispersal of species. Larval stage is morphologically distinct from adult.

(10) **Amphiblastula** is the hollow larva of Sycon etc. Whereas **parencnymula** is the solid larva of **Leucosolenia. Example of sponges** : Sycon(Scypha), Spongilla (Fresh water sponge) and Euspongia (Bath sponge).

CLASSIFICATION: Based on the type of skeleton phylum Porifera is divided into three classes.

Class 1. Calcarea of Calci spongiae

Example : Leucosolenia, Sycon, Grantia.

Class 2. Hexactinellida or Hyalospongiae

Examples : Euplectelia – the venus flower basket, Hyalonema – the glassrope sponge.

Interesting FACT

Euplectella lives in commensal relationship with certain shrimps. Euplectella is given as a precious marriage gift in Japan, symbolizing the idea 'till death us do part'.

Class 3. Demospongiae

(i) **They may contain skeleton of spongin fibres or of siliceous spicules** or both. The spicules are either monaxon or tetraxon (may be eight rayed but never six rayed).

(ii) Choanocytes are small.

(iii) **They occur in marine as well as in fresh water.**

Examples: Euspongia- the bath sponge, its skeleton up only of spongin fibres. **Spongila the fresh water sponge, Cliona – the boring sponge.** The larva of the **sponge bores into the shells of mollusc's and chalina** –"deadman's fingers"

PHYLUM - COELENTERATA (CNIDARIA)

Phylum cnidaria includes about 9,000 species.

General characteristic features of animals of Phylum - Cnidaria

(1) **Habitat:** The animals of this phylum are called coelenterates or cnidarians. They posses aquatic habitat as they inhabit the water bodies. Like sponges, they are also mostly marine but few are fresh water inhabitants also (e.g., Hydra).

(2) **Habit:** On the basis whether the animal lives singly or in association of others the coelenterates can be (i) Solitary or (ii) Clonial.

Those animals which live singly and are independent without association of other individuals of the same type are called **solitary** animals e.g. (Hydra).

Those animals which live in the association of other individuals of the same type are called **colonial** animal. These animals which live in colony become dependent upon each other for fulfilling their needs like nutritic and for protection. e.g., Physalia, Gorgonia, Obelia.

On the basis whether the animal remains attached to some solid support or substratum in the water or no the coelenterates can be either (i) sessile or (ii) free-swimming or free-floating.

Sessile animals remain attached to the underwater substratum and free-floating animal freely swim along with of water and do not remain permanently attached with any support. For example: Physalia Aurelia are the free-swimming coelenterates.

(3) **Body symmetry :** The coelenterates are the **radially symmetrical** animals as any plane passing through the central body axis divides these animals into two identical halves.

(4) **Level of organization :** First time in the animal kingdom cells associated to form the tissues coelenterates. Hence they exhibit the **tissue level** of organization. The tissues are arranged variously perform the basic functions in their body.

(5) **Germ layers :** These are the **diploblastic** animals as cells in their embryonic stages are arranged in the layers, outer ectoderm, inner endoderm with an intervening gelatinous layer mesoglea. This mesoglea provides the jelly-like form to some coelenterates.

HYDRA:

Some important characters of Hydra are :

(i) Hydra flourishes well in cool, clean and stagnant water.

(ii) Number of tentacles surrounding mouth in Hydra is 6-10. Tentacles of Hydra are hollow while that of lobelia are solid.

(iii) No free larval stage in development of Hydra. Hence, development is direct.

(iv) Most species of Hydra are dioecious/unisexual. Male Hydra bears 1-8 conical testes towards distal end whereas female Hydra bears 1-2 rounded ovaries towards proximal end of the body locomotion in Hydra occurs by looping, somersaulting, gliding, walking and floating etc.

(7) **Digestive tract:** The body of coelenterates bear a central gastro-vascular cavity which opens to the outside through a single opening called mouth. Mouth is an aperture present on the hypostome. Hypostome is a conical elevation present on the free (non-attached) end of the body.

Entry of food and exit of waste material place through this single opening mouth. The central cavity of the body is called gastro-vascular cavity because it helps in the digestion of food (referring gastro) as well as in the circulation of materials.

Externally the body bears elongated flexible structures called tentacles which are able to contract (or shorten) as well as elongate. The tentacles help in feeding, feeling and grasping of prey.

(8) **Cnidoblasts or Cnidocytes :** The name cnidaria is derived from one of the most characteristic cell of coelenterates the stinging cells called cnidoblasts or cnidocytes. Cnidoblasts are used for anchorage defence and for the capture of prey.

Fig.: Diagrammatic view of Cnidoblast

Structure of Cnidoblasts : Cnidoblasts are the oval-shaped cells which are present on the tentacles and the body. These specialized cells bear a nucleus which is present near its base (i.e., basal nucleus) and a stinging capsule called nematocyst. This capsule is filled with a poisonous fluid called **hypnotoxin** which is injected with the help of a thread tube. This thread tube acts like a piercing needle. The lower end of thread tube in enlarged to form but which bears spines in some cnidoblasts. These spines are meant to hurt the prey.

Discharging of Cnidoblasts : In some cnidoblasts, a restraining thread called lasso is attached to the base of nematocyst. It prevents the nematocyst being thrown out of cnidoblast. But once stimulated, the cnidoblast discharges the thread tube out. The thread tube once discharged cannot be withdrawn hence explode nematocysts cannot be used again.

(9) Digestion : The food (prey) captured with the help of cnidoblasts present on tentacles is directories to the gastro-vascular cavity. The digestive juices released here act upon the ingested food and various enzymes act on this resulting in its breakdown. This type of digestion occurring in the cavity outside the cells is called extracellular digestion. This results in the breakdown of food initiate smaller fragments. These smaller fragments of food are then engulfed by the body cells and digested within the food vacuole. Hence the digestion of food is first extracellular and the intracellular in the coelenterates.

(10) Skeleton : Some of the cnidarians, e.g., corals have hard skeleton composed of calcium carbonation ($CaCO_3$).

(11) Body forms : Two basic body forms are found in cnidarians which differ in the structure and function from one another. These are called polyp and medusa.

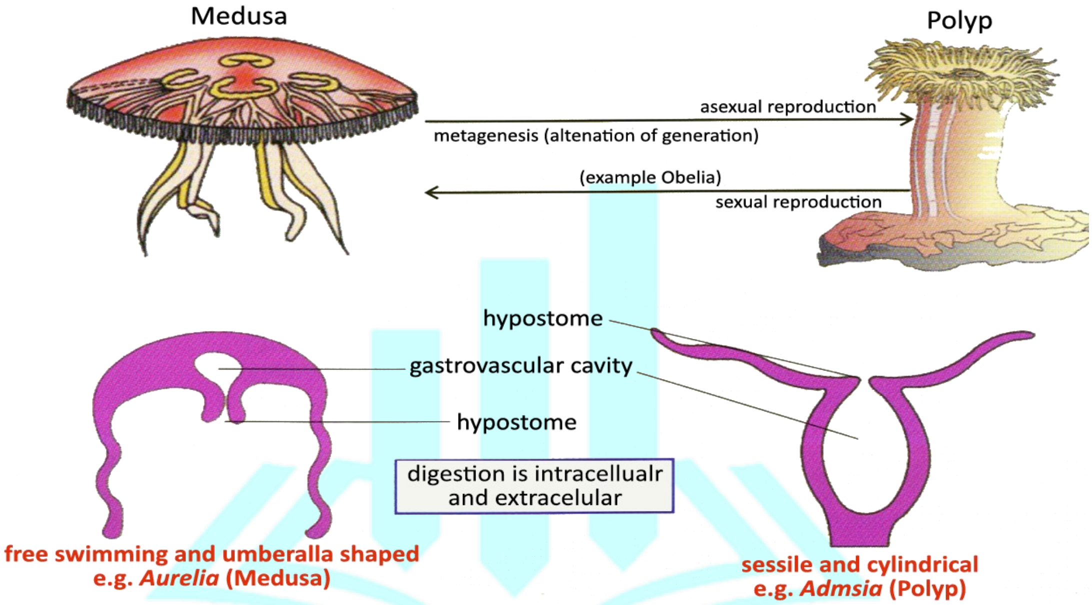


Fig.: Examples of Coelenterata indicating outline of their body form : Aurelia (Medusa), (b) Adamsia (Polyp)

Polyp is a **cylindrical** form which remains attached to the substratum (hence sessile) whereas medusa an **umbrella-shaped** free-swimming form.

Some cnidarians exist only in polyp form, e.g., Hydra, Adamsia (Sea anemone), while some have medusa as the dominant form in their life cycle (polyp may be reduced or absent), e.g., Aurelia (jelly-fish). Some other cnidarians exist in both forms , i.e., polyp as well medusa, e.g., Obelia. Those cnidarians which exist in both the forms show alternation of generation in their life (Metagenesis).

Alternation of generation means polyps alternate with medusa and vice versa. the Polyps product medusa sexually and medusa form the polyps sexually. This is also termed as metagenesis. Polyps undergo pudding (asexual reproduction) to give rise to medusae and medusae produce gametes, sperm and ova (sexual reproduction) to give rise to new polyps.

Metagenesis

Alternation of generation between sexual and asexual forms i.e. medusa (2n) and polyp (2n).

Cnidarians exhibit two basic body forms the polyp and medusa. The polyp is sessile and the body is hydra-like i.e., a cylindrical stalk with mouth and tentacles facing upwards. The medusa is a free-floating or swimming structure like the jelly fish. It is like a bell or an umbrella with mouth and tentacles facing downwards. The medusa can be regarded as an upside-down polyp with reduced stalk which can swim away. In many cnidarians, polyps give rise to medusa by vegetative budding and medusa form polyps following sexual reproduction. Many like Obelia, pass through an alternation of generation between these two forms or stages i.e., metagenesis. During sexual reproduction, medusae liberate gametes into water. Following fertilization the zygote forms a ciliated larva called Planula which swims, settles and grows into a sessile polyp. (Some cnidarians, like Hydra, do not have a medusa stage. Hydra has no larval form, no metagenesis). Polyps reproduce asexually by budding whereas, medusa liberates gametes into water during sexual reproduction. Both asexual and sexual forms are diploid and the only haploid cells are gametes.

CLASSIFICATION

Chiefly on the basis of the dominance of medusoid or polypoid phase in the life cycle, the phylum Cnidaria is divided into three classes

Class 1. Hydrozoa

Examples : Hydra (fresh water popys), Obelia (sea-fur) and Physalia (Portuguese man of war), Porpita, Velella (Sali by Wind), Melipora – Hydroid coral.

Class 2. Scyphozoa

Example : Aurelia (jelly fish), Rhizostoma (jelly fish).

Class 3. Anthozoa

Examples : Gorgonia (sea fan), **Metridium** (sea anemone), **Alcyonium** (dead man's finger), **Fungla** (mushroom coral), **Pennatula** (sea pen or sea feather), **Corallium** (red coral), **Astraea** (red coral), **Astraea** (star coral), **Madrepora** (stag-horn coral), **Tubipora** (organ pipecoral), **Heliopora** (blue-coral), **Meandrina** (brain coral).

PHYLUM – CTENOPHORA

Introduction : In previous classifications, ctenophora was placed under the phylum coelenterate but now it is considered as a separate phylum in the animal kingdom.

The ctenophores are commonly called **comb-bearers.** The phylum takes its name from two Greek words Ketenes-comb and phors-bearing. They are also called **comb-jellies and sea walnuts.**

General characteristic features of animals of Phylum – Ctenophora

(1) Habitat : Ctenophores are exclusively marine hence found in oceans. They are the free-swimming animals.

(2) Body symmetry : They are radially symmetrical animals.

(3) Level of organization: Like cnidarians they also exhibit **tissue level** of organization.

(4) Germ layers: Ctenophores are **diploblastic** animals. Embryonic layers include outer ectoderm, inner that of coidaria, it contains amoebocytes and smooth muscle cells and is comparable to a loose layer cells. Mesoglea gives they jelly like appearance to these animals.

(5) Body form: They have a transparent body. The body shape varies from flat to oval. The external surface the body bears eight median **comb plates.** These comb plates bear cilia which are fused to make these plantes ciliated. The **cilated comb plates** help in the **locomotion.**

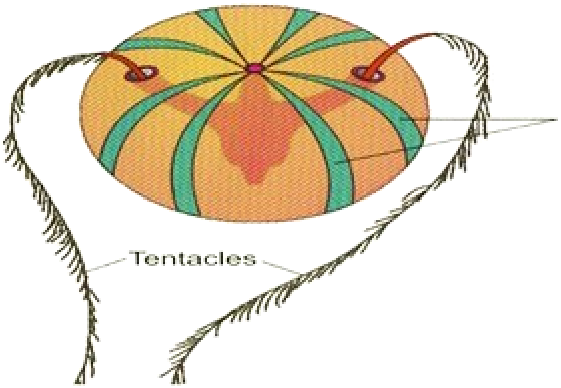


Fig. : Example of Ctenophora (Pleurobrachia)

Cnidoblasts are absent in the ctenophores.

(6) Tentacles may be present or absent. When present the number of tentacles is 2. They are solid and **Bioluminescence** (the property of a living organism to emit light) is well-marked in ctenophores.

(7) Digestion : Digestion is **both extracellular** and **intracellular.** The food is captured by the tentacles and directed to the gastro-vascular cavity of body. First the digestion takes place in the cavity (extracellular and the inside the food vascular intracellular).

(8) Gastrovascular cavity is branched and opens to the exterior by month.

(9) The presence of a special sense organ **'Statocyst'** at the opposite end of the mouth is the characteristic of the members of this pylum.

(10) Skeletal circulatory, respiratory and excretory systems are absent. Nervous system is diffuse type.

(11) Reproduction: Ctenophores are **hermaphrodite** as sexes are not separate. Sperms and ova are produces by the same individual. Asexual reproduction is absent in ctenophores [unlike sponges and cnidarians which also undergo asexual mode of reproduction (fragmentation and budding respectively)]. Reproduction take place only by sexual means.

(12) Fertilization: The fertilization is **external** as fusion of sperm and ovum takes outside the body or animal in the water.

(13) Development: Following fertilization, zygote develops into a free swimming larva called cydippid larva which later develops into the adult. Hence, the development is indirect.

(14) Bioluminescence: Bios means living and lumen means light. Bioluminescence is the property of production and emission of light by a living organism and hence shine in the dark background. This property is well marked in ctenophores.

Example of ctenophores: Pleurobrachia (sea gooseberry), **Ctenoplana, Hormiphro** (sea walnut), Cestrum (venus girdle).

PHYLUM – PLANTYHELMINTHE

Introduction: the animals of this phylum have a dorso-ventrally flattened body. Their upper (dorsal) and lower (ventral) body surfaces are flat and that's why they are commonly called flatworms.

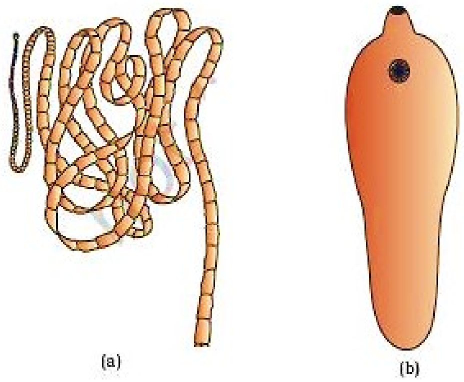


Fig. : Examples of Platyhelminthes :
(a) Tape worm (b) Liver fluke

General Characteristic Features of Platyhelminthes:

(1) Habit and Habitat: These are mostly endo parasites as they live inside the body of other animals (cell hosts) including human beings and thrive nutrition as well as shelter from them e.g., Fesciola, command called liver fluke lives in the liver and bile ducts of higher animals, i.e., vertebrates (sheep, dog, man) and some flatworms are free living. These free-living flatworms are mainly aquatic (marine or fresh water). So forms are terrestrial also. Dugesia (Planaria) is a fresh water flatworm which lives in the freshwater pond lakes and streams.

(2) Body symmetry: These are bilaterally symmetrical animals as their body can be divided into identify left and right halves by a vertical plane passing through the central axis of body.

(3) Level of organization: They are the first animals to have reached the organ level of organization. Body cells aggregated to form tissues and tissues organized to form organs. Some organ systems are present in them.

(4) Germ layers: Platyhelminthes are the **Triploblastic** animals, their body structures are derived from the embryonic germ layers ectoderm, mesoderm and endoderm.

(5) Coelom: Although they are the triploblastic animals bearing mesoderm but coelom (i.e., mesoderm-line body cavity) is lacking in them. Hence flatworms are the acoelomate animals.

(6) Body form: Flatworms have a dorso-ventrally flattened body.

(7) Exoskeleton and Endoskeleton are completely absent. However hooks, spines, suckers (in parasitic form teeth or thorns may be present which act as adhesive organs.

(8) The space between the body wall, alimentary canal and other organs is filled with a peculiar connect tissue called the **parenchyma. It helps in transportation of food materials.**

(9) Respiratory and circulatory systems are absent.

(10) Digestive tract: Digestive system in platyhelminthes has only a single opening to the outside of the body that serves both as mouth and anus and hence it is incomplete. Digestive tract is absent in tapeworms.

(11) Parasitic flatworms: They have special adaptations in their body to obtain nutrition from their hosts which are discussed in the following topic.

Parasitic adaptations:

(i) Hooks: Hooks are the **adhesive structures** which help the worm to attach to the internal body layer of host. Hence hooks act as the organs of attachment present in Taenia.

(ii) Suckers: These help in the **adhesion as well as ingestion** of food. Suckers act as the suctions organs which help in sucking the food from the body of host. Present in Taenia as well Fasciola.

(iii) Direct absorption of food through body surface: As they have a flat body so some of them and able to absorb the nutrients directly through body surface. They are the endoparasites which live inside other living animals and the soluble food materials directly diffuse through their body surface. This seen in Taenia.

(iv) Thick tegument: The body is externally covered with a thick tegument, a protective layer that protect the parasitic worms from the digestive juices of host.

(12) Excretion and osmoregulation: The removal of waste products of metabolism like ammonia and other non-useful material is called excretion and the regulation of amount of fluid (water) in the body is called osmoregulation.

Flame cells are the specialized cells of platyhelminthes which help in excretion as well as osmoregulation.

(13) Nervous system is primitive the main nervous system consists of a pair of cerebral ganglia or brain and one to three pairs of longitudinal nerve cords connected to each other by transverse commissures. This type of nervous system is called ladder like nervous system e.g., **Planaria (Dugesia)**

(14) Reproduction: The flatworms are hermaphrodite (monoecious) except Schistosoma. They mainly reproduction sexually by producing sperms and ova. However some forms reproduce asexually also. For e.g., Planed. It reproduces by **transverse binary fission.**

(15) Fertilization: The fertilization is internal in flatworms.

(16) Development: It is usually indirect with a complicated life cycle involving many larval stages and may have one host.

(17) Regeneration: The ability of an organism to replace its lost or damaged parts or the ability to development a complete and normal individual from a part of the body is called regeneration. **Some flatworm possible a tremendous power of regeneration.** If these animals are cut across into two or three or more part each cut part regenerates into a complete and normal individual e.g., Planaria. It shows a high regeneration power.

Example: Taenia (Tapeworm)**, Fasciola** (liver fluke)

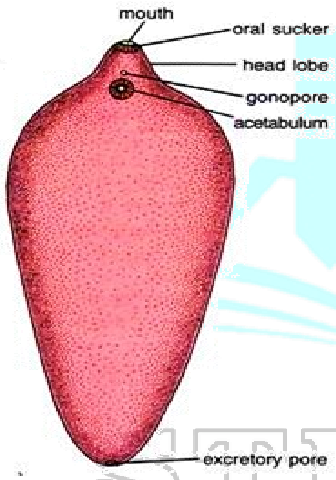


Fig. : *Fasciola hepatica*. Adult in ventral view.

Tenia solium

Taenia solium (pork tapeworm) is ribbon shaped digenetic endoparasite. The adults of Taenia solium are parasites in the small intersine of human beings (Primary host) and its larva infects the muscles of pig (secondary host).

CLASSIFICATION

Phylum platyhelminthes is divide into three classes.

Class 1. Turbellaria

Examples: Dugesia (Planaria).

Class 2. Trematoda

Examples: Fasciola, Schistosoma **(blood fluke of man and other mammals)**, Polystomum (endoparasite of the urinary bladder of frog and turtle). Opisthorchis Clonorchis sinensis is Chinese liver fluke, Paragonimus – lung fluke. In Schistosoma – Redia and Metacercaria stages are absent.

Fasciolopsis – The intestinal fluke occurring in human beings.

Class 3. Cestoda (Gk. Kestos = girdle + eidos = form)

Examples: Taenia (Tapeworm). Echinococcus (Dog tapeworm) is the smallest tapeworm. Taenia saginata (Beef tapeworm).

PHLUM – ASCHELMINTHES/ NEMATHELMINTHES

Introducction: The Aschelminthes are commonly called **roundworms,** because the body appears circular in the transverse cross-section. This phylum is represented by about 15,000 species of round worm.

General characteristic features of Aschelminthes:

(1) Habit and Habitat: They may be free-living or parasitic. They may be aquatic or terrestrial, e.g., Rhabditis is a terrestrial aschelminth which lives freely in the soil rich in organic matter.

Parasitic roundworms live in plants and animals (endoparasites). Ascaris, Wuchereria, etc are common animal endoparasites.

(2) Body symmetry: Roundworms are **bilaterally** symmetrical.

(3) Level of organization: Aschelminthes have the **organ-system** level of organisation. The organs associate to form a distinct system concerned with a specific physiological function such as digestion, respiration, ciruculation, excretion and reprduction.

(4) Germ layers: Roundworms are the **triploblastic** animals.

(5) Coelom: Aschelminthes possess the pseudocoelom and hence called **pseudocoelomates.** The body cavity is present but is not lined by the mesoderm; instead, the mesoderm is present as scattered pouches in between the ectoderm and endoderm.

(6) Body form: The roundworms have an elongated, cylindrical body which tapers towards both ends.

(7) Digestive system: The digestive system is complete having two separate openings. The alimentary cannot is a straight tube extending from mouth at one end to anus on other end of body.

The roundworms have a well-developed **muscular pharynx.** The food of roundworms. Consists blood, lymph, partially of fully digested food particles which is sucked by the rhythmic pumping action or muscular pharynx.

(8) Excretory system: An excretory tube is present in the body of roundworms which removes the body waste through an excretory pore. This excretory tube collects the body waste form body cavity and remove it out though the pore.

Hence the roundworm possess anus (as complete digestive system is present) as well as excretory ponder unlike other lower animals which we have studied till now. The phyla lower to aschelminthes lack complete type digestive tract in them.

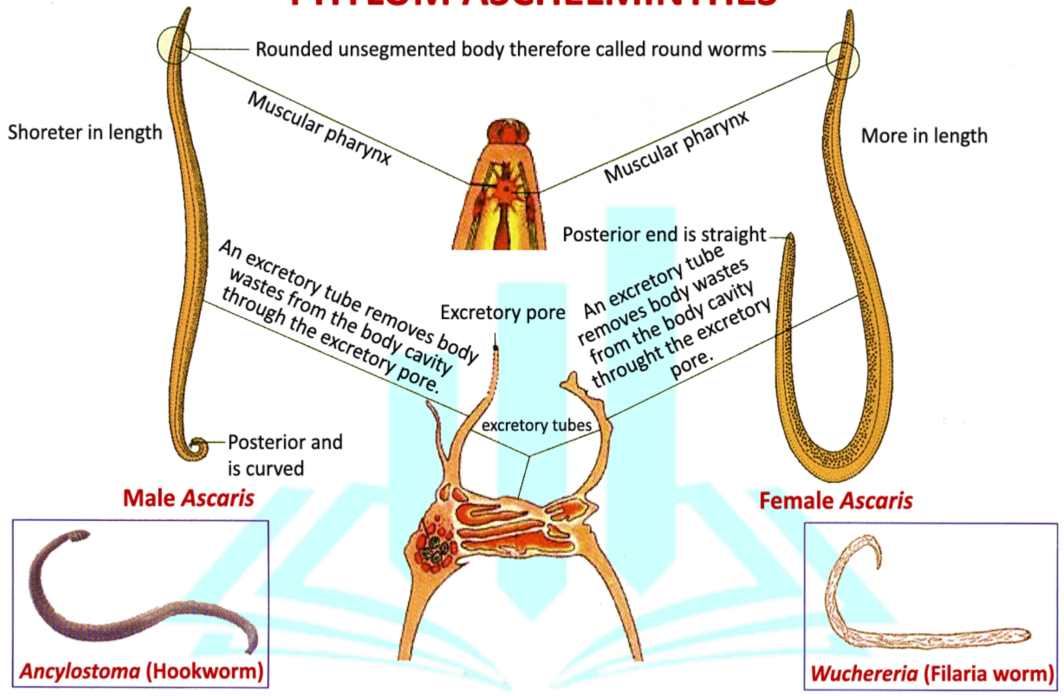
(9) Reproduction system: Sexes are separate, i.e., aschelminthes are dioecious (unisexual). Males and females are distinct externally. Often females are longer than males (see figure). Sperms and ova and produced by different individuals. Only sexual reproduction takes place.

(10) Fertilization: Fertilization is **internal.**

(11) Development: Some develop through an intermediate larval stage and some directly (where young one resemble the adult) without any larval stage. Hence **both direct and indirect** developments are seen in roundworms.

Examples: Ascaris (Roundworm), Wuchereria (Filarial worm), Anchylostoma (Hookworm), Enterobiute (Oxyuris), Dracunculus medinensis (Guinea worm), Rhabdits (Free living).

PHYLUM ASCHELMINTHES



ASCARIS

Ascaris is commonly called round worm and is a very common endoparasite in the small intestine of man. Ascaris is common in children than in adults.

Some important characters of Ascaris are:

(i) The body is elongated, unsegmented, and cylindrical with tapering ends.

(ii) **Body is covered with syncytial epidermis.** Ascaris possesses a cuticle which is resistant to the digestive enzymes of host. Body wall is made of the following layers:

(a) Cortex or cortical layer which is made of keratin, a protein resistant to enzymes.

(b) Below the cortex are matrix, then fibres (collagen) and basement membrane. **Below the basement membrane they have a syncytial epidermis** below which only longitudinal muscles are present circular muscles are absent.

(iii) Sexes are separate with **sexual dimorphism.** Male is smaller than female with a curved tail, two **pineal setae (copulatory organs) and cloaca.** Female is with straight posterior end or the body.

(iv) **In male Ascaris, there are 50 pairs of pre-anal papillae and 5 pairs of post-anal papillae.**

(v) **Female** Ascaris **is didelphic (2 uteri, 2 oviducts, 2 ovaries). Male is monarchic with single testis. The formation of gametes in Ascaris is telogonic** i.e., the gametes or the gametogonia are budded out only from the proximal or the apical end of the gonads.

(vi) Fertilized eggs of Ascaris pass out of the body of the host through faecal matter. Ascaris is **monogenetic,** i.e., no intermediate host as only one host is required for the development. Oval in shape with three protective coverings.

(vii) Embryonic development takes place only outside the body of human host in soil it requires temperature, more oxygen and suitable moisture.

(viii) Infective eggs of Ascaris remain viable for six years.

(ix) Optimum temperature for development of Ascaris of Ascaris in 85°F.

(x) Zygote will develop into a juvenile (first stage) within 10-14 days in soil.

(xi) The larva is called **rhabditoid** or **rhabditiform** for its close resemblance with Rhabditis (Free living nematode).

(xii) The **first stage larva is not infective.** It rests for a week and completes first moult within egg and becomes **second stage rhabditiform larva in soil which is infective.**

(xiii) The transmission of infective stage through **embryonated egg** takes place by contaminated food and water.

1. **Ascaris** Mature female produces as many as 2,00,000 (2 lakh) eggs per day. These eggs have a lipid layer that makes them remarkably resistant to the effects of acids and alkalis. That's why these eggs can remain alive in the moist soil even for about 10 years or more.
2. **Wuchereria** (W. bancrofti and W. malayi), the filarial worms cause a slowly developing chronic inflammation of the organs in which they live for many years, usually the lymphatic vessels of the lower limbs and the disease is called elephantiasis or filariasis. The genital organs are transmitted to a healthy person through the bite by the female Culex mosquito vectors.
3. **Ancylostoma (Hook worm)**
4. **Enterobius (Oxyuris) :**
5. **Dracunculus medinensis:** It is commonly known as **guinea worm. (6)Trichuris –(Whip worm) :**
6. **Trichinella spiralis (Trichina worm) :**
7. **Loa loa (Eye worm)**

PHYLUM – ANNELIDA

The phylum annelid includes over 9,000 species of metamerically segmented animals with true coelom.

General characteristic features of Annelida.

(1) Habits and Habitats: The annelids may be aquatic (marine and fresh water) or terrestrial. For e.g., Nereis is marine, Earthworm is terrestrial and Hirudinaria is a fresh water annelid.

Most of the annelids are **free-living and some are parasitic** in nature e.g., Hirudinaria the blood sucking leech is a common ectoparasite, feeding on the blood of fishes, frogs, cattles and other animals.

(2) **Common name:** The annelids are commonly called the segmental worms. They are called so because of the presence of distinct segments in their body.

(3) **Body symmetry:** The members of phylum Annelida exhibit the bilateral symmetry.

(4) **Level of organization:** They exhibit the organ-systems level of organization.

(5) **Germ layers:** These are the triploblastic animals.

(6) **Segmentation:** The body of annelids is metamerically segmented and the external segmentation the body corresponds to the internal segmentations. They are the first animals to possess true segmentation. Even the body surface can be seen distinctly marked out into segments. The segments are called metameres and the segmentation is called metameric segmentation.

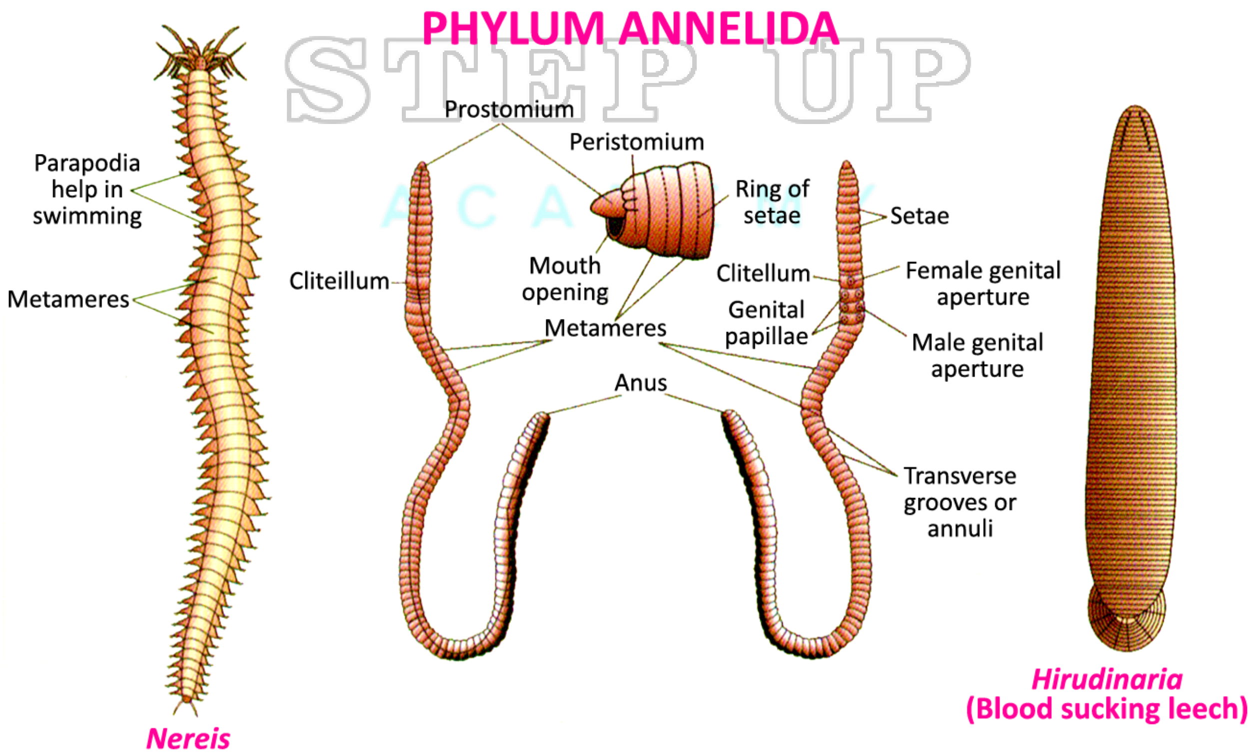


Fig. : Examples of Annelida

The phylum name Annelida is derived on the basis of presence of segmentation in the body of its membrane (Latin, annulus: little ring).

(7) **Body:** Body of annelids is elongated and segmented as we discussed earlier.

(8) **Locomotion:** The annelids have the capability to locomotion, whether they are terrestrial or aquatic. Body wall is muscular and hence possesses muscles which are able to bring motion in the body. On basis of arrangement of muscle fibres two types of muscles are present in the body wall circular longitudinal muscles.

Some aquatic annelids also possess locomotory appendages. They bear fleshy, flattened, laterally projected structures (see Nereis) in their body called parapodia (sing.: parapodium). These parapodia along with body muscles help aquatic annelids are absent in Hirudinaria, Earthworm bear chitinous setae.

(9) **Digestive system:** Digestive system is complete and contains distinct mouth and anus at opposite ends of body. The digestion of food is entirely extracellular taking place outside the cell in the cavity (lumen) of digestive tract.

(10) **Circulatory system:** Blood vascular system is usually closed. Respiratory pigments, either **haemoglobin** or **erythrocrourin,** are dissolved in blood plasma. Free amoebloid blood corpuscles are present, but there are no RBCs. In leech, there is open blood vascular system.

(11) **Excretory system:** Coiled **tubes** are present in the body called nephiridia (singlular nephiridium) which help in removing out the metabolic waste from body. These open out through the pores that excrete out the nitrogenous waste (urea and ammonia). Nephridia also help in maintaining the body fluid (water) and salt concentration. Hence, **nephridia help in exretion as well as osmoregulation.**

(12) **Nervous system:** Body control is provided by the nervous system consisting of paired ganglia (sing: ganglia) brain of annelids. The paired ganglia are connected to the ventrally present nerves. These paired gangalia act like the brain of annelids. The paired ganglia are connected to the ventrally present nerve cord, running along the longitudinal axis of body. This nerve cord appears to be single but in reality it is double, consisting of two compactly united left and right cords.

(13) **Reproductive system:** Earthworms and leeches are **monoecious** (hermaphrodites) as male and female sexes are not separate in them. Each individual of them produces sperms as well as ova. While Nereis is dioecious. In Nereis, male and female sexes are separate sperms and ova are produced by different individuals.

There is indirect development in Nereis. Larva when present in trochophore.

Only sexual reproduction is seen in annelids (no asexual reproduction).

Examples Nereis, Pheretima (Earthworm) and Hirudinaria (Blood sucking leech).

PHYLUM – ARTHROPODA

Introduction: It is the largest phylum of animal kingdom with about 9,00,000 species. Over two thirds (60 to 70 %) of all named species on earth are arthropods. This phylum is a much heterogenous group include a variety of animals differing in structure, habitat, feeding habitats and other characteristics. Cockroach, butterfly, crab, prawn, spider, centipede, millipede, mosquito, honey bee, etc. are some of the well known membrane arthropoda.

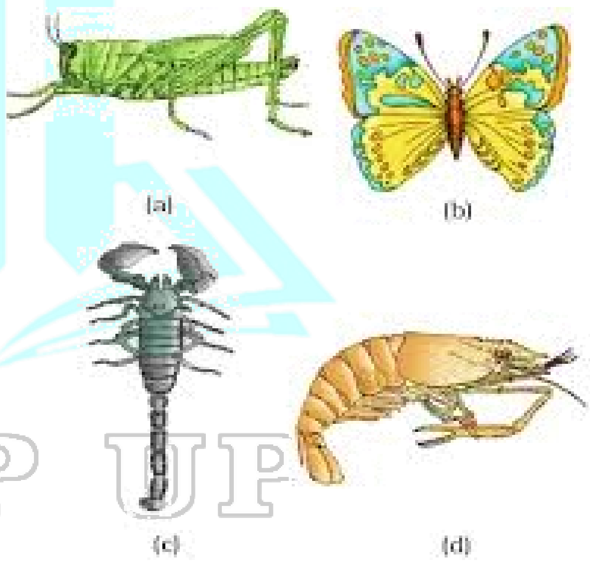


Fig. : Examples of Arthropoda : (a) Locust, (b) Butterfly, (c) Scorpion, (d) Prawn

General characteristic features of Arthropoda:

(1) **Habit and Habitat:** These animals inhabit a variety of habitats like oceans (e.g., Limulus), fresh (e.g., Daphnia), land (e.g., cockroach, locust), air (housefly, mosquito).

(2) **Body symmetry:** Arthropods are the **bilaterally symmetrical** animals.

(3) **Level of organization:** These animals have the **organ-system** level of organization.

(4) **Germ layers:** Arthropods are the **triploblastic** animals.

(5) **Segmentation:** the body of arthropods is segmented.

(6) **Coelom:** Arthropods are the coelomates as true coelom is present in them. Visceral organs are present in the body cavity (coelom).

(7) **Body form:** The body of arthropods is covered by a hard, water-proof exoskeleton made up of chitin. This **chitinous exoskeleton** is one of the reasons of successful existence of arthorpods on the earth. It provides protection and support to the body and the internal organs present inside the body. Moreover it also prevents the loss of water due to evaporation thus enabling the arthropods to live in relatively dry environments.

The body of arthropods is distinctly divided into 3 well- defined regions, i.e., anterior **head, middle thorax** and posterior **abdomen.** Head, thorax and abdomen are further divided into segments making the body segmented.

Arthropods have **jointed appendages** which are the characteristic feature of all arthropods and give the phylum its (arthros-joint, poda-appendages).

(8) **Digestive system:** The digestive tract is complete and has glands. The digestive glands release enzymes to aid the process of digestion. The digestion of food is **extracellular.**

(9) **Respiratory structures:** Various types of respiratory structures are present in different groups of arthropods. These structures are adapted to facilitate the passage of oxygen or air from the environment across the body surface.

- (i) **Gills:** Present in aquatic arthropods like prawns crabs etc.
- (ii) **Book-**gills: Present in Limulus. The gills of Limulus possess much plate – like structures called lamellae. These lamellae lie parallel to each other resembling the pages of a book, hence the name book-gills.
- (iii) **Book-lungs:** Present in scorpions, spiders etc. There are the modified book-gills.
- (iv) **Tracheal system:** Tracheal system constitutes the main organ of respiration in many arthropods including insects. It is an elaborate and efficient gas exchange system made up of branching elastic air tubes called tracheae. These tubes open directly outside through the pores called spiracles. Present in butterfly, cockroach, mosquito and other insects.

(10) **Circulatory system:** The circulatory system is of **open type** and blood flows freely within the body cavity. To compensate the poorly developed circulatory system, respiratory system is well-developed in the arthropods.

(11) **Sensory system :** All the major senses, i.e., touch, smell, hearing, sight are found in arthropods due to various types of sensory organs having receptors for sensing the external stimuli. Different types of sensory organs found in arthropods are :

(12) **Excretory system:** The excretory system consists of fine, long, blind tubules (small tubes) cavity malpighian tubules. These tubules remain attached to the alimentary canal and remove the waste body fluid. The nitrogenous waste is removed out with faeces through the anus.

(13) **Reproductive system:** Arthropods are mostly **dioceious.** Male & female sexes are separate. The female are mostly oviparous (egg-laying).

(14) **Fertilization:** Fertilization is usually internal (all land arthropods).

(15) **Development:** The development is direct in some and indirect in others. Hence both types of development are seen in the arthropods. Examples of arthropods undergoing indirect development are Culex and Bombyx.

Examples of Arthropods

(i) **Economically useful insects:** Many insects are economically important to man as they provide vascular useful products. Some of them are :

- (a) **Apis (Honey bee): Honey** is the most important product of honey bees which is used as was as in the medicines. Other product is **bees wax** which is used in cosmetics, paints.
- (b) **Bombyx (Silkworm):** It provides the silk which is used in making sarees, shawls and other germ.
- (c) **Laccifera (Lac insect):** Lac is the secretion of lac insect which acts as a sealing wax and using making bangles, toys, etc.

(ii) **Vectors:** Many insects act as vectors (transmitters) of deadly diseases. Some of them are

- (a) **Anopheles:** Anopheles mosquito in the vector of **malaria.**
- (b) **Culex :** culex mosquito is the vector of **filariasis** (elephantiasis) which is caused by Wuchereria
- (c) **Aedes:** Aedes mosquito spreads the dengue fever and chikungunya.
- (d) **Xenopsylla/Rat flea :** Spreads plague
- (e) **Glossina (Tse-**tsefly) : Spreads sleeping sickness
- (f) **Pheotomus (Sand fly) :** Transmits kala- azar

(iii) **Gregarious pest:** A pest is an animal which is detrimental of harmful to humans or consent **Locusta (locust)** is a pest which is dangerous to the crops. It causes heavy damage to the

PHYLUM - MOLLUSCA

Introduction: Mollusca are the second largest phylum of animal kingdom. This phylum includes the soft-body animals. The name Mollusca is derived from Latin word mollis which means soft-bodies.

General characteristic features of Mollusca:

1. **Habitat:** Molluscs are found in all habitats: oceans, coral reefs, deserts, forests, rivers, lakes and event underground. Hence they are terrestrial as well as aquatic (marine or fresh water).
2. **Body symmetry:** There are the **bilaterally symmetrical** animals. In some mollusc like Pila, due to tors (twisting) during growth, the adults become asymmetrical (Secondarily).
3. **Level of organization:** Molluscs have an **organ-system** level of organization.
4. **Germ layers:** They are the triploblastic animals.
5. **Segmentation:** Segmentation is not found in body of molluscs hence they have an **unsegmented** body.
6. **Coelom:** They possess a true cavity or coelom lined by the mesoderm. So they are also the **coelomate.**
7. **Body form:** Body is covered by a calcareous shell and is unsegmented with distinct head, visceral human and muscular foot.

   Head is the anterior part of body which bears mouth and other structures like tentacles, eyes, etc: in source molluscs. Visceral hump contains the digestive tract and some visceral organs. Foot is a large muscular part of the body which is chiefly a locomotory organ.
8. **Mantle (Pallium):** A soft and spongy **layer of skin** forms a thin and delicate covering over the visceral human pallial complex and is called mantle. **Mantle is a characteristic feature of mollusc.** It serves many functions
   - **(i)** It provides protection to the head anteriorly by acting as a protective hood over the head.
   - **(ii)** It secretes a calcareous shell over the body which protects it and acts like an exoskeleton absence in Octopus.

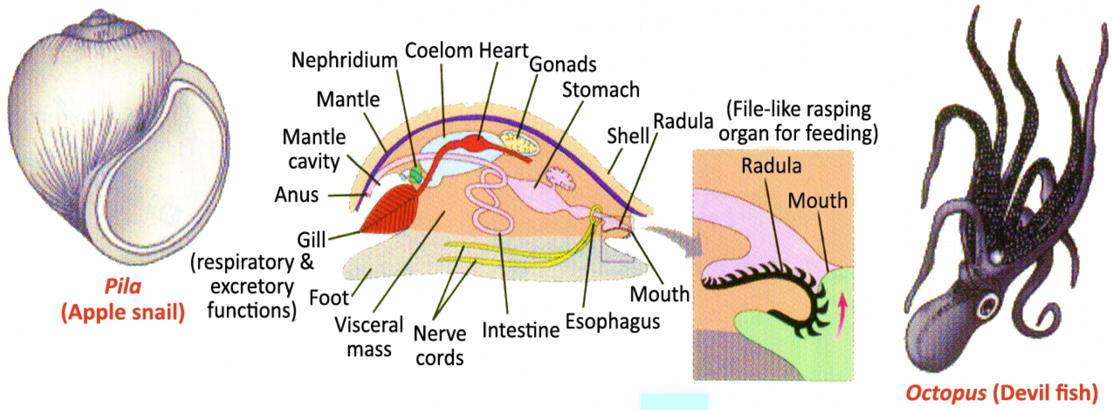
   This mantle cavity encloses the feather-like gills which help in the respiration as well as excretion.
9. **Digestive system:** The digestive system is complete and bears separate openings for entry of food and exit of waste. The digestive glands are also present. The digestion is extracellular. The food of mollusc consists of microorganisms, vegetation in snails and dead plants and animal tissues.

   The mouth of molluscs contains a file-like rasping (feeding) organ called radula which is armed with transverse rows of chitinous teeth. It is curved, ribbon-like structure present in the mouth.
10. **Respiratory system:** present in mantle cavity while terrestrial forms, lungs are the respiratory structures. The gills are called ctenidia (singular: ctenidiuam. They are the comb-like or feather-like gills. They oxygenate the blood with the oxygen taken from the warm.
11. **Circulatory system:** Open circulatory system is present in molluscs in which blood pumped by heart passes through large vessels into open spaces or body cavities called as sinuses. Respiratory pigment is haemocyanin. Amongst molluscs cephalopods have closed circulatory system.
12. **Excretory system:** The gills also perform the excretion along with respiration. Gills separate the nitrogenous waste products from blood as they are richly supplied with blood. Excretion by paired **Organ of Bojanus.** Another excretory organ called **Keber's organ (Pericardial gland)** is present. It pours the waste into pericardium from where the waste is carried to the organ of Bojanus.
13. **Sensory system:** The anterior head region may have sensory tentacles which are sensitive to touch. Alongwith tentacles other sense organs like eyes for light detection, statocyts for balance and receptors for smell, taste etc. are also present in their body which make these animals aware of their surroundings to get food, shelter and protection. Osphradium is a sensory structure which teste the chemical nature of water.
14. **Nervous system:** The nervous system consists of **paired ganglia** and several **nerves** to provide nervous supply to the body. Ganglia (singular: ganglion) are the aggregations of nerve cells.
15. **Reproductive system:** Molluscs are usually dioecious as sexes are separate in them e.g., Pila, Sepia, Loligo, Octopus, etc. Examples of monoecious forms are Aplysia Doris etc. Molluscs are usually oviparous (egg-laying).
16. **Fertilisation:** Both external and internal fertilization are seen in molluscs. **Usually internal fertilization** is more common.
17. **Development:** Both direct and indirect developments are seen in molluscs but usually indirect development occurs which is mediated by a free-swimming larval stage, like trochophore, Veliger (in Pila), glochidium (in Unio) and ectoparasite on fishes, e.g., Pila and Aplysia. Examples of molluscs exhibiting direct development are Loligo, Sepia and Octopus.

Example :

Pinctada (Pearl oyster), Pila (Apple snail), Aplysia (Sea hare), Loligo (Squid), Dentalium (Tusk shell), Chaetopleura, (Chiton), Sepia (Cuttlefish), Octopus (Devil fish)

PHYLUM MOLLUSCA



PHYLUM – ECHINODERMATA

Introduction: Echinodermata literally means "spiny or prickly skinned" (Greek, echinos-spiny, derma – skin). They possess an **endoskeleton** (internal skeleton) of **calcareous ossicles** (small bones), embedded in the skin.

Similarities with chordates:

(i) They have tube within tube of body plan which has evolved along **deuterostomic evolutionary** line.

(ii) They possess a true coelom called **enterocoelom.**

(iii) They have **mesodermal skeleton** made of calcareous plates or ossicles.

General characteristic features of Echinodermata :

1) **Habitat:** All echinoderms are exclusively marine and usually live at the bottom of sea hence they are the bottom dwellers.

2) **Habit:** No parasitic form is found in them. They are the free-living animals.

3) **Body symmetry:** The adult echinoderms are radially symmetrical but their larvae are bilaterally symmetrical. The echinoderms are unique in this feature that the larvae are bilaterally symmetrical (an advanced feature) while the adults developing from them are radially symmetrical (a primitive feature).

4) **Level of organization:** They possess the **organ-system** level of organization.

5) **Germ layers:** These are the **triploblastic** animals.

6) **Segmentation:** Body is unsegmented.

7) **Coelom:** Echinoderms are the coelomate animals.

8) **Body form:** The adult echinoderms have a pentamerous radial symmetry and their body parts are arranged along the five axes. Body shape varies from star-like (star fish) to globular or globe-like (sea urchin) to cylindrical cucumber). An endoskeleton of calcareous ossicles with overlying skin gives spiny appearance echinoderms.

(9) Between the spines, there are pincers like structures called **pedicallariae** to keep the surface of Pedicallariae are made of three calcareous plates. Two calcareous valves like structures in the jaws resting upon a basal calcareous plate.

(10) **Water vascular System:** It is the most distinctive feature of echinoderms. It is in fact a modified panel coelom consisting of a **system of canals** which are filled with watery fluid. Different types of canals together form the water vascular system.

(11) **Functions of water vascular system:** This system is called water vascular because this system acts like the circulatory system of body maintaining the continuous flow of water in and out of the body following are the functions of this system :

(i) **Locomotion:** Most peculiar and interesting role of the water vascular system is in the locomotion. Body is moved by the stepping action of tube feet which are alternatively adhered to and released from the substratum on which the animals move. This happens with the entry and exit of water.

(ii) **Capture and transport of food:** The prey is captured and held in position by the arms and tubes feet. The food is taken in and then transported in the body.

(iii) **Respiration:** The ture feet also serve as the equivalent of gills during respiration. The thin walls of dioxide in it.

(12) Digestive system: Digestive system is complete with two separate opening. It lies along the dorso-vetral axis of body. Mouth lies on the lower (ventral side and anus on the upper (dorsal) side of body.

(13) Excretory system: Specialised excretory system is absent. The excretory products diffuse out from the body tissues into the coelomic fluid from where they are finally eliminated out.

(14) Reproductive system: The echinoderms are usually dioecious (sexes are separate). The reproduction is sexual.

(15) Fertilization: Fertilization is usually external, takes place in the sea water. Mature gametes (sperms and ova) are shed freely in surrounding sea water where fertilization takes place.

(16) Development: Development is indirect with free-swimming bilaterally symmetrical larva.

Example :

Asterias (Star fish), Ophiura (Brittle star), Cucumaria (Sea cucumber), Antedon (Sea lily), Echinus (Sea urchin),

PHYLUM ECHINODERMATA

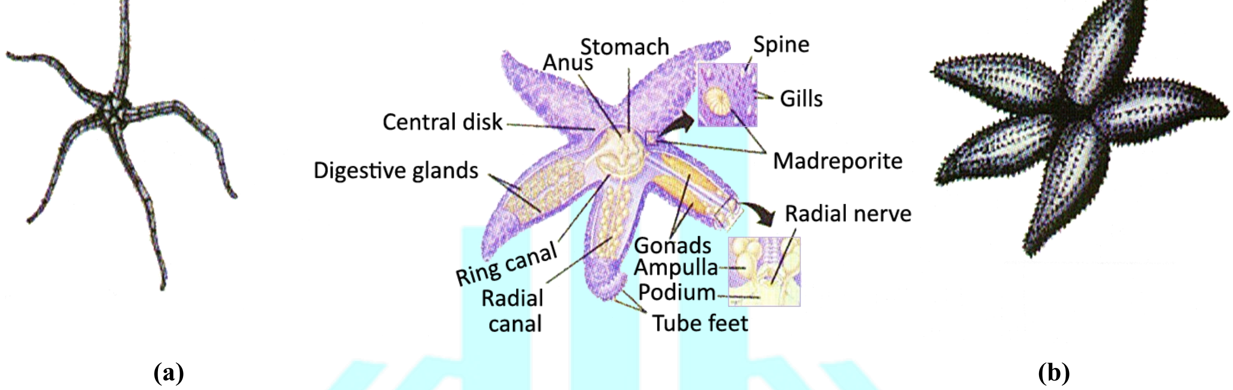


Fig: Example of Echinodermata (a) Ophiura (b) Asterias

PHYLUM – HEMICHORDATA STOMOCHORDATA

Introduction: hemichordate was earlier considered as a sub-phylum under phylum chordate. But now it is placed as a separate phylum under non-chordata.

Name Hemichordata (Greek: hemi-half, Chorde-Cord) literally means they are 'half' chordates a fact that is undisputed. This name was derived on the basis of a structure present in their body which was considered to be their 'notochord'. But this fact is no more supported. That's why hemichordates are now considered non-chordates. This phylum consists of a small group of worm like animal.

General characteristic features of Hemichordate:

(1) Habitat: It includes **exclusively marine** animals (like Echinodermata).

(2) Body symmetry: Hemichordates are **bilaterally** symmetrical animals.

(3) Level of organization: They possess the **organ-system** level of organization.

(4) Germ layers: These are the **triploblastic** animals.

(5) Segmentation: Segmentation is **absent**. They possess an unsegmented body.

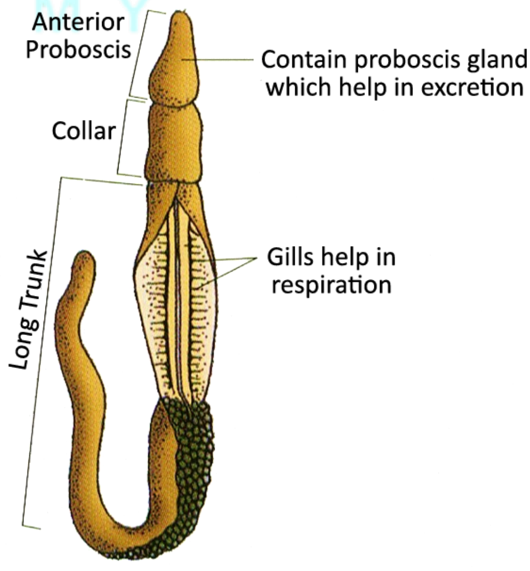
(6) Coelom: These are the coelomate animals possessing mesoderm lined body cavity.

(7) Body form: These animals are very soft, fragile and worm-like appearance. The body is cylindrical in shape and is divisible into three distinct regions or parts

(i) An **anterior proboscis**: It is short and conical in shape.

(ii) **Middle collar:** It is a short and cylindrical part.

(iii) A long **posterior trunk:** It is flat an further differentiated into parts.



Balanoglossus

(8) **Digestive system:** Digestive tract is **complete**.

(9) **Circulatory system:** The circulatory system is of **open** type.

(10) **Respiratory system:** These are the aquatic animals and respiration takes through the gills.

(11) **Excretory system:** Hemichordates are **dioecious** (sexes are separate). Reproduction is sexual.

Fertilization: Fertilization is **external** i.e., in the sea water.

Development: The development is mainly indirect with a free-swimming larva

Introduction: Animals that belong to chordates are fundamentally characterised by the presence of a notochord, a dorsal hollow nerve cord an paired pharyngeal gill slits. The notochord is replaced by a cartilaginous or bony vertebral column in the adult in sub-phylum vertebrate, thus we say all vertebrates are chordates but all chordates are not vertebrates. Besides that basic chordate characters, vertebrates have a ventral muscular heart with two, three or four chambers, kidneys for excretion and osmoregulation and paired appendages which may be fins or limbs.

Example :

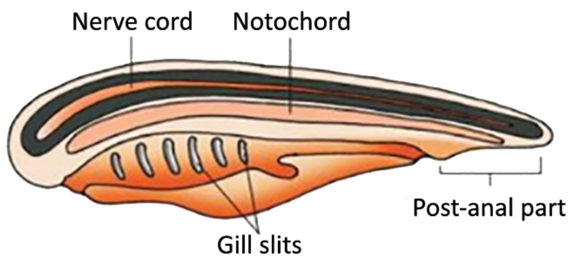
Balanoglossus and Saccoglossus.

PHYLUM CHORDATA

Phylum chordate has four fundamental features.

1. **Notochord** (elastic, solid, unsheathed rod-like structure of vacuolated turgid calls which is present throughout the life or only during early embryonic development located between nerve cord and digestive tube (alimentary canal)).

   In vertebrates, notochord is replaced by a cartilaginous or bony vertebral column in adults.



2. **Dorsal hollow nerve cord:** It differentiates into brain and spinal cord. It is present above the notochord.
3. **Paired pharyngeal gill slits :**

❖ Take part in circulation of water for respiration.

❖ In higher chordates they occur only in embryonic stage.

4. **Post anal tail:** it is present for balancing.

   Along with these features chordates are bilaterally symmetrical, coelomate with organ level of organization and close circulatory system.

Table: Comparison of Chordates and Non-chordates

Chordates	Non-chordates
1. Notochord present.	1. Notochord absent.
2. Central nervous system is dorsal, hollow and single.	2. Central nervous system is ventral, solid and double.
3. Pharynx perforated by gill slits.	3. Gill slits are absent
4. Heart ventral.	4. Heart is dorsal (if present).
5. A post-anal tail is present.	5. Post-anal tail absent.
6. Gut is ventral to nerve cord.	6. Gut is dorsal to nerve cord.

Phylum chordata is divided into three sub-phyla:

<u>Phylum :</u> Chordata

3 sub-phylum

- Uro chordata Or Tunicata
- Cephalo chordata
- Vertebrata

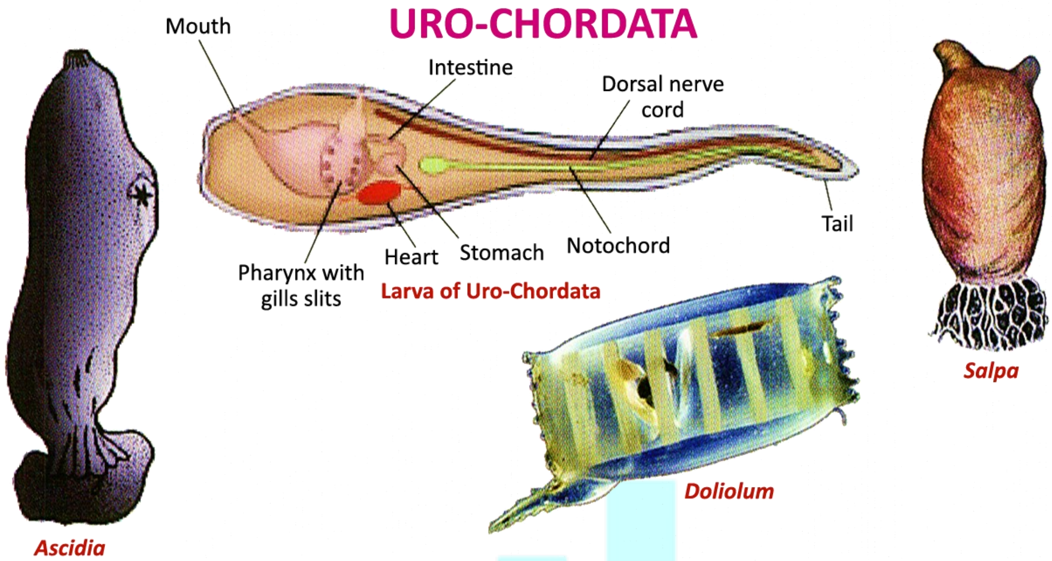
CLASSFICATION OF PROTOCHORDATA OR ACHRANIATES

Sub-phylum –1- UROCHORDATA

1. The adult body is enclosed within a leathery **test or tunic** formed of a cellulose-like organic substance termed **tunicin,** therefore, this phylum is called **tunicata.**
2. Notochord is only present in the tail of the larva (hence named Urochordata) and disappears in the adults.
3. Circulatory system is open tunicates.
4. Development is indirect.
5. Retrogressive metamorphosis shown by the larva i.e. change from better developed larva to less developed adult.

6. Excretion by neural gland.

Example : Ascidia, Salpa, Doliolum



Sub–phylum -2- CEPHALO CHORDATA

1. Notochord extends from head to tail region.
2. Notochord persists throughout the life.
3. Digestive tract is complete. Pharynx large, perforated by numerous persistent gill-slits.
4. Circulatory system well-developed, closed and without heart.
5. Development is indirect, including free swimming larva.
6. Respiration through general body surface.
7. Excretion by protonephridia with solenocytes.
8. Paired appendages absent. Median fins (dorsal, ventral and caudal) and present.

Example : Branchiostoma (Amphioxus or Lancelet)

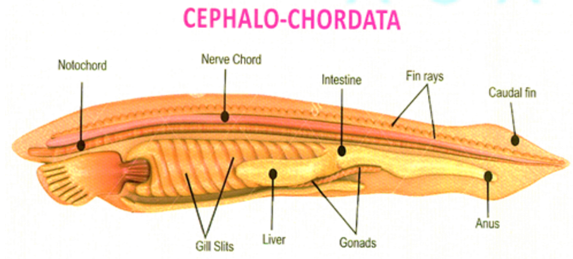


Table : Comparison of Urochordata and Cephalochordata

Urochordata	Cephalochordata
1. Notochord is present only in the tall of the larva.	1. Notochord extends from head to tail region.
2. Notochord disappears in the adult.	2. Notochord persists throughout the life.
3. Circulatory system is open	3. Circulatory system is closed.
4. Excretion by neural gland.	4. Excretion by protonephridia with solenocytes.
Example: Salpa, Doliolum	**Example: Branachiostoma**

phylum – 3 VERTEBRATA/CRANIATA

General characteristics of sub-phylum vertebrata:

1. Brain is enclosed within a cranium.
2. Possess notochord during the embryonic period only.
3. Notochord is replaced by a cartilaginous or bony vertebral column in the adult, thus all vertebrates are chordates but all chordates are not vertebrates.
4. Vertebrates have ventral muscular heart with two, three or four chambers.
5. Kidneys are present for excretion and osmoregulation.
6. For locomotion, they have paired appendages which may be fins or limbs.
7. They are unisexual.
8. They have single pair of gonads.

Sub-phylum-Craniata or Vertebrata
Notochord is replaced by Vertebral column
Dryson

- Agnatha (lacks jaw) — 2 classes
  - Ostracodermic e.g. Dephalaspis (Extinct)
  - Cylostomata e.g. Petromyzon, Myzine
- Gnathostomata (lacks jaw) — 2 supar classess
  - Pisces (bears fins) — Classes
    - Placodermi e.g. Climatius (Extinct)
    - Chondrichthyes e.g. Scoliodon, Pristis
    - Osteichthyes e.g. Labeo, Hippocampus
  - Tetrapoda (bears limbs) — Classes
    - Amphibia e.g., Bufo, Rana
    - Reptilia e.g. Chelone, Testudo
    - Aves e.g. Corvus, Columba
    - Mammalia e.g. Macropus, Pteropus

Division -1 : AGNATHA (The Jawless Vertebrates)

1. They are the most primitive of all craniates.
2. Mouth does not possess jaws hence named Agnatha.
3. Notochord persists throughout life.
4. They do not have exoskeleton and paired appendages.
5. They have a single nostril.
6. They are cold-blooded.

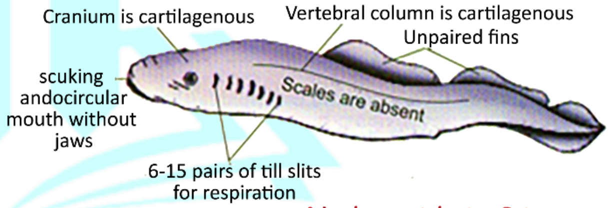
CLASS 1. CYCLOSTOMATA

General characteristics of Cyclostomata

1. All living members of this class are ectoparasites on some fishes.
2. They have an elongated body bearing usually 6-15 pairs of gill slits for respiration.
3. Cyclostomes have a sucking circular mouth.
4. Mouth is without jaws hence they are also called as jawless fishes.
5. Their body is devoid of scales and paired fins.
6. Cranium and vertebral column are cartilaginous.
7. Circulation is of closed type.
8. Stomach is absent.
9. Cyclostomes are marine but migrate for spawning to fresh water. After spawning, within a few die. Their larvae, after metamorphosis, return to the ocean.

   Examples: Petromyzon, Lamprey and Myxine (Hagfish).

CLASS - CYCLOSTOMATA



A jawless vertebrate - *Petromyzon*

Division-2 GNATHOSTOMATA (The Jawed Vertebrates)

1. It includes advanced vertebrates.
2. Mouth has jaws hence it is named **gnathostamata.**
3. Embryonic notochord is usually replaced in adult by a vertebral column.
4. Paired fins or limbs are present.
5. They have paired nostril.
6. They are both cold-blooded and warm-blooded.
7. Gnathostomata is divided into two super classes: **Pisces and Tetrapoda.**

SUPERCLASS-1 : PISCES

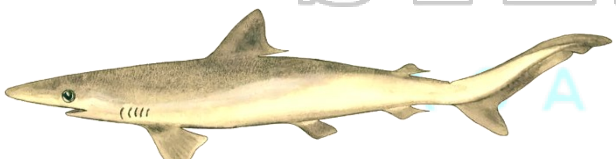
1. It includes true fishes.
2. All are aquatic.
3. Paired and unpaired fins present.
4. Respiration occurs typically by gills.
5. Each eye has a well-developed nictitating membrane, eyelids are absent.
6. Lateral line sense organs are present.

7. Heart is two chambered (S-shaped venous heart) with sinus- venosus and conus -arterious.
8. Mono condylic skull, slimy glands present on skin.
9. Vertebrae are Amphicoelous type.
10. Both renal portal and hepatic portal system are found. Hypophyseal portal system is also present.
11. Kidneys – Mesonephric, ammonotelic (sharks- Ureotelic).

CLASS-1 CHONDRICHTHYES

1. They are marine animals with streamlined body.
2. Endoskeleton is made up of cartilage.
3. Their jaws are powerful. Mouth is located ventrally.
4. Gill slits are separate and without operculum (gill cover). Except in the Chimaeras.
5. Air bladder or swim bladder is absent, so they have to swim constantly to avoid sinking.
6. Heart is two clambered one auricle and one ventricle.
7. Organisms belong to this class are cold-blooded (poikilothermous) i.e., they lack the capacity to their body temperature.
8. Organisms are predaceous, some of them have electric organs (e.g. ,Torpedo) and some possess sting (e.g. Trygon).
9. Sexes are separate and show sexual dimorphism.
10. Fertilization is internal.
11. There are 10 pairs of cranial nerves.

Examples: Scoliodon (Dog fish), Pristis (Saw fish), Trygon (Sting ray), Carcharodon (Great white shark).



Scoliodon

Pristis

Torpedo (Electric Ray)

CLASS-2 : OSTEICHTHYES

1. It includes both marine and fresh water fishes with streamlined body.
2. Mouth is located terminally.
3. Teeth are present in the jaws.
4. Skin is covered with cycloid/ctenoid scales.
5. Air bladder is present which regulates buoyancy.
6. Heart is two-chambered (one-auricle and one ventricle). Lung fishes have a three chambered he auricles and one ventricle.
7. Caudal in usually homocercal.
8. Kidneys are meso nephric. Ammonia is chief nitrogenous waste. Cloaca is absent.
9. There are present 10 pairs of cranial nerves.
10. They are cold-blooded.
11. Sexes are separate.
12. Fertilisation is usually external.
13. They are oviparous.
14. Development is direct.

Example: Marine – **Exocoetus** (Flying fish), **Hippocampus** (Seahorse)

Fresh water – **Labeo** (Rohu), **Catla** (Katla), **Clarias** (Magur)

Aquarium – **Betta** (Fighting fish), **Pterophyllum** (Angel fish)

1. Marine water fishes

(a) Exocoetus (Flying Fish) :

(b) Hippocampus (Sea Horse) :

Hippocampous (Sea Horse)

2. Fresh Water Fishes

(a) Labeo (Rohu)

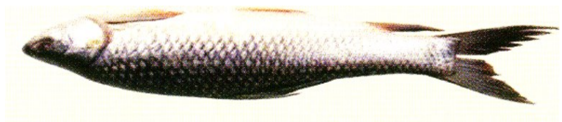


Fig: Labeo

(b) Catla (Bhakur) :

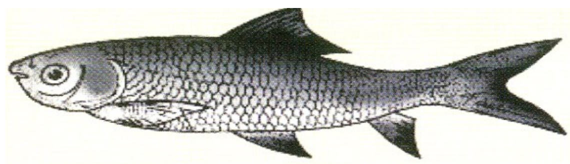


Fig. : Catla

(c) **Clarias (Magur) :**

Fig. : Clanas (Magur)

3. **Aquarium Fishes**

Eg. Betta (fighting fish)

Pterophyllum altum : Also known as Angel fish,

Fig. : Betta (Fighting Fish)

Agnatha	Gnathostomata
1. They are the most primitive of all craniates.	1. It includes advanced vertebrates.
2. Mouth does not possess jaws hence named Agnatha.	2. Mouth has jaws, hence it is named gnathostomata.
3. Notochord persists throughout life.	3. Embryonic notochord is replaced in adult by a vertebral column.
4. They have single nostril	4. They have paired nostrils.

SUPERCLASS-2 : Tetrapoda

1. These possess two pairs of limbs.
2. Skin is adapted to withstand exposure to air.
3. They have lungs for aerial respiration.
4. Their sensory organs are adapted for reception in air, such as vision, vision, hearing, smelling, etc.

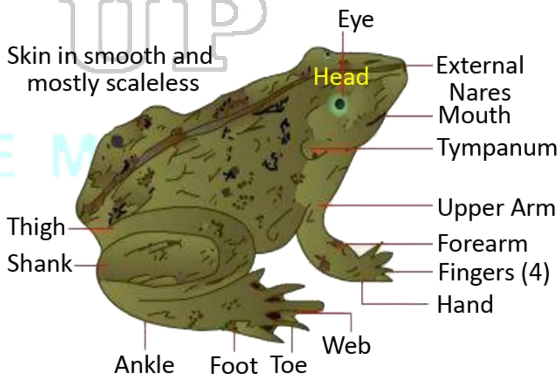
Tetrapoda is divided into four classes : **Amphibia, Reptilia, Aves and Mammalia.**

CLASS : 1 AMPHIBIA (Gr. Amphi : dual,

General characteristics of Amphibia :

1. **They are poikilothermal animals.** They are amphibious in nature, viz. they can live on land as well as in water. They are mostly found in warm countries. They are ectothermic (cold blooded).
2. The skin is smooth or rough having cutaneous glands which keep it most. They are usually without scales, but if present they are hidden beneath the skin (e.g.,Caecilians).
3. Two pairs of limbs are used for locomotion.
4. The gills are present at least in the larval stage, some adult forms also carry them in addition to lungs (e.g., Necturus).
5. The respiration organs are lungs, buccopharyngeal cavity, skin and gills.
6. Skull is dicondylic i.e., with two occipital condyles for articulation with vertebral column.
7. The heart is three chambered, having two auricles and one ventricle. In the heart, there are present sinus venous and truncus arteriosus. Both hepatic portal and renal portal systems are well developed.
8. Kidneys are mesonephric.Urinary bladder is present in frog. Larvae and tailed amphibians (e.g., Salamanders) are ammonotelic. Frogs and toads are ureotelic.
9. Ear consists of internal and middle ear, Tympanus (outer membrane) covers the middle ear. The middle ear has a single ear ossicle called Columella Auris.
10. Ten pairs of cranial nerves are present.
11. They return to water for breeding. Male lacks copulatory organs. The metamorphosis is usually present. A fish like stage, the tadpole is present.

Example : Rana (Frog), Bufo (Toad), Salamandra (Salamander), Hyla (tree frog), Ichthyophis (Limbless amphibia).



Ichthyophis : It is a limbless amphibian.

Ichthyophis (Limbless amphibia).

Salamandra

CLASS-2 REPTILIA
(Latin or reptum, to creep or crawl)

General characteristics of Reptilia:

1. The class name refers to their creeping mode of locomotion.
2. There are the first true land vertebrates.
3. Their body is covered by dry and cornified skin, epidermal scales or scutes.
4. External ear openings may be present or absent.
5. Tympanum represents ear.
6. Limbs, when present, are two pairs.
7. Heart is usually three-chambered, but four-chambered in crocodiles.
8. Mouth is terminal with conical teeth which are pleurodont in lizards and snakes and the crocodiles. Teeth are absent and replaced by horny beaks in turtles.
9. Endoskeleton is horny, skull is monocondylic (with one occipital condyle).
10. Kidneys are metanephric. Excretion is uricotelic. Urinary bladder is absent in snakes.
11. Cranial nerves are nerves are 12 pairs. Jacobson's organ (vomeronasal organ) present in the roof of bucked concerned with smell, is well developed in snakes and lizards. They do not have external ears. Tympanum represents ears.
12. Reptiles are cold-blooded or poikilotherms.
13. Snakes and lizards scales on their skin.
14. Sexes are separate.
15. Fertilization is internal.
16. They are oviparous. Eggs are covered by a shell.
17. Development is direct.

    Example : Chameleon (Tree lizard), Chelone (Turtle), Calotes (Garden lizard), Alligator (Alligator), Crocodilus (Crocodile), Hemidactylus (Wall lizard),

    Poisonous snakes – 1 Naja Naja (Cobra), Bangarus (Krait) Vipera (Viper).

CLASS-3 AVES (Birds)

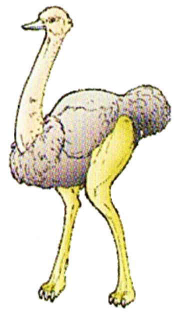
General characteristics of Aves:

1. Birds are feathered bipeds, truly flying vertebrate.
2. Most of them can fly except flightless birds (e.g. Ostrich).
3. They possess beak and have streamlined body.
4. Forelimbs are modified into **wings.**
5. The hind iambs generally have scales and are modified for walking. Swimming or clasping the tree branches.
6. Skin is dry without glands except the oil gland or green gland or uropygeal gland at the base of the tail for lubrication of feathers.
7. Endoskeleton is fully ossified (bony) and the long bones are hollow with air cavities. Such bones are known as pneumatic bones and lack bone marrow.
8. The digestive tract of birds has additional chambers. The crop gizzard.
9. Heart is completely four-chambered.
10. Only right aortic (systemic) arch persists in the adults. Renal portal system is vestigial. Erythrocytes are minute, oval and nucleated. The blood of the birds may be called the richest blood in the animal kingdom. It has more RBCs per cubic mm of blood than in any other animal.
11. Kidneys meta nephric and three-lobed. Ureters open into cloaca. Urinary bladder is absent. Excretion is uricotelic.
12. Cranial nerves are 12 pairs.
13. Olfactory organs are poor. Middle ear contains a single ossicle. Eyes possess nictitating membrane. Pecten is a comb-like structure found in the eyes near blind spot. Pecten helps in providing nutrition to the eyeball.
14. They are warm-blooded (homeothermous animals) i.e., they are able to maintain a constant body temperature.
15. Respiration is by lungs.
16. Air sacs connected for producing voice, lies near the junction of trachea and bronchi.
17. Syrinx is present for producing voice, lies near the junction of trachea and bronchi.
18. Sexes are separate.
19. Fertilization is internal.
20. They are oviparous and development is direct.

    Example : Corvus (Crow), Columba (Pigeon), Psittacula (Parrot), Struthio (Ostrich), Pavo (Peacock), Aptenodytes (Penguin), Neophron (Vulture).

Corvus (Crow)

Neophron (Vulture)

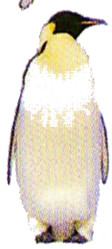


Struthio (Ostrich)

Psittacula (Parrot)

Pavo (Peacock)
(National bird of India)

Columba (Pigeon)



Aptenodytes (Penguin)
(Found in Antartica)

CLASS-4 : MAMMALIA (L. Mamma = breast)

General characteristics of Mammalia :

1. The most unique mammalian characteristic is the presence of milk producing glands (mammalian by which the young ones are nourished.
2. They are found in variety of habitats – polar ice caps, deserts, mountains, forests, grasslands and drawn.
3. They have two pairs of limbs, adapted for walking, running, climbling, burrowing or swimming.
4. The skin of mammals is unique in possessing hair.
5. External ears or pinnae are present.
6. Different types of teeth are present in the jaw.
7. Heart is four-chambered.
8. They are homeothermous.
9. Respiration is by lungs.

★ Sexes are separate and fertilisation in internal.

★ They are viviparous with few exceptions. For example, Omithorhynochus (Platypus), which is oviparous. Development is direct.

★ In males, testes have come to lie outside the body cavity in scrotal sacs (except in elephants and aquatic mammals and prototherian mammals).

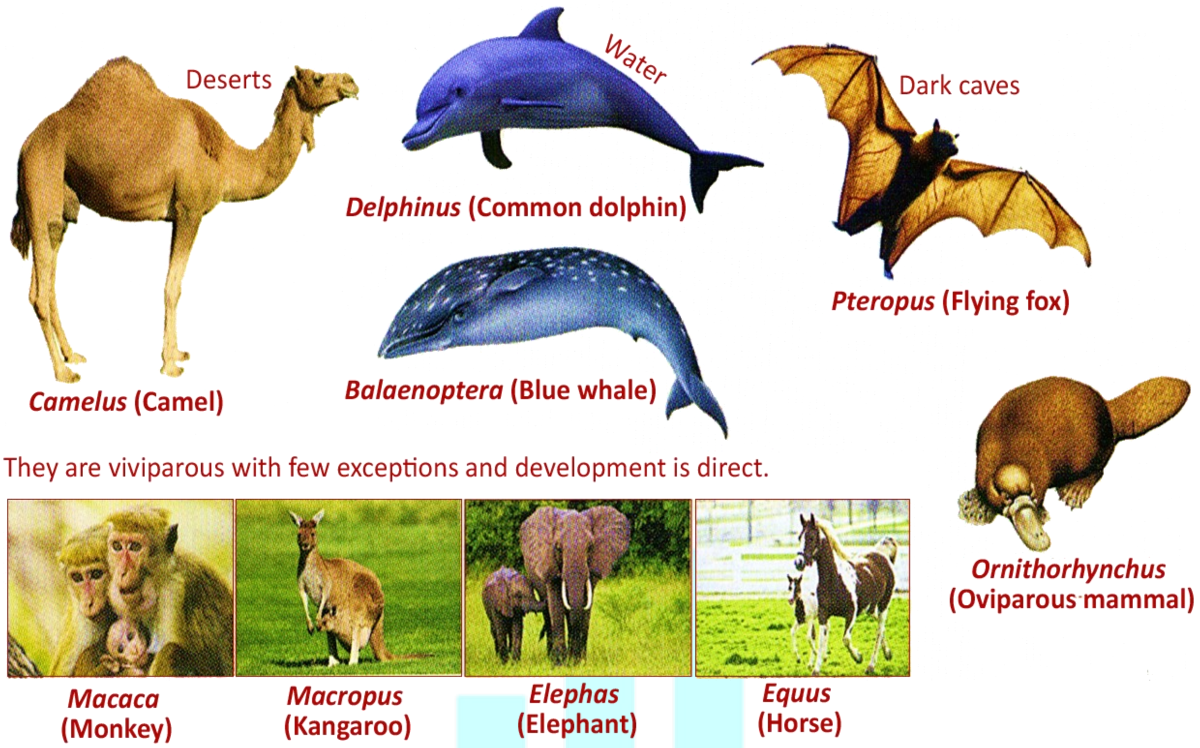
★ Cerebral hemispheres and cerebellum are large-sized and highly developed with great increase in the cortex. The two cerebran hemispheres are joined by a transverse band of nerve fibres called corpus callosum. There are four solid optic lobes called corpora quadrigemina in the mid-brain. **12 pairs of cranial nerves.**

★ The middle ear has three ear ossicles called malkeus, incus and stapes : the internal ear has a spirally coiled cochlea as an efficient organ of hearing.

★ The neck generally has seven cervical vertebrae.

Example: Oviparous-Ornithorhynchus (Plastypus) : Viviparous Macropus (Kangaroo), Pteropus (Flying fox), Camelus (Camel), Macaca (Monkey), Rattus (Rat), Canis (Dog), Felis (Cat), Elephas (Elephant), Equus (Horse), Delphinus (Common dolphin), Balaenoptera (Blue whale), Panthera tigris (Tiger), Panthera leo (Lion).

They are found ina variety of habitats - polar-ice caps, mountains, forests, grasslands and



Mammals are homoiothermous. Sexes are separate and fertilisation is internal.

Table : Difference between Prototheria, Metatheria and Eutheria

Prototheria	Metatheria	Eutheria
1. They are oviparous.	1. They are viviparous.	1. They are viviparous.
2. Ear is devoid of pinna.	2. Ear possess a pinna.	2. Pinna is present except in aquatic forms.
3. Scrotum is absent in male.	3. Scrotum in present but in front penis.	3. The scrotum is present on the sides or behind the penis.
4. Vagina and uterus are absent	4. Both vagina and uterus are double.	4. They are single structure.
5. Nipples are absent over the ammary gland.	5. Nipples are present.	5. Nipples are present.

Table: Differences between Pisces and Tetrapoda

Pisces	Tetrapoda
1. All aquatic, either freshwater or marine.	1. Aquatic, amphibious, terrestrial and aerial.
2. Body stream-lined adapted for swimming.	2. Various forms and adapted to varied modes and different habitats.
3. Skin is usually moist and scaly.	3. Skin usually dry and cornified.
4. Exoskeleton in the form of dermal scales.	4. Exoskeleton in the form of epidermal scales, scutes, dermal plates, hair and feathers.
5. Sense organ functional in water.	5. Sense organ functional in air.
6. Breathing gills.	6. Breathing by lungs except in some amphibians which have external gills.
7. Paired appendages in the form of paired fins.	7. Paired appendages are pentadactyl limbs.

Table : Difference between Tetrapod classes

Particulars	Amphibia	Reptilia	Aves	Mammalia
1. Skin	Slippers, moist, rich in mucous glands, respiratory	Dry, Scaly, lacks glands, not respiratory	Dry, lacks glands, except a long oil gland on tail, not respiratory	Dry, contains many types of glands, not respiratory
2. Heart	3-chambered	3-chambered, 4-chambered in crocodilian	4-chambered with right systemic arch.	4-chambered with left systemic arch.
3. Erythrocytes	Oval, biconvex, nucleated	Oval, biconvex, nucleated	Oval, biconvex, nucleated	Circular, biconcave, non-nucleated
4. Lungs	Sac-like	Sac-like	Solid and spongy	Solid and spongy
5. Ear	No external ear, middle ear with one auditory ossicle	External ear may be present, only one auditory ossicle	External ear present only one auditory ossicle	External ear with pinna, 3 auditory ossicles
6. Cloaca	Present	Present	Present	Mostly absent
7. Body Temperature	Variable/cold blooded (Poikilothermous)	Variable/cold blooded (Poikilothermous)	Fixed/warm blooded (Homoiothermous)	Fixed/warm blooded (Homoiothermous)
8. Breading	Oviparous	Mostly oviparous	All oviparous	Most forms viviparous
9. Scales	Generally absent	Present	Present only on hindimb	Absent

Chapter 5

Morphology of Flowering Plants

Introduction:

You know that flowering plants are multicellular organisms. They grow by cell division and their morphological features and traits are genetically determined. Even though the angiosperms show such a large diversity in external structure, they are all characterised by presence of roots, stems, leaves, flowers and fruits. Morphology deals with the study of forms and features of different plant organs like roots stem, leaves, flowers, seeds, fruits etc. Morphology plays a key role in the classification of angiosperms. In this unit, you will learn about the important morphological features of the flowering plants. We shall learn how to describe a flowering plant using examples from selected families you will also learn how different parts of plants are modified to serve specific needs including defense from their enemies. You will get some idea of the economic importance of selected plant families.

THE ROOT

Roots are cylindrical underground and non-green part of plant. It is generally the descending portion of the plant axis *i.e.*; it grows downward into the soil. It lacks nodes, leaves, buds but gives rise to endogenous lateral branches. Roots move in the direction of gravity (geotropism) and against the direction of light (phototropism). Hence, the roots are said to be positively geotropic and negatively phototropic.

Plant have well developed root systems. The main root and its lateral branches form the **root system.** There are three types of root system.

(i) Tap root system: The **primary root** is directly elongated from the radical and grows inside the soil (e.g. dicots. It bears lateral roots of several orders that are referred to as secondary, tertiary roots etc. The primary roots and its branches constitute the tap root system.

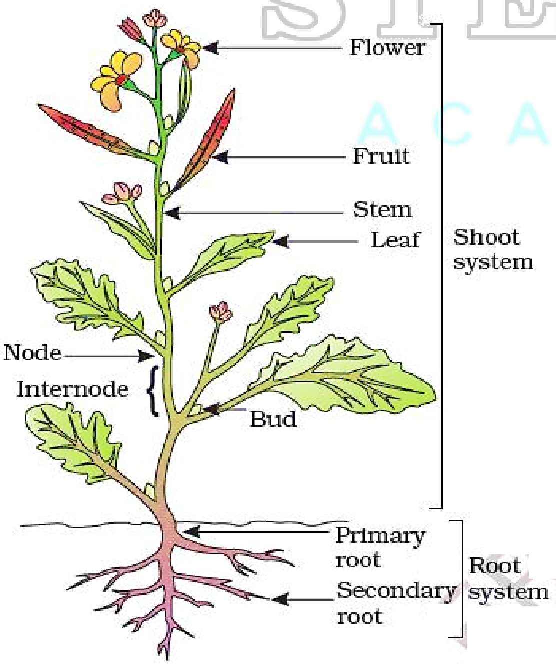
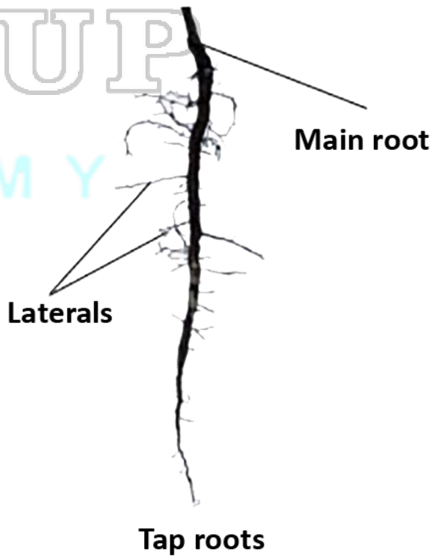


Fig.: Parts of a Flowering Plant



(ii) Fibrous root system: In monocotyledonous plants, the primary root is short-lived and is generally replaced by a number of fine fibrous roots. These roots originate from base of the stem and constitute the fibrous root system as seen in wheat plant.

Fibrous roots

(iii) Adventitious root system: Some plants have specialised roots called adventitious roots. These roots develop from any parts of the plant other than the radical e.g., Grass, Monstera, Banyan tree.

Adventitious roots

Fig. : Adventitious root of sweet potato

Main Functions of Root

I. Absorption of water and minerals from the soil.

II. Provide anchorage to the plant parts.

III. Storage of reserve food material.

IV. Synthesis of plant growth regulators.

Regions of the Root

(i) Root cap: The apex of the root is covered by a thimble-like, structure called **root cap.** It is multicellular and is made up of parenchymatous cells. It protects the tender apex of the root as it makes its way through the soil.

(ii) Region of meristematic activity: This layer is few millimeter above the root cap. The cells of this layer are thin-walled, small with dense protoplasm. They divide repeatedly to produce new cells.

(iii) Region of elongation: The cells proximal to the meristematic region undergo rapid elongation and enlargement and are responsible for the growth of roots in length.

(iv) Region of maturation: The cells elongation zone gradually differentiates and mature. Hence, this zone proximal to region of elongation is called the **region of maturation.**

Some epidermal cells from the region of maturation form very fine and delicate thread-like structures called **root hair.** The root hair increases the surface area for absorption of water and minerals from the soil.

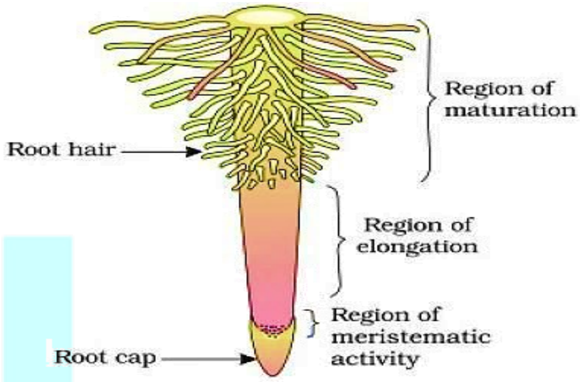


Fig. : The regions of the root-tip

Modifications of Root

The roots are mainly involved in absorption of water and minerals form the soil.

Roots in some plants undergo modifications in their shape and structure in order to perform functions like respiration, storage and protection.

(i) Storage roots: In some plants the primary tap root is modified to store food and assumes various shapes, e.g., tap root of carrot, turnip, radish, beet and adventitious roots of sweet potato get swollen and store food.

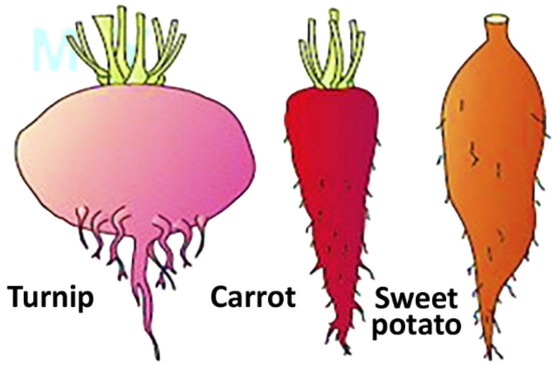


Fig: Modification of root for storage

(ii) Respiratory roots: In some plants such as Rhizophora growing in swampy areas, many roots come out of the ground vertically upwards to get oxygen for respiration. Such roots are called **pneumatophores.**

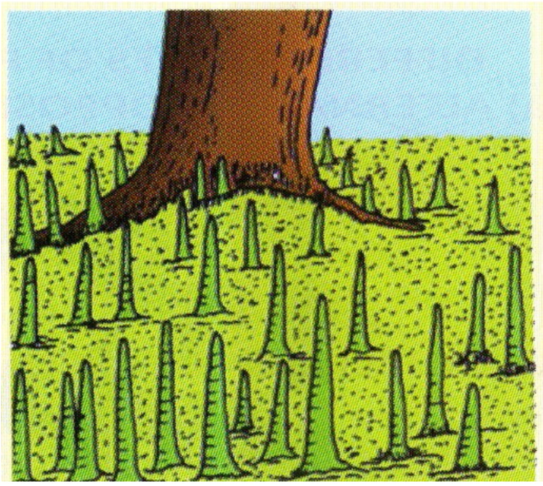


Fig. : Pneumatophore in Rhizophora

(iii) Prop roots : They arise from the branches of stem for providing mechanical support to heavy branches as pillars e.g., banyan tree.

Fig.: Prop of pillar roots of Ficus benghelensis (banyan tree)

(iv) Stilt roots: They arise from lower nodes of stem to support main axis and enter the soil obliquely e.g., sugarcane, maize.

THE STEM

The ascending part of the plant axis which bears branches, leaves, flowers and fruits is called **stem.** It generally grows above the ground and hence is considered as the aerial part of the plant. The plumule of the embryo. Present in the germinating seed gives rise to the stem.

The stem is generally green in colour at the initial young stage but later it becomes woody and dark brown. It is differentiated into nodes and internodes. The region bearing leaving, present at regular intervals on the stem and its branches are called **nodes** and the part of stem present between the two nodes is called **internode.** The stem bears buds which may be terminal or axillary. A bud is defined as the young, immature, under developed, compact school. The buds present on the stem are of two types namely.

(i) Terminal bud: The bud present at the tip of the stem is called **terminal bud.** The growth of the stem and its branches is accomplished through the terminal bud. The terminal bud is also called apical bud.

(ii) Axillary bud: The leaf makes an angle with the upper part of the stem. The angle made between the leaves and the upper part of the stem is called the axil. The bud which is present at the axil is called **axillary bud.**

Functions of the Stem

1. Stem bears and supports leaves, flowers and fruits.
2. It conducts water and minerals salts from roots to leaves and fruits.
3. The food manufactured in the leaves is transported to the roots, fruits and organs of storage through the stem.

Modifications of Stem

The stem of some plants is modified to perform different functions in order to help plants to adapt to the present environmental conditions. Some of the modification occurring in plants are :

(i) Underground stem : Stem it is generally the aerial part of the plant i.e., it present above the ground but in some plants, it is modified for storing food materials, where it forms underground stem of potato, ginger etc. store food material. They also act as organs of perennation to tide over conditions unfavourable for growth. They also act as organs of perennation to tide over conditions unfavourable for growth.

(a) Rhizome: It grows parallel or horizontal to soil surface. It bears nodes, internodes, buds and scalysic leaves e.g., Ginger, Banana, Turmeric, Ferns. It is two types :

(i) Rootstocks: It is upright or oblique with the tip almost reaching the soil surface e.g., Dryopteris.

(ii) Straggling: It is horizontal and branched. Branching may be :

Racemose – Axis is monopodial, e.g., Saccharum, Lotus.

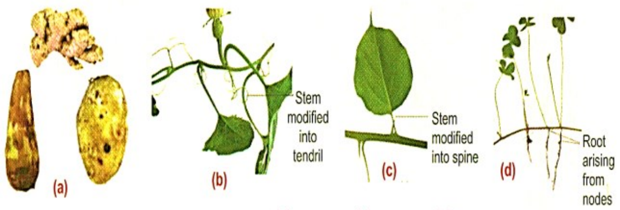
Uniparous cymose – Axis is sympodial e.g., Zingiber officinale (ginger), Curcuma domestics (turmeric) and Canna.

(b) Tuber. It is terminal portion of underground stem branch which is swollen on account accumulation of food, e.g., Potato, Helianthus tuberosus (Jerusalem artichoke).

(c) Corm. It grows vertically beneath soil surface. It is usually unbranched. It bears nodes, internodes buds and scale leaves, e.g., Colocasia, Gladiolus Colchicum, Crocus, Amorphophalla (Zaminakand).

(d) Bulb. Stem is reduced and disc shaped. The bud is surrounded by many concentric scale leave. Leaf bases of inner ones are fleshy and edible and of outer ones are dry, e.g., onion, lily, garlic.

It is of two types – tunicated and scaly. Tunicated bulb is covered by a sheath of membranous scale called **tunic.** It may be **simple tunicated bulb –** covered by a sheath, e.g., onion and Narcissus **compound tunicated bulb –** concentric rings of bulblets surrounded by a white membranous sheath or tunic e.g., garlic. **Scaly** or **naked** bulbs do not have tunic e.g., lily.



MODIFICATIONS OF STEM FOR : (a) STORAGE (b) SUPPORT (c) PROTECTION (d) SPREAD AND VEGETATIVE PROPAGATION

(ii) Stem tendrils: In some plants the axillary buds present on the stem modify to for, **tendrils.** Tendrils are long, thin, thread-like spirally coiled, sensitive structures. They are the climbing organs of the plant which coil around the nearby support. They provide support to the weak and tender stem e.g., tendrils are present in grape vine, grounds (pumpkins, watermelon, and cucumber).

(iii) Thorn: The axillary buds of plants like Citrus and Bougainvillea lose their ability to grow and form hard, woody and pointed structures called thorns. These thorns protect the plants from browsing animals. Thus, these thorns are protective in function.

(iv) Sub-aerial Weak Stem

(a) Offsets: Aquatic plants such as Pistia and Eichhornia contain a lateral branch which bears short internodes. In these lateral branches the distance between the two nodes decreases and each node bears a rosette of leaves above and a cluster (tuft) of roots.

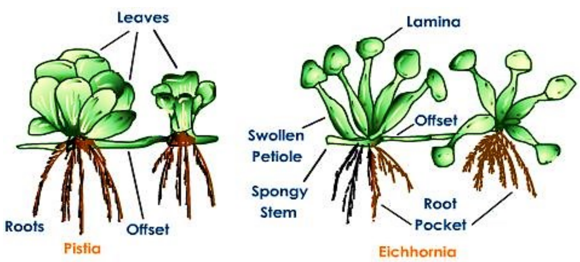


Fig. Offsets: A. Pistia, B. – Eichhornia

(b) Suckers: In plants like banana, pineapple, Chrysanthemum, the lateral branches originate from the basal and underground portion of the main stem. They grow below the surface of the soil to some distance and then emerge out obliquely to form the aerial shoot.

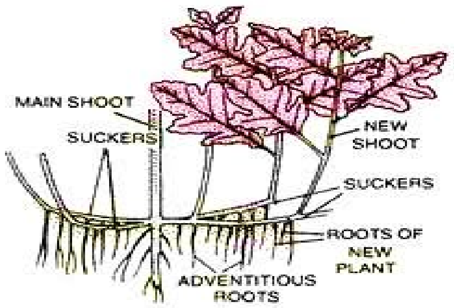
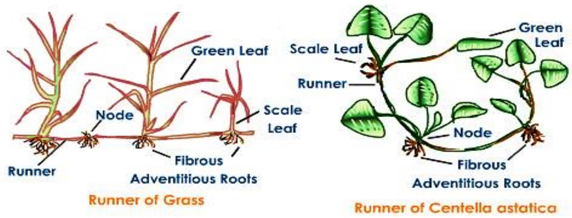


Fig. : Suckers of Chrysanthemum

(c) Runners : It is elongated, prostrate branch with long internodes and roots at nodes, e.g., grasses.



(d) Stolons: In plants like mint and jasmine a slender lateral branch arises from of the base of the main axis and after growing aerially for some time arch downwards to touch the ground.

Example - *Jasmine, Mint.*

(v) Aerial stem: Plants present in arid regions modified their stem into flattened (Opuntia) or fleshy cylindrical structures (Euphorbia) called **phylloclade.** These structures are green color due to the presence of photosynthetic pigments. These are green stems have unlimited growth. These structures perform the function of photosynthesis.

THE LEAF

A leaf is a lateral, generally flattened structure born on the stem. It develops at the node and bears a bud in its axil. It originated from the shoot apical meristem and arranged in an acropetal order of the stem. Leaves are the most important vegetative organ for photosynthesis.

Parts of a Leaf

A typical leaf consists of three parts:

(i) Leaf base: The lowermost (basal) part of the leaf by which the leaf is attached to the node of the stem is called **leaf base.** Leaf base may bear two lateral small leaves like structures called **stipules.** In monocots, leaf base expands to form a sheath covering the stem wholly or partially. In some leguminous plants, the leaf base swells and is called **pulvinus.**

(ii) Petiole: The cylindrical stalk that joins the leaf base with leaf blade (lamina) is called **petiole.** It and holds the leaf blade above the level of the stem so as to provide sufficient light to the leaf. The long, thin, cylindrical, flexible petiole allows leaf blade to flutter in wind. It thus produces a cooling effect in the leaves by bringing fresh air to the leaf surface.

(iii) Lamina or leaf blade: It is green expanded part of the leaf. The leaf blade is supported by the veins and veinlets. The prominent vein present in the middle of the leaf blade is called **midrib.** The veins provide rigidity and strength to the leaf blade and also act as a channel for transport of water minerals and food material. The shape, margin, apex, surface and extent of incision of lamina vary in different leaves.

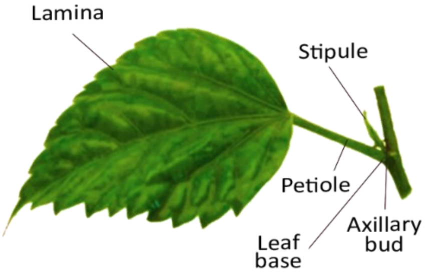


Fig. : Parts of a typical leaf

Venation

The lamina of leaf blade contains veins and veinlets. The arrangement of veins and veinlets in the lamina or leaf blade is termed as **venation.** It gives us a pattern in which the veins and veinlets are distributed or arranged in the leaf blade. Venation can occur in two ways.

(i) Reticulate venation: The veinlets form a network. It generally occurs in dicots such as peepal, Hibiscus. Luffa etc.

(ii) Parallel venation: The venation where the veins run parallel to each other within a lamina. It generally occurs in monocots e.g., banana.

Fig: Parallel venation

Types of Leaves

Different types of leaves which exist in nature are:

(i) Simple leaf: The leaf in which the leaf blade is not divided or when incised, the incisions do not touch the midrib. It has bud at the axil of the petiole.

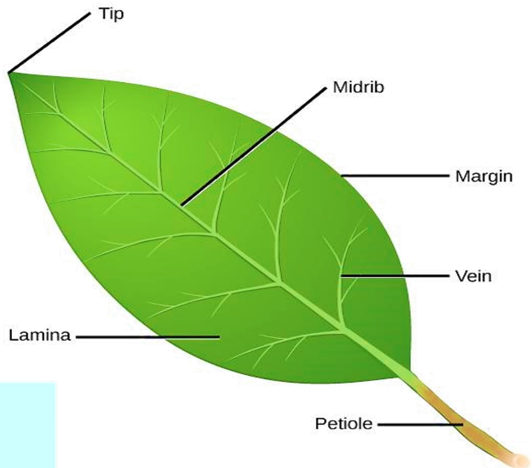


Fig . : Simple leaves (A to D)

(ii) Compound leaf: The leaf in which the lamina or leaf blade is completely broken into distinct leaflets is called **compound leaf.** The leaf has incisions which reach the midrib. Compound leaf contains a bud at the axil or the petiole but is absent in the axil of leaflets. The compound leaves are of two types :

(a) Pinnately compound leaf: In pinnately compound leaf, the midrib forms a common axis called **rachis.** A number of leaflets are present on rachis e.g., Neem.

(b)

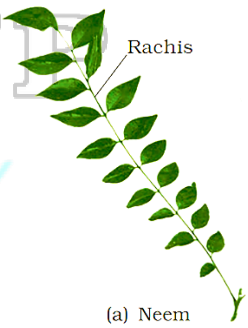


Fig: Compound leaves: Pinnately compound leaf

These may be:

(i) Unipinnate. Midrib of the directly bears the leaflet and is now called rachis. The unipinnate compound leaf is called **paripinnate** when terminal leaflet is absent (leaflets are in even number) e.g., Cassia, Tamarindus or **Imparipinnate** when terminal leaflet is present (leaflets are in odd number) e.g., Rosa, Tephrosia, Azadirachta (Neem).

(ii) Bipinnate. Midrib produces secondary axis or branches which bear leaflets e.g., Acacia, Mimosa, Delonix.

(iii) **Tripinnate:** Secondary axis produces tertiary axis which bear leaflets e.g., Moringa, Melia.

(iv) **Decompound.** Rachis is divided repeatedly without any definite pattern so that the lamina is dissected into narrow segments e.g., Carrot, Parthenium, Coriandrum.

(c) **Palmately compound leaf:** In palmately compound leaf, the leaflets are attached to a common point i.e., at the tip of the petiole. The tip of the petiole bears all the leaflets in a form of a bunch or cluster e.g., silk cotton.

(b) Silk Cotton

Fig: Compound leaves : Palmately compound leaf

Phyllotaxy : The pattern in which the leaves are arranged on the stem or its branches is called **phyllotaxy.** The leaves are arranged in such a way so that all of them get proper sunlight. The leaves can be arranged in three ways i.e., phyllotaxy is of three types:

(i) **Alternate phyllotaxy:** In alternate phyllotaxy, single leaf is present at each node in an alternate fashion. e.g., China rose (shoe flower), mustard, sunflower.

(ii) **Opposite phyllotaxy:** In opposite phyllotaxy, a pair of leaves arise at each node on opposite side. The leaves generally lie opposite to each other at each node e.g., Guava, Calotropis.

(iii) **Whorled phyllotaxy:** In whorled phyllotaxy, more than two leaves arise at each node and form a whorl or a circle. The leaves of one whorl alternate the leaves of the next successive whorl so that all the leaves receive maximum sunlight e.g., Alstonia, Nerium.

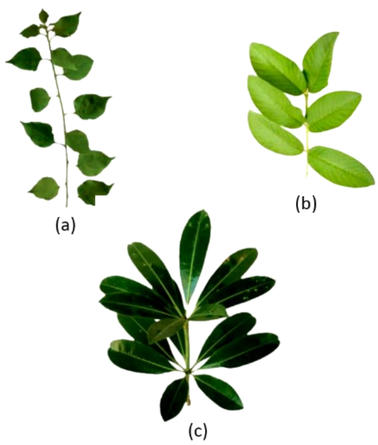


Fig. : Different types of phyllotaxy : A. Alternate, B. Opposite, C. Whorled

Modification of Leaves

Leaves are generally responsible for the process of photosynthesis, transpiration, gaseous exchange etc. But at some place where the conditions are unfavourable, leaves get modify and perform other functions such as storage, protection, support, defenses etc. Different types of modifications that occur in leaves are :

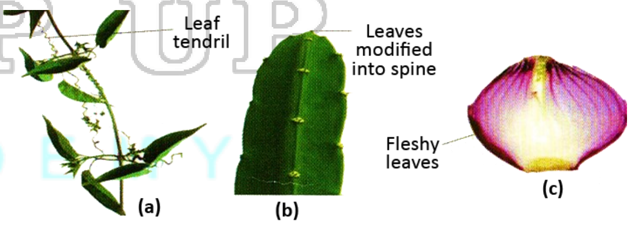
(i) **Leaf tendrils:** In some plants, leaves modify into long, slender, thread-like, sensitive structures called tendrils. They are sensitive to touch and therefore coil around a support to which they come in contact with and help the plant while climbing. Their main function is to provide support to the climbing plants e.g., peas, sweet pea.

(ii) **Leaf spines:** In some plants such as Aloe, cactus etc. leaves modify into small, sharp-pointed structures which reduce transpiration and protect the plants from browsing animals. The sharp-pointed structures are called leaf spines.

(iii) **Storage organ**: In some plants such as onion, garlic etc., fleshy leaves. store food and hence forms the storage organ in plants.

(iv) **Phyllodes:** In certain plants such as Australian Acacia the leaves are small and short lived. In these plants the petioles modify to form flat, green-colored leaf-like structure which performs the function of photosynthesis. These are known as **phyllodes.**

(v) Leaves of certain insectivorous plants such as pitcher plant, Venus-fly trap are modified leaves. Pitcher is used to trap insects. These plants obtain nutrients by digesting the insects trapped in the pitcher.



MODIFICATIONS OF LEAF FOR :
(a) Support : Tendril, (b) Protection : Spines,
(c) Storage : Fleshy leaves

THE INFLORESCENCE

The shoot modified to form the flower i.e., the flower is considered as the modified shoot. When the apical shoot meristem changes to floral meristem then the shoot bears flower during the formation of floral meristem the axis condenses and internodes do not elongate. The axis bears flowers at successive nodes instead of leaves.

The flower are born either single or in clusters on the shoot. When the shoot tip transforms into a flower it is always **solitary.** The arrangement of flowers on the floral axis or the plant is known as **inflorescence.**

The flowers can be arranged in different ways, depending upon whether the shoot apex continuous to grow or convert into a flower. Two major type of inflorescence that can occur are :

(i) Racemose: In racemose inflorescence, the shoot axis continue to grow indefinitely and the flowers are born in an **acropetal succession** i.e., younger flowers are present towards the apex and the older flowers are present at the base e.g., radish, lupin, mustard.

(ii) Cymose: In cymose inflorescence, the main axis (peduncle) terminates into a flower and hence has a limited growth. In cymose inflorescence the flowers are born in a basipetal order, e.g., Begonia, Teak, Bougainvillea, Dianthus, and Solarium.

THE FLOWER

This flower is the reproductive unit in the angiosperms. It is a modified shoot meant for sexual reproduction. It consists of four-whorls which are successively arranged on the thalamus or receptacle. **Thalamus** is the swollen end of the pedicel or the stalk. The four whorls present in a flower are **calyx, corolla, androecium, gynoecium.** The calyx and corolla are non-essential, accessory organs and androecium and gynoecium are the reproductive organs of a flower. In some flowers like lily, the calyx and corolla are not distinct and are termed as perianth.

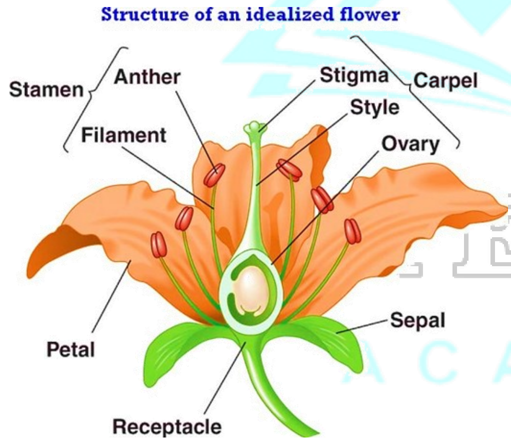


Fig. : Plants of a Typical Flower

Terminology used *w.r.t.* Flower

(i) Bisexual flower: When a flower has both androecium and gynoecium e.g., Pea, Hibiscus.

(ii) Unisexual flower: A flower having either only stamens (androecium) or only carpels (gynoecium) e.g., Maize.

(iii) Trimerous flower: When all the floral appendages (whorls) are in the multiples of three.

(iv) Tetramerous flower: When all the floral appendages are in the multiples of four.

(v) Pentamerous flower: When all the floral appendages are in the multiples of five.

(vi) Bracteate flower: Flower with bracts (reduced leaf found at the base of the pedicel).

(vii) Ebracteate flower: Flower without bracts.

Symmetry of Flower

The arrangement of the floral organs around the axis of flower is known as floral symmetry.

I. Actinomorphic flower (radial symmetry) : When a flower can be divided into two equal radial halves in any radial plane passing through the centre e.g., mustard, Datura, chilly.

II. Zygomorphic flower (bilateral symmetry) : When a flower can be divided into two similar halves only in one particular vertical plane e.g., pea, gulmohur, bean, Cassia.

III. Asymmetric flower (irregular): When a flower cannot be divided into two similar halves by any vertical plane passing through the centre e.g., canna.

Position of Floral Parts on Thalamus

Depending upon the position of calyx, corolla, androecium in respect of the ovary on the thalamus the flowers can be hypogynous, perigynous and epigynous. The flower in which gynoecium i.e., female reproductive part (ovary) occupies the highest position while the other parts are situated below it are called **hypogynous** flowers. The ovary in such flowers is said to be **superior** e.g., mustard, China rose, brinjal, petunia.

If gynoecium is situated in the centre and other parts of the flower is called **perigynous.** The ovary in such flowers are said to be **half inferior** e.g., plum, rose, peach.

The flowers in which the margin of the thalamus grows upward enclosing the ovary completely and getting fused with it, the other parts of the flower arise above the ovary. Such type of flowers is called **epigynous.** The ovary is said to be **inferior** e.g., guava, cucumber bitter gourd, the ray florate of sunflower.

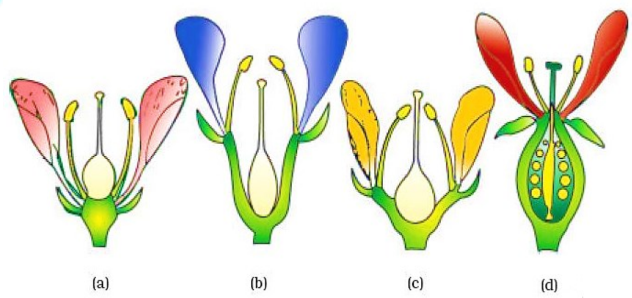


Fig. : Position of floral parts on thalamus :
A. Hypogynous B. Perigynous; C. Perigynous, D. Epigynous

Parts of a Flower

A flower normally has four whorls namely calyx (sepals), corolla (petals), androecium (stamen) and gynoecium (carpel).

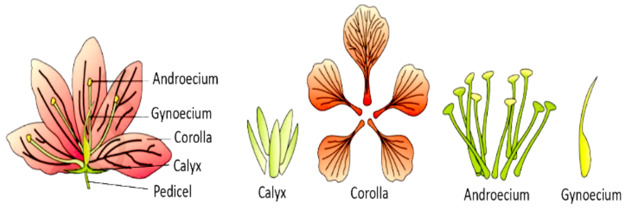


Fig. : Parts of a Flower

Calyx (sepals)

Calyx is the outermost whorl of the flower and the members are called **sepals.** The sepals are generally green leaf-like structure that protects the flower in the bud stage. The calyx may be gamosepalous (sepals united) or polysepalous (sepals free).

Corolla (Petals)

Corolla is the second whorl of the flower. The individual leaf segment of the corolla is said to be petals. The corolla or petals are generally brightly colored have fragrance which makes the flower more attractive. The shape and structure of corolla varies in different flowers. The different shapes of corolla that exist in nature are – tubular, bell-shaped, funnel-shaped, wheel-shaped etc. Like calyx corolla may be also free (polypetalous) or united (gamopetalous).

Aestivation

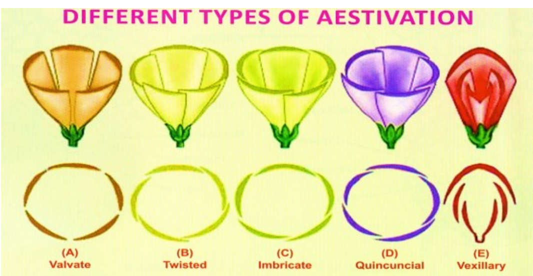
The mode of arrangement of sepals or petals in a floral bud with respect to the other member of the same whorl is called **aestivation.** It may be of following types:

(i) Valvate: In valvate aestivation, the margin of sepals or petals, present in a whorl just touches each other. These are no overlapping between the sepals of petals. e.g., Calotropis.

(ii) Twisted: In twisted aestivation, margin of one petal or sepal overlaps the margin of the adjacent successive petal or sepal and so on e.g., China rose, lady's finger and cotton.

(iii) Imbricate: In imbricate aestivation, margin or petals or sepals overlaps each other but not in a particular direction. e.g., Cassia, gulmohur.

(iv) Vexillary: In vexillary aestivation, the largest petal (standard) overlaps the two smaller lateral petites (wings) which in turn overlap the two smallest anterior petals (keel) e.g., Pea and bean flower.



Androecium

Androecium is the third whorl of the flower which arises inner to the corolla. It is the male reproductive system which is composed of **stamens.** A stamen consists of a filament and anther. Anthers are usually bilobed. Each lobe contains two microsporangia or pollen sacs. The pollen grains are produced in pollen sacs. A sterile stamen is called **staminode.** There may be a variation in the length of filaments within a flower, as in Salvia and mustard.

Adhesion of stamens: The stamen may be attached to other floral organs such as petals, sepals etc. When a stamen is attached to the petal then it is called **epipetalous** e.g., brinjal and when the stamen is attached to the perianth then it is said to be **epiphyllous** e.g., lily.

Cohesion of stamens: The stamens may be free or united. When the stamens are free then they are called **polyandrous** and when stamens are united in a single bundle, then it is called **Monadelphous,** as in China rose, when they are united in two bundles then it is called **Diadelphous** e.g., pea and when into more than two bundles it is called **Polyadelphous** e.g., Citrus.

Gynoecium

It is fourth and the last whorl of the flower. Gynoecium in the female reproductive part of the flower which is composed of one or more carpels. Carpels may be free of fused. When the carpels are free (as in lotus and rose) then they are said to be **apocarpous** and when the carpels are fused (as in mustard and tomato) then they are said to be **syncarpous.** A carpel has three parts namely.

(i) Ovary: Ovary is the basal swollen part of the carpel. It is the lower part of the lower part of the carpel which bears one or more ovules. These ovules after fertilization mature into seeds. The ovules are attached to a flattened, cushion-like structure called **placenta.** The ovary has one or more chambers of loculi. The ovary containing one chamber is **unilocular,** two chambers is **bilocular,** and three chambers are **trilocular** and so on. The ovules are born chambers. The wall of the ovary after fertilization forms the pericarp (fruit wall).

(ii) Style: The tube-like structure which connects the stigma to the ovary is called style. It lies above the ovary is carpal.

(iii) Stigma: Stigma is generally situated at the tip of the style. Stigma acts as the receptive organ for pollen grains during pollination.

After fertilisation ovules develop into seeds and ovary matures into a fruit.

Placentation

Ovary bears ovules on a cushion-like structure called **placenta.** An ovary may have one or more placenta. The arrangement of ovules on placenta within the ovary is known as placentation. It is of following types:

(i) Marginal: The placenta in marginal placentation forms a ridge along the ventral suture of the ovary. The ovules are born in two alternate rows along the ridge e.g., Pea plant.

(ii) Axile: In axile placentation, the placenta is present in the axial position and the ovules are attached to it in a multilocular ovary e.g., China rose, tomato and lemon.

(iii) Parietal: The ovary is one-chambered (unilocular) but become two chambered due to the formation of the false septum. The ovules develop on the inner wall of the ovary or on the peripheral part e.g., Mustard, Argemone.

(iv) Free central: The ovules are born on central axis and septa are absent in the ovary e.g., Primrose, Dianthus.

(v) Basal: The placenta develops at the base of the ovary. It has a single ovule attached to the placentas e.g., Sunflower, Marigold.

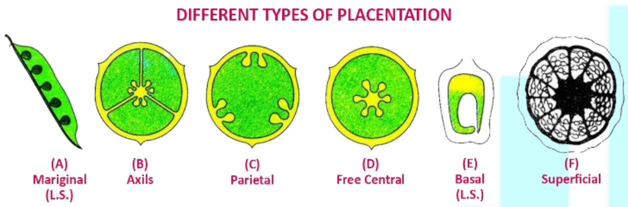


Fig. : Types of placentation : A. Marginal, B. Axile, C. Parietal, D. Free central, E. Basal

THE FRUIT

The flowering plants or the angiosperms are characterised by the presence of a fruit. After fertilisation the ripened or mature ovary is called fruit. Some fruits which are formed without fertilisation are called parthenocarpic fruits, e.g., Banana.

Parts of a Fruit

A fruit mainly consists of two parts namely fruit wall and seed.

(i) Fruit wall: Fruit wall or pericarp develops from the wall of the ovary. It can be dry or fleshy. If the pericarp is thick and fleshy then it differentiates into three different layers namely:

(a) **Epicarp** (outer cover)

(b) **Mesocarp** (middle layer)

(c) **Endocarp** (innermost layer)

(ii) Seeds Develop from Ovules: In some plants ovary grows into fruit without fertilization, such fruits are called **parthenocarpic fruits.** They are seedless, e.g., Banana, Grapes.

The fruit which develops from ovary is called **true fruit.** Most of the fruits are true fruits. If any other floral part takes part in fruit formation, it is called **false fruit (pseudocarp),** e.g., Apple, Pear.

Simple fruit develop from the syncarpous ovary of the single flower with or without accessory parts. Aggregate fruits are formed from polycarpellary, apocarpous ovary. Each carpel develops into a fruitlet and all fruitlets together form an aggregate fruit. The multiple fruit develops from the entire inflorescence.

Classification of different kinds of fruits

- Fruits →
  - Simplefruits →
    - Dry Fruits →
      - **Dehiscent :** Legume or pod (Pea). Siliqua or silicuta (Brassicaceae). Capsule (Datura).
      - **Indehiscent :** Cypsela (Sunflower). Caryopsis (Wheat, Maize, Rice), Achene (Mirabitis). Nur. (Litch)
    - Succulent of Fleshy Fruits →
      - Drupe e.g., Mango. Coconut
      - Berry e.g., Tomato, Guava, Grapes
      - Pepo e.g., Cucumber
      - Pome e.g., Apple, pear
      - Hesperidium e.g., Orange and all otrus fruits
      - Balausta e.g., Pomegranate
  - Aggregate fruits → e.g., Strawberry. Raspherry
  - Composite fruits → e.g., Jackfruit, Mulberry, Pineapple, Ficus (fig)

Types of Fruits

1. Simple Fruits

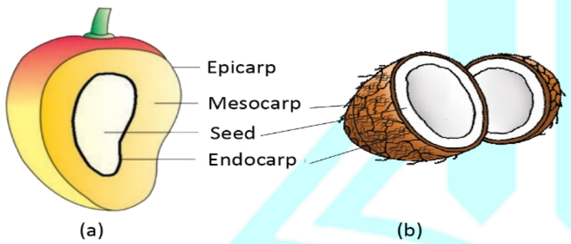
Fruit developing from the syncarpous ovary the single flower with or without accessory parts is called simple fruit. Simple fruits are of following types:

A. Dry indehiscent fruits, they do not split or burst. Seeds are liberated only by the decomposition or destruction of pericarp.

B. Dry dehiscent fruits, these fruits burst automatically and discharge their seeds.

C. Fleshy or Succulent fruits, they are of following types :

(i) Drupe: Mostly one seeded fruits with pericarp differentiated into **epicarp, mesocarp** and hard and **stony endocarp,** e.g., Mangifera indica (**Mango-** epicarp forms skin, mesocarp-fleshy, juicy and edible, endocarp is hard and stony, Cocos nucifera (Coconut-Mesocarp is fibrous which is used in making coir so called as **fibrous drupe),** Juglans regia (walnut).



Parts of a fruit. A. Mango; B. Coconut

(ii) **Berry:** One to many seeded fruits. Epicarp forms the outer skin. Middle thick and fleshy part is called mesocarp with a membrane like endocarp, e.g. Tomato, guava, papaya, grapes, banana, brinjal, chilies. **Betel nut is a one seeded berry.**

(iii) **Pepo (hard walled berry) :** Develops from tricarpellary, syncarpous, unilocular and **inferior ovary.** Epicarp forms skin of fruit. Mesocarp and endocarp are fleshy and edible. Sometimes, fruits are bitter in taste due to **tetracyclic triterpenes** e.g., Cucumber, gourd, watermelon.

(iv) **Pome:** Develops from syncarpous inferior ovary which is surrounded by fleshy thalamus. So, true fruit lies inside the swollen fleshy and edible thalamus. It is false fruit or **pseudocarp**. e.g., Apple, pear. Edible part is fleshy thalamus.

(v) **Hesperidium:** Develops from multicarpellary, multilocular, syncarpous, superior ovary with axile placentation. The epicarp arid mesocarp fused together to form skin or rind of the fruit. Endocarp projects inwards forming a number of distinct chambers. The juicy unicellular hairs are present on the inner side of the endocarp. e.g., Orange and all citrus fruits.

2. Aggregate Fruits

Aggregate fruits are formed from polycarpellary, apocarpous ovary. Each carpel develops into a fruitlet and all fruitlets together form an aggregate fruit. An aggregate of simple fruits born by apocarpous ovary of a single flower is otherwise known as 'etaerio'. Aggregate fruits are of the following types:

(i) **An etaerio of achenes** e.g., Strawberry

(ii) **An etaerio of berries** e.g., Artobotrys

(iii) **An etaerio of follicles** e.g., Delphinium, Michelia.

(iv) **An etaerio of drupes** e.g. Raspberry.

3. Multiple or Composite Fruits

The multiple fruit develops from the entire inflorescence. These fruits are of two types :

(i) Sorosis: These fruits develop from spike, spadix or catkin inflorescence. The flowers fuse together by their sepals or perianth and the whole inflorescence forms a compact mass e.g., Jackfruit, mulberry, pineapple

(ii) Syconus: This fruit develops from hypanthodium inflorescence e.g., Ficus sp. (Fig, gular, banyan, peepal) the fruitlets are achenial in nature.

THE SEED

The ovules develop into seeds after fertilization. A seed is made up of a seed coat and an embryo. The embryo is made up of an embryonal axis and one (as in wheat, maize) or two cotyledons (as in gram and pea).

Structure of Dicotyledonous Seed

I. Seed coat: Outer, protective covering of the seed is called seed coat, which develops from integuments of ovule. The seed coat has two layers, the outer **testa** and the inner **tegmen**. The hilum is a scar on the seed coat through which the developing seeds were attached to the fruit. Above the hilum is a small pore called the **micropyle**.

II. Embryo: Embryo is the most important part of the seed. Embryo consists of an **embryonal axis** and two cotyledons. The cotyledons are often fleshy and full of reserve food materials. At the two ends of the embryonal axis is present the **radicle** and the **plumule**.

III. Endosperm: Endosperm is formed as a result of double fertilization. In some seeds such as castor it is a food storing tissue. But in plants such as bean, gram and pea, the endosperm is not present in mature seed and such seeds are called non-endospermous.

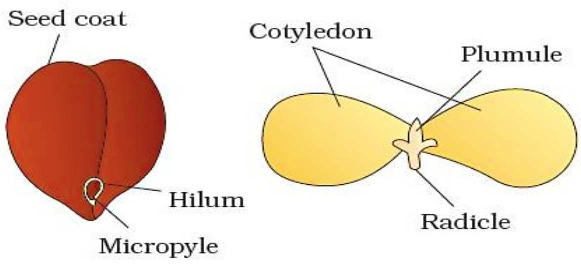


Fig. : Structure of Dicotyledonous Seed

Structure of Monocotyledonous Seed

In the seeds of cereals such as maize the seed coat is membranous and generally fused with the fruit wall. Below the grain covering are present two structures **endosperm** and **embryo**. The endosperm is bulky and stores food. So monocotyledonous seeds are endospermic but some as in orchids are non-endospermic. The outer covering of endosperm separates the embryo by a proteinaceous layer called **aleurone layer**. The embryo is small and situated in a groove at one end of the endosperm. It consists of one large and shield shaped cotyledon known as scutellum and a short axis with a plumule and a **radicle**. The plumule and radicle are enclosed in sheaths which are called **coleoptile** and **coleorrhiza** respectively.

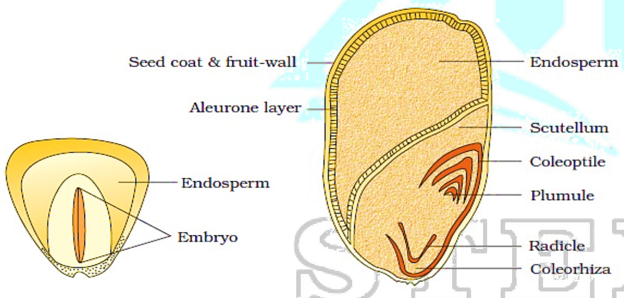


Figure 5.19 Structure of a monocotyledonous seed

Fig. : Structure of a monocotyledonous seed

SEMI-TECHNICAL DESCRIPTION OF A TYPICAL FLOWERING PLANT

Different characteristics of a family are the diagnostic features which enable us to differentiate them. These diagnostic features are mainly based on floral characters like sexuality of flowers, symmetry of flowers, and position of ovary with respect to floral whorls, bracts, and conditions of calyx, corolla, androecium and gynoecium.

For a systematic study and quick comprehension of all the diagnostic features of a family, these characters are symbolised and put in the form of a floral formula. Floral diagrams are also drawn which give some extra information's like placentation, position of the mother axis, aestivation etc. Floral formulae and diagrams are given with the respective family descriptions later in the chapter.

Symbols used in Floral Formula

(1) Br : Bracteate flower

(2) Ebr : Ebracteate flower (bract absent)

(3) ⊕ : Actinomorphic flower

(4) % : Zygomorphic flower

(5) ⚥ : Bisexual flower

(6) ♀ : Unisexual; female flower

(7) K : Calyx
K : Polysepalous
$K_{(n)}$: Gamosepalous
where n = Number of sepals

(8) Epi : Epicalyx (below sepals)

(9) C : Corolla
C_n : Polypetalous
$C_{(n)}$: Gamopetalous
where n = Number of petals

(10) P : Perianth

(11) A : Androecium
A_∞ : Infinite stamens
$\widehat{C\ A}$: Epipetalous stamens
$\widehat{P\ A}$: Epitepalous or epiphyllous stamens

(13) G : Gynoecium
$G_{(n)}$: Syncarpous ovary
G_n : Apocarpous ovary
$\underline{G}_n$: Superior ovary
$\overline{G}_n$: Inferior ovary
where n : Number of carpels

(14) In the floral diagram the dot (*) represents the position of mother axis. It denotes the posterior side of the flower.

Distinguishing features of a family (Brassicaceae):

(1) Inflorescence corymb or corymbose-raceme

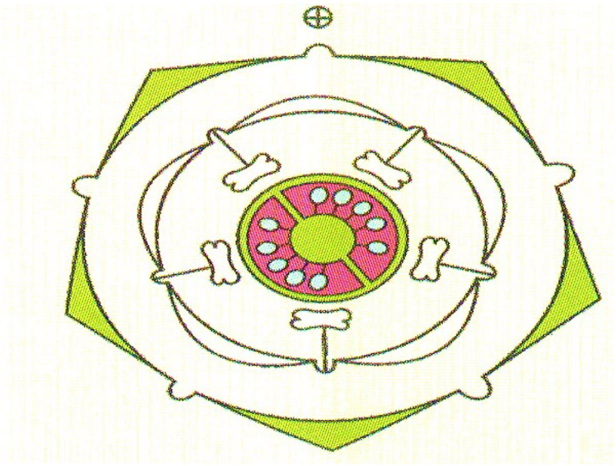
(2) lowers tetramerous

(3) Cruciform corolla

(4) Tetradynamous condition, sometimes didynamous

(5) Bicarpellary, syncarpous, superior ovary, unilocular but becomes bilocular due to false septum or **replum**, parietal placentation, stigma bifid.

(6) Fruit is siliqua or silicula



Floral Diagram

DESCRIPTION OF SOME IMPORTANT FAMILIES

This includes major distinguishing features and important plant? of the family with floral diagram and floral formula.

Fabaceae

It is distributed all over the world. This family was (earlier called Papilionoidea, a sub-family of family Leguminosae.

Vegetative Characters

Habit : Trees, shrubs, herbs, climbers

Root : Tap root system, roots with root nodules, branched. Root nodules contain nitrogen-fixing bacteria (Rhizobium).

Stem : Erect or climber.

Leaves : Alternate, rarely simple, generally pinnately compound, stipulate, leaf base pulvinate, venation reticulate, leaves or leaflets modified into tendrils.

Floral Characters:

Inflorescence : Racemose.

Flower : Bisexual, zygomorphic.

Calyx : Sepals five, gamosepalous, valvate/imbricate aestivation.

Corolla : Petal five, polypetalous, papilionaceous, consisting of a posterior standard, two lateral wings, two anterior ones forming a keel (enclosing stamens and pistil), vexillary aestivation. Ten, diadelphous, anther dithecous.

Androecium : Ten, diadelphousm anther dithecous.

Gynoecium : Ovary superior, monocarpellary, unilocular with many ovules, style single, many ovules in two alternate rows.

Fruit : Legume

Seed : One to many, non-endospermic.

Economic importance :

1. **Pulses** : Gram, arhar, sem, moong, soyabean.
2. **Fodder** : Trifolium, Sesbania, etc.
3. **Edible oil** : Soyabean, groundnut, etc.
4. **Dyes** : Indigofera
5. **Fibres** : Sunhemp
6. **Ornamental** : Lupin, sweet pea
7. **Medicines** : Muliathi

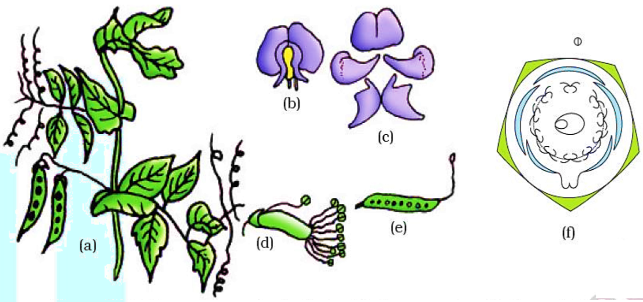


Fig. : Pisum sativum (pea) plant : A. Flowering twig, B. Flower, C. Petals, D. Reproduction parts, E. L.S. carpel, F. Floral diagram

Solanaceae

It is a large family, commonly called as the -potato family'. It is widely distributed in tropics sub-tropics and temperate zone.

Vegetative Characters

Habit : Herbs, shrubs, small trees.

Root : Tap roots.

Stem : Herbaceous rarely woody, aerial, erect, "cylindrical, solid, branched or hollow, hairy or glabrous (smooth), underground stem in potato (Solanum tuberosum).

Leaves : Alternate, simple, rarely pinnately compound, exstipulate. hairy, venation reticulate.

Floral Characters

Inflorescence : Solitary, axillary or cymose as in Solarium.

Flower : Bisexual, actinomorphic.

Calyx : Sepals five, united, persistent, valvate aestivation, gamosepalous.

Corolla : Petals five, gamopetalous, valvate aestivation.

Androecium : Stamens five, epipetalous, anthers dithecous.

Gynoecium : Bicarpellary, syncarpous, ovary superior with oblique septa, bilocular, placenta swollen with many ovules, placentation axile.

Fruit : A many seeded berry or capsule.

Seed : Many, endospermous.

Flora formula :

$$\oplus \; \text{⚥} \; K_{(5)} \, C_{(5)} \, \overparen{A_5 \; \underline{G}_{(2)}}$$

Economic Importance:

1. **Food** : Potato, tomato, brinjal
2. **Spices** : Chilli
3. **Tobacco** : It comes from the dried and cured leaves of Nicotiana tabacum. It is a fumigatory plant.
4. **Medicine** : Belladonna, Ashwagandha
5. **Ornamental** : Petunia

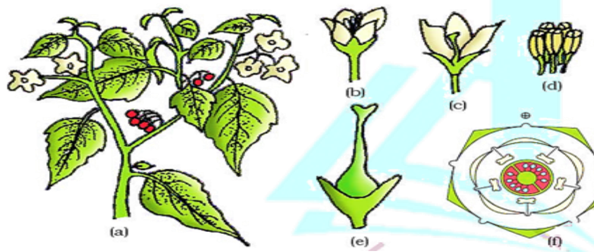


Fig. : Solanum nigrum (makoi) plant : A. Flowering twig, B. Flower, C. L.S. of Flower, D. Stamens, E. Carpel, F. Floral diagram

Liliaceae

It is commonly called the lily family. The plants belonging to this family are monocotyledonous plants. They are widely distributed worldwide.

Vegetative Characters:

Habit : Perennial herbs with underground bulbs, corns, rhizomes.

Roots : Adventitious, fibrous.

Stem : Aerial or underground, herbaceous or woody.

Leaves : Mostly basal, alternate, linear, exstipulate with parallel venation.

Floral Characters :

Inflorescence : Solitary/cymose, often umbellate clusters.

Flower : Bisexual, actinomorphic.

Perianth : Tepal six (3 + 3), often united into tube, valvate aestivation,

Androecium : Stamen six, (3 + 3).

Gynoecium : Multicarpellary, syncarpous, ovary superior, trilocular with many ovules, axile placentation.

Fruit : Capsule, rarely berry.

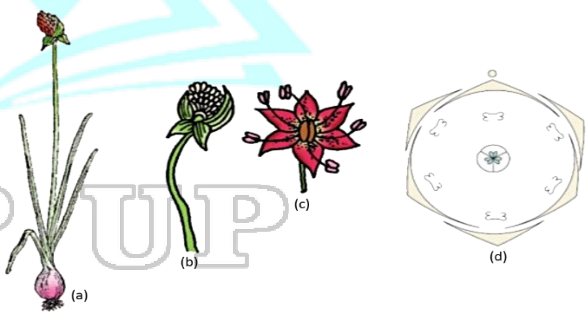
Seeds : Endospermus.

Floral Formula :

$$\oplus \; \text{⚥} \; \overparen{P_{(3+3)} \; A_{3+3}} \; \underline{G}_{(3)}$$

Economic Importance

1. **Food** : Young shoots and root tubers of Asparagus species are cooked.
2. **Medicines** : Aloe is a source of medicine.
3. **Ornaments** : Gloriosa and tulip
4. **Colchicine** : Colchicum autumnale yield colchicine which is used in doubling of chromosomes.



ALLIUM CEPA (ONION) PLANT : (A) PLANT (B) INFLORESCENCE (C) FLOWER (D) FLORAL DIAGRAM

ADDITIONAL INFORMATION

- Thigmonasty movement in response to stimulus of contact (bending of tentacles in Drosera, folding of leaves in Venus fly trap, Dionaea)
- Development of fruit inside the soil is called as geocarpy e.g., ground nut.
- Caruncle is an outgrowth of integument which helps in seed germination and seed dispersion e.g., castor.

Chapter 6

Anatomy of Flowering Plants

THE TISSUES

As the cells group together, they form tissues. Different tissues arise as a result of interactions among the constituent cells. Properties of tissues are not present in the constituent cells. These cells usually perform a common function. however, they may be structurally similar or dissimilar to one another. Hence, a tissue can be defined as a group of **structurally similar** or **dissimilar cells** that perform a **common function** and have a **common origin**. Each tissue has a specific function to perform and different types of tissues of a plant body coordinate with one another to maintain the life of a plant.

A plant is made up of different kinds of tissues. The plant tissues are broadly classified into two main groups namely **meristematic** and **permanent tissues**, based on whether the cells being formed are capable of dividing or not.

The meristematic tissues are further of different kinds but the basic characteristic of all of them is that the cells constituting them persist the power of division. On the other hand, the cells constituting the permanent tissues become structurally, functionally specialised, and temporarily or permanently lose the ability to divide. Hence, the basic criterion for classifying the plant tissues is the persistence or loss of 'ability of division'.

Meristematic Tissues

A meristematic tissue is a group of **immature cells** that are preparing to divide or are in continuous state of division. The basic function of these tissues is to contribute in the growth of the plants. These tissues are found in the **growing regions** of plants. These are responsible for the formation of primary plant body and then its growth year by year.

For understanding the meristematic tissue, we should have the basic knowledge of growth in plants. Plant growth is unique because plants retain the capacity for unlimited growth throughout their life. And this capability of plants is due to the presence of continuously dividing meristematic tissue.

Meristems

Meristems are the specialised areas in the plant body that possess the meristematic tissue (Gk. meristos: divided). These are the areas of **active cell division** as the cells present in them keep on dividing to form other cells. The cells produced by division of meristematic cells soon lose the capacity to divide and such cells make the plant body.

Classification of Meristems

The meristems can be divided on the basis of

1. Origin or order of appearance in the life of a plant.
2. Their position in the body of a plant.

1. On the basis of origin in life of plant: On this basis, the meristems can be distinguished into:

(a) Primary meristems: The meristematic cells that appear early in the life of a plant and contribute to the formation of primary plant body are called primary meristems. **These cells are always in active state of division.** They form primary permanent tissues.

(b) Secondary meristems: The meristems that appear later than primary meristems in life of a plant and are responsible for producing the secondary tissues, particularly the woody areas, are called secondary meristems. They are not present from the very beginning of the formation of an organ but develop at a later stage to give rise to other tissues.

2. On the basis of position in the plant body: The meristems occupy different areas in the body of plants and depending upon this they can be divided into:

(a) Apical meristem: As the name signifies, these tissues are found at the apices or tips of stem, root or branch. These are further of two types, *i.e.,* root apical meristem and shoot apical meristem. Root apical meristem occupies the tip of a root and shoot apical meristem occupies the tip of a shoot.

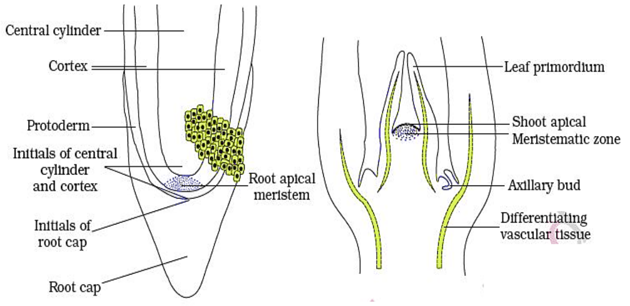


Fig.: Apical meristem: A. Root, B. Shoot

Function of apical meristem: The apical meristems produce the **primary tissues** of plant body and are responsible for the **primary growth** of the plants. They principally contribute to increase in the length, *i.e.,* elongation of the plants along their axis. The growth of roots and stems in length with the help of apical meristems is called primary growth.

Formation of axillary bud: Plant bud is an under developed shoot. We know that the cells of shoot apical meristem continuously divide to increase their number to elongate the stem. While the stem is elongating and leaves are forming on it, some cells 'left behind' from shoot apical meristem in the axil of leaves and constitute the **axillary bud. Axil** is the angle between the upper surface of a leaf stalk and the stem that bears it. These buds are capable of forming a branch or a flower.

(b) Intercalary meristem: As the name depicts, these meristems are **intercalated** in between the mature tissues, *i.e.,* the permanent tissues. Hence, these meristems are separated from the apex of the organ by mature tissue. The activity of intercalary meristem also adds to the length of plant or its organs.

Intercalary meristems are found in grasses where they help to regenerate the parts removed by the grazing herbivores. They help in elongation of organs and also allow fallen stems of cereals to become erect.

> ***Note:*** *Both apical meristems and intercalary meristems are the **primary meristems** because they appear early in the life of a plant and contribute to the formation of primary plant body.*

(c) Lateral meristem: These meristems are present along the lateral sides of roots and shoots of many plants. They are found in the mature regions of roots and shoots. **These do not occur in all plants.** They occur only in those plants that produce the woody axis or show secondary growth. **These are generally not present from the very beginning of life of a plant** and appear later than the primary meristems that are why they are called **secondary meristems.** The lateral meristems are the **cylindrical meristems**, which divide in the radial direction resulting in the increase in **girth** of the stems and roots. Lateral meristems are responsible for producing the secondary tissues like secondary xylem, secondary phloem, secondary medullary rays, cork, secondary cortex, etc.

The various examples of lateral meristems are:

(i) Fascicular vascular cambium: It is meristematic tissue, which develops within the vascular bundles. It is also called intrafascicular vascular cambium.

(ii) Interfascicular cambium: The meristematic tissue, which develops between the vascular bundles, is called interfascicular cambium.

(iii) Cork cambium: This lateral meristem forms the cork, a tough protective material during the secondary growth.

Hence, lateral meristems are secondary meristems on the basis of origin (**except** intrafascicular cambium) and lateral on the basis of location.

Permanent Tissues

Till now, we have studied that the cells of primary and secondary meristems undergo division and differentiation to produce primary and secondary permanent tissues of the plant body respectively. Now, the new cells, which are formed, following the divisions of cells of primary and secondary meristems; become structurally and functionally specialised and lose the ability to divide. These newly formed cells are called **permanent** or **mature** cells and tissues formed by these cells are called **permanent tissues.** These mature or permanent tissues perform specific functions in the body of plants. This phenomenon leading to maturation of plant cells is called **differentiation**. Hence, we can say that the meristematic cells 'differentiate' to form the permanent cells.

Classification of permanent tissues:

Permanent tissues are of two types:

1. Simple permanent tissues: A tissue is said to be simple when it is made up of only **one** type of cells. Here 'one' type of cells means that they are structurally and functionally 'similar' to one another. Hence, simple permanent tissues are composed of cells which are similar in their structures and co-ordinate with one another to perform a common function or set of functions.

Various simple tissues are found in plants, which make up the body of plants. These are:

(i) Parenchyma

(ii) Collenchyma

(iii) Sclerenchyma

(i) Parenchyma: The various features of parenchyma are:

(a) This tissue forms the major component within various organs of plants and is present in all of them, *i.e.,* roots, stems, leaves, flowers, fruits and seeds. It forms the main bulk of the plant body.

(b) The cells of parenchyma are called the parenchymatous cells. The parenchymatous cells do not lose their protoplasm (the living contents of a cell) during their maturation hence, they are **living** cells.

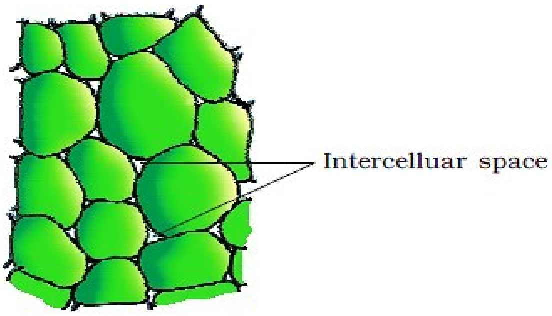


Fig. Parenchyma

(c) The cells of the parenchyma are **generally isodiametric**. 'Iso' means equal and 'diametric' refers to diameter. The parenchymatous cells have nearly equal diameters in different planes. These cells may be spherical, oval, round, polygonal or elongated in shape (polygonal cells have many sides and elongated cells are longer in shape).

(d) The parenchymatous cells are **thin-walled**. Their cell walls are made up of **cellulose** which is a major structural component of cell walls of plants.

(e) Cells in the parenchyma tissue may either be closely packed with no intercellular spaces or have small intercellular spaces.

Functions of Parenchyma: Parenchyma performs various functions like:

(a) Storage of food: One of the main functions of this tissue is **storage of food**. The parenchymatous cells store various food materials like carbohydrates, oils, fats, proteins, etc.

(b) Photosynthesis: Some parenchymatous cells develop **chloroplasts** in them and perform photosynthesis, *i.e.,* synthesis of food from inorganic substances in presence of light energy. Chloroplasts containing parenchyma is called the **chlorenchyma**.

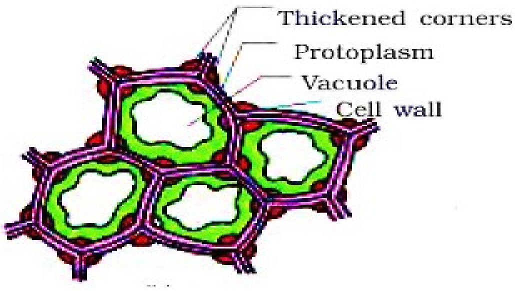
(c) Secretion: Some parenchymatous cells secrete the substances like resin, nectar, oil, etc. These cells lie in the resin ducts and other secretory structures and help in release of their products from plant body.

(ii) Collenchyma: Various features of collenchyma are as follows:

(a) Collenchyma is an **elastic, living, mechanical tissue.**

(b) Cells of this tissue are called collenchymatous cells, which may be oval, spherical or polygonal in shape.

(c) **The intercellular spaces are absent** because these cells are closely packed with each other. At the corners of these cells, thickenings of **cellulose, hemicellulose** and **pectin** develop due to which the cell walls become thick at corners. Cellulose, hemicellulose and pectin are complex carbohydrates which provide the strength to the walls.



(d) The collenchyma occurs in layers **below the epidermis** in dicotyledonous plants. (Epidermis is the outer-most layer of the primary plant body, which is in direct contact with the external environment). Collenchyma usually occurs in the form of 3-4 layers below epidermis in dicotyledonous plants. It is found either as homogeneous, (*i.e.,* continuous) layer or in the form of patches discontinuously. **Collenchyma is absent in monocotyledonous plants.**

(e) Some of the collenchymatous cells contain chloroplasts and those, which contain chloroplasts, perform photosynthesis and assimilate the food.

Function of Collenchyma:

(a) Collenchyma is a living mechanical tissue, which provides the **mechanical support to the growing part of the plant such as young stem and petiole of a leaf**. It also resists the bending of stems and pulling out and tearing of young leaves due to action of wind. Hence, collenchyma provides support as well as strength to the growing parts of plants.

(b) Collenchyma takes part in the synthesis of food, *i.e.,* photosynthesis also, when its cells possess the chloroplasts.

Sclerenchyma: Sclerenchyma is a Greek word meaning **hard tissue**. It has following features.

(a) Cells of sclerenchyma are called sclerenchymatous cells. They are **usually dead** and without protoplasts. During maturation, the cells lose their protoplasm and become dead.

(b) Cells are elongated and narrow and possess highly thickened cell walls. Their walls consist of cellulose, hemicellulose and a specialised organic material **lignin, which** provides mechanical strength to the plant and its parts. Lignin deposition is so thick that the cell walls become strong, rigid and impermeable to water.

(c) Walls of the sclerenchymatous cells possess few to numerous pits.

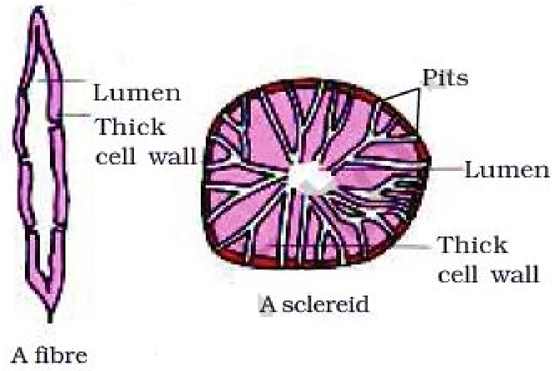


Fig: Sclerenchyma

Types of cells in sclerenchyma: On the basis of variation in origin and development, form and structure, two types of cells are found in sclerenchyma.

(a) Sclerenchymatous fibres: These are the highly elongated cells, which have pointed, or oblique ends. Their elongated and narrow shape makes them look like fibres. These are the thick-walled cells and, in some cases, the cell wall becomes so much lignified that the lumen (inner space or cavity) is greatly reduced.

These fibres generally occur in groups or bundles, in various parts of the plants like stems. They are usually found associated with xylem and phloem of the vascular bundles. These provide the **mechanical strength** to the organs that possess them.

(b) Sclereids: These are spherical oval or cylindrical cells with highly thickened cell wall. The cell walls are so thickened that the lumen of the cells is almost reduced or **obliterated**. These are also the **dead cells**. Sclereids may occur singly or in groups. The sclereids can be found in the roots, stems, leaves, flowers, fruits and seeds. Sclereids are commonly found in the hard parts of the plant, however, they occur in the soft parts, *i.e.,* pulp of the fruits also. Sclereids are present in:

(i) **Fruit walls** of nuts like walnut, almond, etc.

(ii) **Pulp** of fruits like guava, pear and sapota (cheeku) etc. They 'gritty' (crisp) texture of these fruits is due to the presence of hard cells or sclereids in their pulp.

(iii) **Seed coats** of legumes like peas, beans etc. (Seed coats are the outer protective coverings of seeds).

(iv) **Leaves** of tea.

2. Complex permanent tissues: The complex tissues are made up of more than one type of cells. These cells differ from one another in their form and structure. however, these cells work together as a until. Hence, a complex tissue can be defined as a collective of structurally dissimilar cells performing a common function or set of functions.

Types of complex tissue: Two types of complex tissues are found in the plants:

(i) Xylem

(ii) Phloem

(i) Xylem: It is the chief water-conducting tissue of the plants. Xylem functions as a conducting tissue for water and minerals from the roots to the top of plants, *i.e.,* to the stems and leaves.

Along with acting like a conducting tissue, xylem also provides the **mechanical strength** to the plant parts. Mechanical strength is the ability to tolerate stress, pulling forces, compressive forces etc. without breaking off or tearing off.

Types of xylem: On the basis of origin, xylem tissue can be (a) primary xylem, (b) secondary xylem

A. Primary xylem: The xylem, which arises early, *i.e.,* during primary growth of plant body is called primary xylem. It is further of two types on the basis of origin (*i.e.,* relative state of maturity): (i) Protoxylem, (ii) Metaxylem.

The first formed primary xylem is called **protoxylem** and the later formed primary xylem is called **metaxylem**. The metaxylem is more mature than the protoxylem. Protoxylem has vessels with narrow diameter and metaxylem has vessels with broad diameter.

Arrangement of primary xylem: Now on the basis of relative position of protoxylem and metaxylem in an organ, the arrangement of xylem can be: (i) Endarch, (ii) Exarch.

In **endarch** type of arrangement of primary xylem, the protoxylem or the first-formed primary xylem lies towards the centre (pith) and the metaxylem or later-formed primary xylem lies towards the periphery of the organ. Endarch type of primary xylem is seen in the **stems**.

In **exarch** type of arrangement of primary xylem, protoxylem lies towards the periphery and metaxylem lies towards the centre (pith) of the organ. Exarch type of primary xylem is seen in **roots**.

B. Secondary xylem: Secondary xylem is the xylem that is formed during the secondary growth. It is formed by the vascular cambial ring (a lateral meristem).

Elements of xylem: Xylem is a complex tissue which is composed of following four different kinds of elements: **A.** Tracheid's, **B.** Vessels, **C.** Xylem fibres, **D.** Xylem parenchyma.

A. Tracheids:

Structure: Tracheids are the elongated **cells** with tapering ends. These are the tube-like cells (one tube is one cell) whose both ends taper slowly to give an appearance of pointed ends.

(a) The tracheids have thick and lignified walls (having a deposition of lignin in the cell walls).

(b) These are the dead cells and are without protoplasm.

(c) When a tracheid is cut and seen, the inner layers of its cell wall show many types of thickenings. These thickenings are of lignin and very in form.

(d) Even after the presence of thickenings, a cavity (lumen) is always present inside the tracheid, which is meant, for the transport of water and minerals through it.

(e) The tracheids form a long row, placed one above the other and form a continuous 'channel' for the conduction of water and minerals from roots to the stems and leaves.

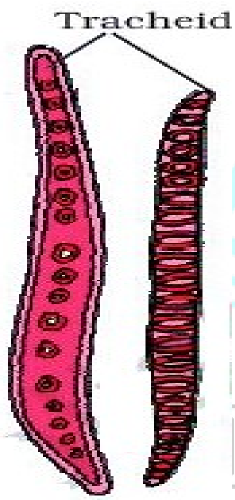


Fig: Tracheid

Occurrence: Tracheids are found in all categories of vascular plants, *i.e.,* Pteridophytes, Gymnosperms and Angiosperms (flowering plants).

Functions:

(i) Main purpose of tracheids is to transport water and minerals from roots to stems and leaves.

(ii) Due to the presence of thickened and hard wall, they also provide the mechanical support to the plant body.

B. Vessels:

Structure: Vessels are also called the tracheae.

(a) Vessel is a long cylindrical tube-like structure made up of many cells (one tube has many cells). These cells, which constitute the vessel, are called vessel members or vessel elements.

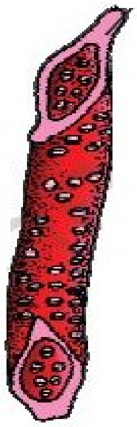


Fig.: Vessels

(b) Vessel differ from tracheids in being cell fusions because tracheid is a single long cell while vessel is a long tube-like structure made up of many cells which are fused together to form it. So, a vessel is composed of row of cells placed one above the other in which the intervening walls get dissolved.

(c) Each vessel member has lignified cell wall and a large central cavity (space) for facilitating the water transport.

(d) Vessel cells are also devoid of protoplasm and are dead.

(e) The end walls of vessel cells are generally oblique and are called the **perforation plates**. The vessel members are interconnected through the perforations (openings) present in these perforation plates.

Occurrence: The presence of vessels is a characteristic feature of angiosperms. Gymnosperms and pteridophytes lack vessels in their xylem, although, other xylary elements are present in them to permit the conduction of water and minerals.

Functions:

(i) Longitudinal water and mineral transport.

(ii) Mechanical support.

C. Xylem fibres: They are the **sclerenchymatous fibres**. They are long, narrow and tapering at both ends. They are also the dead elements like vessels and tracheids.

(a) They have highly thickened lignified walls.

(b) Xylem fibres have **obliterated** central lumens. They are obliterated due to very thick walls which leaves no space inside them.

(c) The fibres may either be **septate** or **aseptate**. The fibres which are septate have internal septa or cross walls and those which are aseptate do not have internal septa.

Occurrence: Xylem fibres are the components of xylem in all categories of vascular plants.

Functions: They are mechanical in function and provide support to the plant organs.

D. Xylem parenchyma: Cells of xylem parenchyma are **living** and **thin-walled**. Their cell walls are made up of cellulose. They have a prominent nucleus and dense cytoplasm.

Occurrence: Xylem parenchyma is present in the xylem of all vascular plants.

Functions:

(i) The xylem parenchyma cells, as usual, store food materials in the form of reserve foods like starch or fat.

(ii) They also store other substances like tannins.

(iii) These cells help in the **radial conduction** of water, *i.e.,* in the radial directions.

Parenchymatous cells, which help in radial conduction of the water, are called **ray parenchyma** cells.

(ii) Phloem: It is a living tissue that carries food materials, (in particular, sucrose, a sugar), from the place it is available (source) to the places where it is needed (sink). It transport the organ materials, usually from leaves to other parts of the plants like roots, growing tips of stems and leaves, flowers, fruits etc. The food prepared in the leaves through the process of photosynthesis needs to be transported to each and every part of plant body, which is facilitated by this conducting tissue called phloem.

Types of phloem: Like xylem, phloem is also classified into primary and secondary phloem on the basis of origin.

A. Primary phloem: The phloem which is formed during primary growth of the plant body called primary phloem. It is further of two types on the basis of relative states of maturity (i) Protophloem (ii) Meta phloem.

B. Secondary phloem: The phloem which is formed during secondary growth of the plant body is called **secondary phloem**. It is formed by the vascular cambial ring (a lateral meristem).

Elements of phloem: Phloem is also a complex tissue like xylem and is composed of the following four elements in angiosperms: **A**. Sieve tube elements, **B**. Companion cells, **C**. Phloem fibres, **D**. Phloem parenchyma.

A. Sieve tube elements:

Structure: Like each vessel, sieve tubes are also made up of many cells called sieve tube elements or sieve tube members.

(a) Sieve tube elements are the long tube-like structures, which are arranged longitudinally. These cells are arranged one above the other is distinct linear rows to form the sieve tubes.

(b) Sieve tube elements are thin-walled living structures having cellulosic cell walls (made of cellulose). However, their walls are thicker than surrounding parenchyma cells.

(c) A mature sieve tube element possesses a peripheral cytoplasm and a large central vacuole but lacks a nucleus. The cytoplasm occurs in the form of a thin-living layer along the inner side of cell walls.

(d) The end walls of sieve tube elements are called **sieve plates, which** are generally oblique. A sieve plate has numerous sieve pores through which the food materials move from one element to another. The end plates are called sieve plates because they are perforated in a sieve-like manner.

(e) Sieve tube elements are associated with the companion cells (another element of phloem). As mature sieve tube elements lack nuclei the functions of sieve tubes are controlled by the nucleus of companion cells which are found closely associated with sieve tube elements. Both sieve tube and companion cells are ontogenetically related hence, they are called **sister cells**.

(f) Protophloem consists of narrow sieve tubes and metaphloem has bigger sieve tubes.

Occurrence: Sieve tubes are **absent in the pteridophytes and gymnosperms**. These plants have **sieve cells** in place of sieve tubes, which are not arranged distinctly in linear rows. Like sieve tubes, the sieve cells also have sieve plates but, not on their end plates rather on their lateral or side walls. Moreover, sieve cells are not much specialised like sieve tubes of angiosperms.

Functions: Sieve tube elements are the **food conducting elements** of plants. The synthesised food translocates through sieve tube elements in the form of a continuous channel.

B. Companion cells:

Structure: Companion cells are the specialised **parenchymatous** cells, which are closely associated with sieve tube elements due to which they are called the companion cells.

(a) These are long, narrow and thin-walled cells usually attached to the lateral sides of sieve tube elements.

(b) The common wall present between sieve tube element and companion cell is usually thin and contains **pit fields**. Pit fields are the wall areas of greatly reduced thickness, which look like holes in the walls. The pit fields are present between the common longitudinal walls of sieve tube elements and companion cells as these two are longitudinally attached with each other. The pit fields enable the easy transfer of materials between them. Hence, pit fields maintain close cytoplasmic connections between sieve tube elements and companion cells.

(c) In contrast to sieve tube elements, the companion cells retain a nucleus throughout their life. They are thus, living cells.

Occurrence: Companion cells are found in angiosperms only. Gymnosperms and pteridophytes lack these cells. Gymnosperms possess **albuminous cells** in place of companion cells. The albuminous cells are associated with sieve cells in them.

Functions: The companion cells help in **maintaining** the **pressure gradient** in the sieve tube. The pressure gradient can be defined as the difference in pressure that decides the direction of flow of a fluid.

C. Phloem fibres: They are also called the **bast fibres**

(a) These are the sclerenchymatous fibres.

(b) These are much elongated fibres which do not have branches (unbranched).

(c) The fibres have pointed needle-like apices.

(d) The cell wall of phloem fibres is quite thick due to which they provide mechanical support to the plant.

(e) At maturity, these fibres lose their protoplasm and become dead.

Occurrence: These fibres are generally absent in the primary phloem but are found in the secondary phloem.

Functions: Phloem fibres provide the mechanical support to the plant.

Commercial use: Phloem fibres of jute, flax and hemp are used commercially for various purposes.

D. Phloem parenchyma: It is composed of the living parenchymatous cells. These are the elongated cells, which have tapering ends. They are cylindrical in shape.

(a) These cells have dense cytoplasm and a prominent nucleus.

(b) The cell walls of these cells are made up of cellulose and have pits. With the help of these pits the adjoining cells get connected in the common walls between them. Plasmodesmata are the microscopic channels, which are formed by these pits connecting the cells. Hence, pits form the plasmodesmatal connections between the phloem parenchyma cells.

Occurrence: It is found in both primary and secondary phloem. **Phloem parenchyma is absent in most of the monocotyledons.**

Functions:

(i) The cells of phloem parenchyma perform the main function of storing the food synthesised by the cells carrying out photosynthesis. The also help in the transport of food.

(ii) These cells also store various organic materials like resins, tannins, mucilage (thick gluey substance), latex (the milky fluid). These can be seen exuding from the plants. The food materials and other organic materials enter in these cells due to the presence of pitted cell walls.

THE TISSUE SYSTEM

Till now we have discussed the various types of tissues in plants based on the types of cells present. Now we will discuss how these different tissues associate with each other to work as a unit. How these tissues form the tissue systems and what are the location and functions of these different tissue systems in the body of flowering plants?

On the basis of structure and location, there are **three** types of tissue systems in plants.

i. Epidermal tissue system

ii. Ground or fundamental tissue system

iii. Vascular fascicular or conducting tissue system

These three tissue systems make the complete framework of the plants. Each tissue system serves different functions. Let us discuss these systems one by one.

Epidermal Tissue System

This tissue system forms the outermost covering of the plant body. It is the direct contact with the external environment. The epidermal tissue system comprises

(a) Epidermal cells

(b) Epidermal structures, *i.e.,* stomata

(c) Epidermal appendages - the trichomes and hairs

(a) Epidermis: Epidermis is the outermost layer of the primary plant body. It is usually single-layered, *i.e.,* composed of single layer of epidermal cells. However, it may be multilayered, *i.e.,* composed of several layers of epidermal cells, *e.g., Nerium Ficus.*

The epidermal cells are the **living** cells having cytoplasm and a nucleus. These are the elongated cells which are compacity arranged leaving less space between themselves. They form a continuous layer of epidermis, which is interrupted by the epidermal structures, *i.e.* stomata in leaves and certain stems.

The epidermal cells are the **parenchymatous** cells which possess a large central vacuole and peripheral cytoplasm lining the cell wall. The wall of these cells very in structure. In a transversely cut stem or root, the outermost cell layer represents the epidermis.

The outside of the epidemis is often covered with a waxy thick layer called the **cuticle** which prevents the loss of water because of deposition of a waxy substance called **cutin** on the outer walls of cells. **Cuticle is absent in roots** and **hydrophytes**.

(i) Specialised upper epidermal cells called **bulliform cells** are present in certain monocot leaves, which will be discussed later in the anatomy of monocot leaves.

(ii) Root epidemis is termed as **epiblema** or **rhizodermis**.

(b) Stomata (Singular-Stoma): Stomata are the minute structures present in the epidermis of leaves. They are **absent in the epidermis of roots**. Each stoma is composed of

(a) Two bean-shaped or kidney-shaped cells known as guard cells, and

(b) A tiny stomatal pore the pore surrounded by two guard cells together form a stoma.

Guard cells: Guard cells are called so because they 'guard' the **opening** and **closing** of the stomatal pore. They are the living cells. They possess chloroplasts and regulate the stomatal movement. These cells are generally bean-shaped or kidney-shaped but in grasses, the guard cells are dumb-bell shaped.

The walls of the guard cells towards the stomatal pore are called inner walls and away from the stomatal pore are called outer walls. The **outer walls** of the guard cells are **thin** while the **inner walls** are **highly thickened**. The thickening is limited to the middle part in the dumb-bell shaped guard cells.

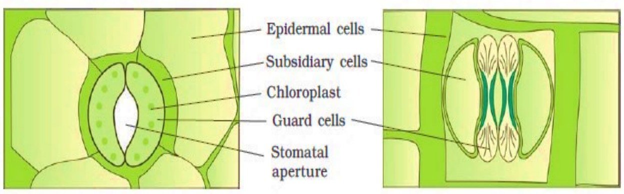


Fig.: Diagrammatic representation:
(a) Stomata with bean-shaped guard cells,
(b) Stomata with dumb-bell shaped guard cells

Function of guard cells: Guard cells control the opening and closing of the stomatal pore. When they are turgid (swollen), the stomatal pore is open and when they are flaccid (shrunken), the stomatal pore is closed.

Subsidiary cells: These are the specialised epidermal cells. In some flowering plants, the epidermal cells surrounding the guard cells become specialised in their shape and size and are called the subsidiary cells they are also called **accessory cells**. They provide support to the guard cells. They do not possess chloroplasts and do not carry out the photosynthesis.

Function of stomata: Stomata regulate the process of **transpiration** and **gaseous exchange**. Transpiration is the loss of water by plants through the process of evaporation. Gaseous exchange involves the exchange of oxygen and carbon dioxide between plant and the environment. The loss of water and entry and exit of gasses occurs through these epidermal structures called stomata.

Usually, the lower surface of a dicotyledonous leaf has a greater number of stomata than the upper surface while is a monocotyledon leaf, they are about equal in number on both the surfaces.

Stomatal apparatus: The stomatal aperture (pore), guard cells and the surrounding subsidiary cells are together called **stomatal apparatus.**

(c) Epidermal appendages: An appendage can be defined as an outgrowth from the external surface of the body. Epidermal appendages are the outgrowths from the epidermis layer. These are commonly present on the roots and shoots.

(i) **Root hairs:** Root hair is the epidermal appendages of roots. They arise from the cells of epidermis. These are the **unicellular elongations** of the epidermal cells or we can say that each root hair is a single cell having its cytoplasm and nucleus. The root hairs help in absorption of water and minerals from the soil. They increase the surface area for absorption in the roots. Root hairs are the thin-walled structures into which the water along with minerals enter by diffusion.

(ii) **Trichomes:** The epidermal hairs on the stem are called trichomes. They are also the epidermal outgrowths like root hairs. They are usually multicellular. They may be unicellular also.

(a) They may be branched or unbranched

(b) They may be soft or stiff

(c) Trichomes mainly help in **preventing the water loss** due to transpiration. The trichomes cover the evaporating surfaces and prevent the evaporation by blocking the flow of air across the plant surface.

(d) They may even be **secretory** in some plants. The sticky secretions of trichomes help in trapping the insects for killing and obtaining the nutrition from them.

Functions of epidermal tissue system

All the functions of the above discussed structures are the functions of epidermal tissue system which can be summarised as:

(i) Protection: It provides protection from extremal injuries, excessive evaporation, scorching solar radiations, etc. with the help of cuticle, trichomes, etc.

(ii) Secretion : Secretion of many sticky substance is facilitated by trichomes.

(iii) Gaseous exchange: By stomatal apparatus, trichomes and cuticle.

(v) Absorption of water and minerals: By root hairs.

The Ground Tissue System

It is also called the **fundamental tissue system.** This tissue system constitutes the main bulk of the body of plants. The tissues that do not come under the epidermal tissue system and vascular tissue system constitute the fundamental or ground tissue system. Various simple like parenchyma, collenchyma and sclerenchyma are present in it.

The ground tissue system is clearly differentiated into various zones. In the transverse section of all dicot stems, monocot roots and dicot roots; the ground tissue exhibits clear zonation into an outer cortex and central pith. In between cortex and pith various other tissues are present which will be discussed later in anatomy of stems and roots. Such differentiation is not present in the monocot stems. In the leaves of monocot and dicot plants, ground tissue is called mesophyll and is not distinguished into cortex and pith.

Zonation in Ground Tissue System : In dicot stems and all roots of angiosperms, following zonation is usually seen from outer side in a transverse and longitudinal view.

(a) Cortex : It lies below the epidermis. It may be few to many layered in thickness. It is further differentiated into three sub-zones, i.e., hypodermis, general cortex and endodermis.

(i) **Hypodermis :** This is the outermost portion of cortex in stems of flowering plants. Hypodermis is absent in roots. It may be single to multilayered. The dicotyledonous stems have collenchymatous hypodermis, i.e., made up of collenchymatous cells and the monocotyledonous stems have sclerenchymatous hypodermis. i.e., made up of sclerenchymatous cells. Hypodermis is protective in function. Its cells may have chloroplasts in them and thus, may perform photosynthesis also.

(ii) General cortex : Next to hypodermis in stems and to epidermis in roots. Lies the general cortex. It is few to many layered in thickness. It is parenchymatous in both stems and roots. the cells are thin-walled and may or may not have the intercellular spaces between them. The intercellular spaces between them. The cells of cortex of young stem and leaves possess chloroplasts and perform photosynthesis. General cortex provides the mechanical support, performs photosynthesis in leaves and leaves and young stems and also stores the food material.

(iii) Endodermis: The innermost layer of cortex is called endodermis. All the tissues on the inner side of the endodermis constitute the stele, which comprises pericycle, vascular bundles and pith. Hence, endodermis is the border between the general cortex and the stele.

(a) Endodermis is a single layer of compactly arranged cells. The cells constituting this layer are elongated with their long axis parallel to the longitudinal axis of plants.

(b) In transverse section (T.S.), the cells of endodermis appear barrel-shaped (drum or large cylinder shaped) or oval shaped.

(c) The cells constituting endodermis are living and may starch grains. This is the reason that endodermis is also called the starch sheath.

Casparian strips: Endodermis is characterised by the presence of a special 'thickened' band in their wall called casparian strip. This thickening was first observed by Caspary. hence the name. This thickening appears on the radial as well as on the tangential walls of endodermal cells. This band-like structure is generally formed by the deposition of a water-impermeable waxy material suberin. Hence, walls of endodermal cells are suberized. Due to presence of casparian strips, the endodermis is impervious to water.

A distinct endodermis is a constant feature of roots of all plants but in stems, it is not very distinct.

(b) Pericycle: It is the outermost portion of stele. It is a cylinder of thin-walled parenchymatous or sometimes thick-walled sclerenchymatous tissue. It may be single layered to multilayered. The cells may be thin-walled to thick walled. Pericycle may be present in the form of patches also. Pericycle is not present in monocotyledonous stems.

Functions of pericycle :

(i) Thick-walled pericycle gives mechanical support to the plant.

(ii) When composed of parenchymatous cells, it may act as storage organ of food material.

(iii) In dicot roots, the pericycle becomes meristematic and forms a part of the cambial ring. This cambial ring gives rise to the secondary tissues.

(iv) Pericycle gives rise to the lateral roots.

(c) Pith : It is also called medulla. It occupies the central part in dicot stems, dicot roots and monocot roots. In monocot stems, pith cannot be distinguished as vascular bundles are present throughout the stem. Pith is generally composed of large parenchymatous cells with intercellular spaces present between them. Sometimes sclerenchymatous cells are also present in pith. e.g., Compositae.

Pith rays or medullary rays : These are the extensions of pith. In most dicotyledons, the peripheral layers of pith extend between the vascular bundles and are in contact with the pericycle. These extensions appear like rays and thus, they are called the pith rays. The pith rays are also called the medullary rays.

Ground tissue in leaves

The ground tissue is not differentiated into cortex and pith in the leaves. Ground tissue consists of thin-walled chloroplast containing cells and is called mesophyll.

The Vascular Tissue System

Have you ever wondered how water reaches from roots to the top of tall trees and how the food synthesised by the leaves reaches the root tips embedded deep inside the soil? The water and mineral nutrients taken up by the roots have to reach each and every cell of the plant body. Similarly, the food synthesised by leaves also has to be moved to each and every cell of the plant body. Plants do not have proper circulatory system or circulatory medium (like animals) to transport these materials.

(a) These functions are carried out by the complex tissues in plants, i.e., xylem and phloem. These tissues constitute the vascular system in plants.

(b) Earlier, we had discussed that the central cylinder of the shoot or root surrounded by cortex is called stele. The varying number of vascular bundles formed inside the stele constitute the vascular tissue system. These vascular bundles may be found either scattered in general ground tissue or properly arranged in the stele. For example, in the monocotyledonous stems, the ground tissue is not distinguished into cortex and pith and vascular bundles are scattered in the ground tissue whereas in the dicotyledonous stems, the vascular bundles are properly arranged in the stele.

(c) Transport of substances over long distance through the vascular system (the xylem and the phloem) is called translocation. Xylem is concerned with the translocation of water and minerals and phloem translocate the synthesised food.

Elements of a vascular bundle in dicots and monocots

(i) Xylem : In dicotyledonous and monocotyledonous stems, the development of xylem takes place from cetre towards periphery i.e., protoxylem is formed towards centre and metaxylem towards the periphery. Such a condition is called endarch condition and xylem is called centrifugal xylem as the xylem grows from centre (pith) to periphery.

While in dicotyledonous and monocotyledonous roots, the development of xylem takes place from periphery towards centre, i.e., protoxylem is formed towards periphery and metaxylem towards the centre. Such a condition is called exarch condition and xylem is called centripetal xylem as the xylem grows from periphery to centre (pith).

(ii) Phloem: In stems, the vascular bundles usually have phloem away from the centre, on the outer sides of xylem. Hence, metaxylem lies close to the phloem in stems. In dicotyledonous plants, phloem is made up of sieve tubes, companion cells, phloem parenchyma and phloem fibres while in monocotyledonous plants, phloem is made up of sieve tubes, companion cells and phloem fibres. Phloem parenchyma is absent in most of the monocotyledons.

(iii) Cambium: It is a thin strip of primary meristem present between the xylem and phloem in dicot stems. Cambium is absent in the monocotyledons. This cambium is also called intrafascicular cambium because it is present 'within' the vascular bundle. The cambium is responsible for the secondary growth in the plants and is a meristematic tissue present between the permanent tissues (xylem and phloem).

Classification of vascular bundles

The vascular are classified into the following types:

(i) On the basis presence or absence of cambium, the vascular bundles are grouped into two categories.

(a) Open vascular bundles

(b) Closed vascular bundles

(a) Open vascular bundles : When cambium is present in between the xylem and phloem elements, the bundle is said to be open. Such vascular bundles because of the presence of cambium, possess the ability to form secondary xylem and phloem tissues. Hence, they are called open vascular bundles as they are 'open' for the secondary growth. e.g., Dicotyledonous stems.

(b) Closed vascular bundles : When there is no cambium present between the xylem and phloem elements, the bundle is said to be closed. Such vascular bundles because of the absence of cambium, do not possess the ability to form sencodary xylem and phloem tissues. Hence they are called closed vascular bundles as they are 'closed' for the secondary growth. e.g., Monocot stem and root, leaves of dicots and monocots. and monocots.

(ii) On the basis of relative positions of xylem and phloem, the vascular bundles are categorised into:

(a) Radial vascular bundles

(b) Conjoint vascular bundles

(a) Radial vascular bundles : When xylem and phloem within a vascular bundle are arranged in an alternate manner (one next to another) on different radii, the arrangement is called radial and the vascular bundles is called radial vascular bundle. vascular bundles are found in the roots of dicots and monocots.

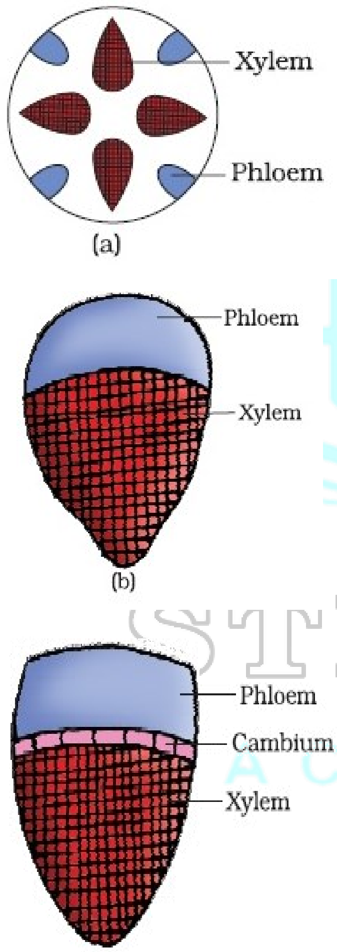


Fig. : Various types of vascular bundles :

(a) Radial, (b) Conjoint closed, (c) Conjoint open

(b) Conjoint vascular bundles: When xylem and phloem are situated on the same radium of vascular bundles, the arrangement is called conjoint and the vascular bundle is called conjoint vascular bundles. Such vascular bundles are common is stems and leaves of dicots and monocots. The conjoint vascular bundles are further, either open or closed, on the basis of presence or absence of cambium, respectively.

The conjoint vascular bundles have the phloem located only on the outer side of xylem, towards the periphery.

Table: Summary of types of vascular bundles in dicots and monocots

	Roots	Stems
Dicots	❖ Radial vascular bundles. ❖ Vascular cambium absent but develops at the time of secondary growth.	❖ Conjoint open vascular bundles. ❖ Vascular cambium present.
Monocots	❖ Radial vascular bundles. ❖ Vascular cambium absent.	❖ Conjoint closed vascular bundles. ❖ Vascular cambium absent.

ANATOMY OF DICOTYLEDONOUS AND MONOCOTYLEDONOUS PLANTS

For a better understanding of tissue organisation of roots and stems of dicots and monocots, it is convenient to study the transverse sections of the mature zones of these organs.

Anatomy of Root

(i) Dicotyledonous root: T.S. a mature dicot root shows the following arrangements.

(a) Epidermis or epiblema: It is the outermost layer of body. It is usually single-layered. The outer walls of many of epidermal cells protrude outwards in the form of tubular elongations. These unicellular tubular extensions are called root hairs which help in the absorption of water and minerals from the soil.

T.S. OF DICOTYLEDONOUS ROOT

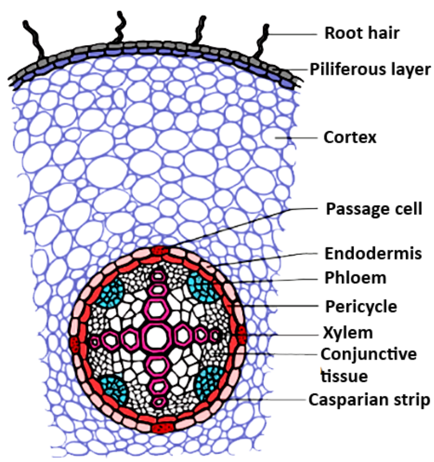


Fig. : Detailed structure of a portion of T.S. of gram (dicot) root

(b) Cortex: Below epidermis and up to endodermis, several layers of parenchymatous cells are present which comprise the cortex. These cells are thin-walled and are loosely packed which allows the free movement of water through them. Such an arrangement offers no resistance to water movement.

Endodermis: It is the innermost layer of the cortex, which acts like a border between cortex and the stele. All tissues on the inner side of the endodermis such as pericycle, vascular bundles and pith constitute the stele. Endodermis comprises a single layer of barrel-shaped cells which possess special thickenings of waxy material suberin in their radial and tangential walls called casparian strips. Water molecules are unable to penetrate this in the areas of casparian strips.

(c) Pericycle: Next to endodermis, lies the pericycle which consists of thick-walled parenchymatous cells. It may be single-layered to several layered.

The cells of pericycle play an important role during the secondary growth of dicot. Cambium is absent in the vascular bundles of dicot roots but develops later at the time of secondary growth in the form of ring-like structure called cambial ring. The parenchymatous cells of pericycle become meristematic, they divide and give rise to part of vascular cambium and lateral roots during the period of secondary growth in the dicot roots.

(d) Vascular bundles: Xylem and phloem are arranged along radii hence; vascular bundles are present. Exarch condition of xylem is present in which metaxylem lies towards the centre and protoxylem towards the periphery. These are two to six xylem and phloem patches but usually their number varies from two to four. The root is called tetrarch when it has four xylem bundles, triarch when it has three xylem bundles, diarch when it has two xylem bundles in it. In the given figure, dicot root is tetrarch as it has four xylem bundles.

(e) Conjunctive tissue: In between the xylem and phloem, patches of parenchymatous cells are present.

(f) Pith: It is found in the centre. It is made up of parenchymatous cells which have intercellular spaces. Pith is not well developed in the roots of dicotyledons. It is small and inconspicuous in them.

(ii) Monocotyledonous roots: The anatomy of the monocot root is similar to the dicot root in many respects. However some differences are also found.

T.S. OF MONOCOTYLEDONOUS ROT

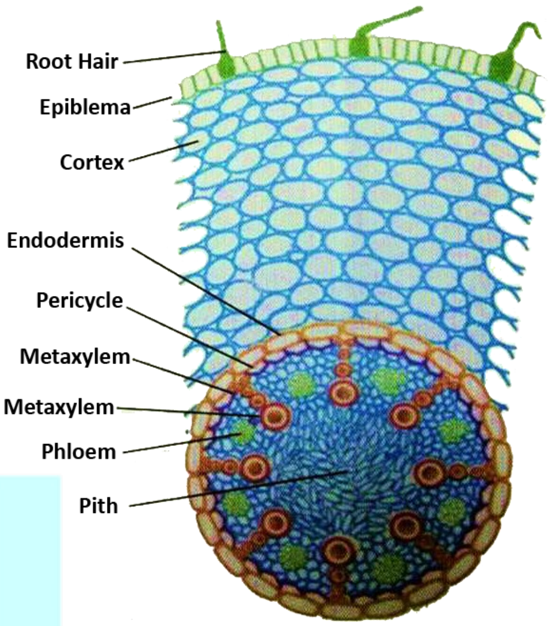


Fig. T.S. Monocot root

Figure shows a portion of the transverse section of a monocot root. The tissue organisation of a monocot root can be explained as:

(a) Epidermis: Outermost layer, bears large number of unicellular root hair. Cuticle and stomata are absent.

(b) Cortex: Hypodermis is absent. Cortex is made up of parenchymatous cells. Cells are loosely arranged.

Endodermis is very distinct. Made up of barrel-shaped cells having casparian strips.

(c) Pericycle: It is also very distinct. The cells of pericycle give rise to lateral roots only as cambium is absent in the monocots.

(d) Vascular bundles: Vascular bundles are of radial type. They are arranged along the different radii of the root. Vascular cambium is lacking in them so the vascular bundles are closed. Due to the absence of cambium, monocotyledonous roots do not undergo secondary growth.

As compared to the dicot roots which have fewer vascular bundles, there are usually more than six (polyarch) xylem bundles in the monocot root. Phloem has sieve tubes, companion cells and phloem fibres. Phloem parenchyma is absent in the monocotyledonous plants.

(e) Conjunctive tissue: In between the patches of xylem and phloem , parenchymatous cells are present which comprise the tissue.

(f) Pith: Pith is large well developed in roots of monocotyledonous plants.

Table : Comparison of dicot and monocot root anatomy

Character	Dicot root	Monocot root
(i) Pericycle	Gives rise to secondary (lateral) roots, vascular cambium and cork cambium.	Gives rise to lateral roots only.
(ii) Vascular bundles	Diarch to hexarch, i.e., vascular bundles are 2 to 6 in number.	Polyarch, i.e., usually more than 6 vascular bundles are present.
(iii) Cambium	Develops at the time of secondary growth.	Cambium is absent. No secondary growth.
(iv) Pith	Small and inconspicuous.	Large and well developed.

Anatomy of Stem

(i) Dicotyledonous stem : The transverse section of a typical young dicotyledonous stem shows the following zones in its primary structure.

(a) Epidermis: This is the outermost layer and is protective in function. It is made up of single layer of cells. The outer walls of epidermal cells are cuticularized as they are covered with a thin cuticle. It may bear epidermal appendages in the form of trichomes and a few stomata. Young stems bear the stomata.

(b) Cortex: Next to the epidermis, is cortex. It is several layered. The cells arranged in multiple layers between the epidermis and pericycle constitute the cortex. It has three sub-zones in a dicotyledonous stem :

1. **Hypodermis**: It is the outer area of cortex which lies just below the epidermis. It consists of 3 to 5 layers of collenchymatous cells in dicot stem. The intercellular spaces are absent in between these cells. Their cell walls are much thickened at the comers due to the deposition of cellulose, hemicellulose and pectin. The collenchymatous cells in hypodermis provide mechanical strength to the young stems.
2. **General cortex or cortical layers:** Below hypodermis and above endodermis, general cortex is present which consists of parenchymatous cells. The cells are thin-walled and rounded in shape. They possess the intercellular spaces in between them.
3. **Endodermis:** The innermost layer of the cortex whose cells store starch grains. Therefore, it is also called the starch sheath,

(c) Pericycle: It is present on the inner side (below) of the endodermis and above the phloem. In between the endodermis and the phloem, pericycle is present in the form of patches. These patches are of semi-lunar (half-moon) shape and comprise of sclerenchymatous cells.

(d) Vascular bundles: A large number of vascular bundles are present in the dicot stem. Each vascular bundle is made of xylem, phloem and a cambium between the two.

(i) Xylem is situated towards the inner side of each vascular bundle and is endarch, i.e., protoxylem lies towards the pith and metaxylem towards the periphery. Hence, vascular bundles are conjoint, open and with endarch protoxylem.

(ii) The cambium consists of meristematic cells. The division of meristematic cells adds to the phloem towards periphery and xylem towards the centre during the secondary growth.

(iii) A characteristic 'ring' arrangement of vascular bundles is seen in the dicot stems. The bundles are arranged in a ring-like manner around the central pith.

(e) Pith or Medulla: The central portion of the stem is occupied by a large number of parenchymatous cells which comprise the pith. These cells are rounded in shape and have large intercellular spaces.

Medullary rays or pith rays: The cells of pith present in between the vascular bundles constitute the pith rays, also called medullary rays. These parenchymatous cells are radially arranged in between the bundles and give the appearance of rays. The pith rays help in the radial conduction of food.

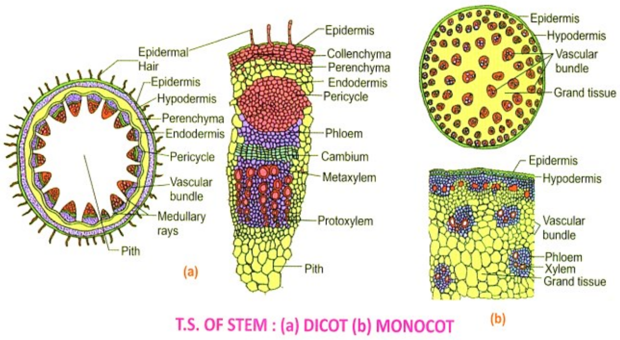


Fig: T.S. of Stem : (a) Dicot, (b) Monocot

(ii) Monocotyledonous stem : In the transverse section of a monocotyledonous stem, following layers are present from outer to inner side :

(a) Epidermis: It is the outermost layer which is made up of single layer of cells. The outer walls of epidermal cells are covered with cuticle. Stomata may be present.

(b) Hypodermis: It lies below the epidermis. It is constituted by the sclerenchymatous cells in monocot stems (collenchymatous in dicots). Due to presence of sclerenchyma tissue, hypodermis provides the mechanical support to the stems.

(c) Ground tissue: Main area of a monocot stem is occupied by the ground tissue. Unlike dicot stems, the ground tissue in monocot stems is not well differentiated into cortical layers, endodermis, pericycle, pith and pith rays. All cells lying inner to the hypodermis comprise the ground tissue. It is made up of parenchymatous cells.

(d) Vascular bundles: A large number of vascular bundles are present. They are not arranged in ring-like manner as present in the dicot stems. Rather the vascular bundles are found scattered in the whole ground tissue. These are smaller in size and densely arranged towards the periphery but larger vascular bundles are loosely arranged towards the centre of the stem.

(i) The bundles are almost oval in outline. They have xylem and phloem elements but cambium is absent. Each vascular bundle is surrounded by a sheath made up of sclerenchymatous tissue. It is called as bundle sheath.

(ii) The vascular bundle are conjoint and closed. Hence, monocot stems cannot undergo the secondary growth.

(iii) Endarch xylem is present as protoxylem lies towards the centre and metaxylem lies towards the periphery. Water-containing cavities (Schizolysigenous in origin). In the vascular bundle is a characteristic feature of monocot stems.

(iv) Phloem consists of sieve tubes, companion cells and phloem fibres. Phloem parenchyma is absent.

Table : Comparison of dicot and monocot stem anatomy

Character	Dicot stem	Monocot stem
(i) Ground tissue	Differentiated into cortex and pith.	Not differentiated into cortex and pith.
(ii) Hypodermis	Collenchymatous	Sclerenchymatous
(iii) Endodermis	Single layered	Absent
(iv) Pericycle	Made up of parenchymatous and/or sclerenchymatous cells.	Absent
(v) Vascular bundles	Almost all are of uniform size. Arranged in a ring Conjoint and open. Bundles sheath absent. Phloem parenchyma present.	Larger towards centre and smaller towards periphery. Scattered Conjoint and closed. Bundle sheath present. Phloem parenchyma absent.
(vi) Pith (Medulla)	Water-containing cavities are absent.	Water-containing cavities are present.
(vii) Medullary rays	Made up of parenchymatous cells, situated in the centre.	Absent
(viii) Stele	Found in between the vascular bundles. Eustele (Conjoint, collateral, open)	Atactostele (Conjoint, collateral, closed)

Table: Comparison of internal structure of angiospermic stem and root

Character	Dicot stem	Monocot stem
(i) Epidermis	Without cuticle	Usually with cuticle
(ii) Hypodermis	Absent	Present – collenchymatous of sclerenchymatous
(iii) Endodermis	Distinct	Poorly developed
(iv) Vascular bundles	Radial	Conjoint
(v) Xylem	Exarch	Endarch

Anatomy of Leaf

The leaf is usually a flat structure. It is the main photosynthetic organ in the plants. Leaf has epidermis on both of its surfaces. The photosynthetic tissue of a leaf is sandwiched between its upper and lower epidermis and is well supplied by the vascular system. The photosynthetic tissue in leaf possesses chloroplasts.

It is noteworthy that in a leaf, xylem always faces upper epidermis while phloem is towards lower epidermis also.

The internal structure of a leaf is studied in its vertical section. On the basis of anatomy, leaves are of two types :

(i) **Dorsiventral:** Dorsiventral leaves are found in the dicotyledonous plants. Such leaves generally remain horizontal and sunlight falls on their upper surface.

Upper surface of a leaf is called ventral surface or adaxial surface and lower surface is called dorsal or abaxial surface. These are called the dorsiventral leavers their dorsal and ventral surfaces differ in colour and anatomical feature and are therefore, distinguishable into two different surfaces. Upper surface is darker green as compared to the lower surface.

(ii) **Isobilateral:** Isobilateral leaves are found in the monocotyledonous plants. Such leaves generally remain vertical. These are called the isobilateral leaves as their both surfaces (upper and lower) are equally green and similar to one another.

Dicotyledonous Leaf (Dorsiventral Leaf): The vertical section of a dorsiventral leaf through the lamina shows three parts, namely:

(a) Epidermis

(b) Mesophyll

(c) Vascular system

(a) Epidermis: It covers both upper and the lower surface. The epidermis covering the upper or adaxial surface is called adaxial epidermis while the one covering the lower or abaxial surface is called abaxial epidermis.

1. Adaxial or upper epidermis: This is the outermost layer of leaf. It is single layered, made up of parenchymatous cells. The outer walls of the epidermal cells are cuticularized. There are no chloroplasts in them. Stomata are lesser in number on the adaxial epidermis as compared to the abaxial epidermis. Stomata may be even absent on upper epidermis in dicot leaves.

T.S. OF DORSOVENTRAL LEAF

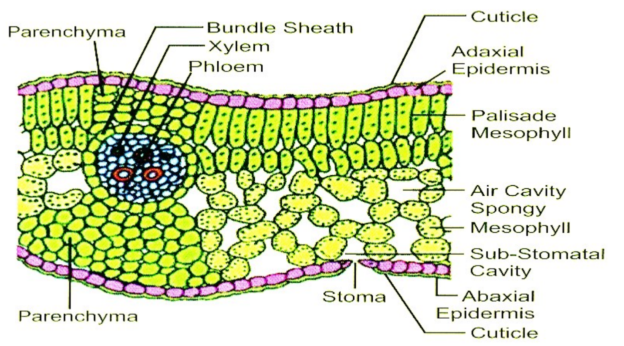


Fig: T.S. of a dicot leaf

2. Abaxial or lower epidermis: Lower epidermis is like upper epidermis in structure as it is also, single layered, made up of parenchymatous cells and covered with cuticle. It differs from upper epidermis in bearing more stomata. Just below the stomata, a cavity is present which is called sub-stomatal cavity. It helps in the exchange of gases. Chloroplasts are absent in the epidermal cells but are found in the guard cells surrounding the stoma.

(b) Mesophyll: The tissue present in between the upper and lower epidermis is called the mesophyll. It is the ground tissue of leaf which consists of thin-walled chloroplasts containing parenchymatous cells. Mesophyll is the photosynthetic tissue of leaf. It is divided into two regions :

1. Palisade parenchyma: It lies below the upper epidermis; hence it is adaxially placed. The palisade parenchyma extends up to one or two layers. It is made up of elongated cells which are arranged vertically forming an angle of 90° with the upper epidermis. These vertically arranged cells lie parallel to one another. These cells have numerous chloroplasts and take active part in photosynthesis. The cells do not have intercellular spaces in between them and are closely packed.

2. Spongy parenchyma: Spongy parenchyma lies below the palisade parenchyma and extends up to the lower epidermis, hence it is abaxially placed. It is made up of oval or rounded cells, which are irregularly arranged without any particular arrangement. The cells possess large intercellular spaces in between them. Due to presence of large number of intercellular spaces and air cavities between these cells, this tissue is called spongy parenchyma (spongy-loosely arranged cells). These cells also have chloroplasts and participate in the photosynthesis.

(c) Vascular system: Vascular system includes the vascular bundles. Bundles are scattered in the spongy parenchyma. These can be seen in the veins and the midrib of the leaves. (Middle prominent vein of the leaf is called the midrib). The dicotyledonous leaves possess reticulate venation in which the veins form a network. The veins vary in thickness in the reticulate venation.

The size of the vascular bundles are dependent on the size of the veins. Hence, vascular bundles are larger in the thicker veins and smaller in the thinner veins. The vascular bundles do not possess cambium. Hence, they are conjoint and closed. Around each vascular bundle, a layer of thick-walled bundle sheath cells is present.

Monocotyledonous leaf (Isobilateral Leaf): The anatomy of an isobilateral leaf is similar to that of the dorsiventral leaf in many ways. It shows the following characteristic features:

(a) Epidermis: There is an upper (adaxial) and lower (abaxial) layer of epidermis. Both the layers are composed of a single layer of cells and possess stomata. The stomata are present on both the surfaces in near equal numbers. That is why, the leaf is called isobilateral. Both layers of epidermis are cuticularized.

T.S. OF ISOBILATERAL LEAF

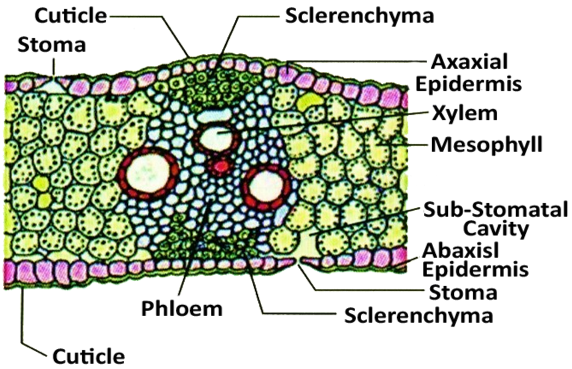


Fig. : T.S. of a monocot leaf

(i) In grasses, some cells in the upper epidermis become large. These adaxial epidermal cells along the vein modify themselves into large, empty and colourless cells. These are called the bulliform cells. Such cells occur in groups. They help in the rolling of leaves during drought or lack of water. This can be explained as:

When the water supply is sufficient to the plant, the bulliform cells in the leaves absorb water and due to absorption of water, they become turgid. When they are turgid, the leaf surface straightens and is exposed. The leaf straightening permits the loss of water. Whereas on the other hand, at the time of insufficient water supply, these cells lose the water become flaccid due to the water loss. When they are flaccid during the water stress, they make the leaves **curl inwards** so that leaf surface is not exposed. The curling of leaves minimises the water loss. Hence, the bulliform cells minimise the loss of water during the conditions of water stress.

(ii) **Sub-stomatal cavity** is present below the stoma of the abaxial epidermis.

(b) **Mesophyll:** The mesophyll lies between the upper and the lower epidermis. It is not differentiated into the palisade and spongy parenchyma. The cells are almost spherical in shape and are irregularly arranged. These cells contain the chloroplasts and carry out the photosynthesis.

(c) **Vascular bundles:** There are a number of large and small vascular bundles. Each bundle is surrounded by a layer of thin-walled cells which form a bundle sheath around them. The vascular bundles are conjoint and closed. Xylem lies towards the upper epidermis and phloem towards the lower epidermis. These complex tissues are clearly distinct in the larger bundles.

Unlike the dicot leaf, in which larger vascular bundles are present in the larger veins and smaller in the narrower veins, near similar sizes of vascular bundles are seen in the monocot leaf, which is due to the parallel venation in the monocot leaves. In parallel venation, veins are present parallel to one another and are of nearly equal size.

Table: Comparison of Anatomy of Dicot and Monocot leaf

Character	Dicot stem	Monocot stem
(i) Type of lead	Dorsiventral	Isobilateral
(ii) Stomata	Usually more in number on lower epidermis.	Equal in number on lower and upper epidermis.
(iii) Mesophyll	Differentiated into two types of tissues-palisade and spongy parenchyma.	Not differentiated into palisade and spongy parenchyma.
(iv) Bulliform cells	Absent	Present, particularly in grasses.
(v) Vascular bundles	Differ in size due to presence of reticulate venation.	Nearly similar in size due to presence of parallel venation.

SECONDARY GROWTH

In the beginning of this chapter, we studied that both apical and intercalary meristems contribute to the formation of primary plant body and lateral meristems contribute to the formation of secondary tissues. Before discussing the secondary growth in detail, let us define the primary and secondary growth first. The growth of roots and stems in length with the help of apical meristems is called the **primary growth** whereas the growth of roots and stems in girth with the help of lateral meristems is called the **secondary growth**.

(i) All plants undergo primary growth but apart from primary growth, most of the dicotyledonous plants exhibit secondary growth also. Generally secondary growth does not occur in monocots due to the lack of vascular cambium in them.

(ii) **Intrafascicular cambium, interfascicular cambium and cork cambium** are the lateral meristems that participate in the secondary growth of dicots.

(iii) After the formation of primary tissues, these lateral meristems become active and start dividing to form the secondary tissues. The secondary tissues include secondary xylem, secondary phloem, secondary medullary rays, cork and secondary cortex. These all tissues constitute the secondary body of most dicotyledons. Secondary growth occurs in the stems and roots of gymnosperms also.

Secondary Growth in Dicot Stems

In a normal dicot stem, the secondary growth takes place as follows :

(a) Formation of cambial ring: In dicot stems, vascular bundles are arranged in a 'ring' like manner around the central pith and are conjoint and open. The bundles are called open as they possess the cambium, also called fascicular cambium or intrafascicular cambium as it is found within the vascular bundles. In young stems, it is present in patches as a single layer between the xylem and phloem but later these different patches join up and form a continuous ring.

Medullary rays lie in between the vascular bundles. When their cells become dedifferentiated (meristematic), they give rise to the new cambium which is called the interfascicular cambium because this new cambium lies between any two intrafascicular cambia. Intrafascicular and interfascicular cambia together form the vascular cambial ring.

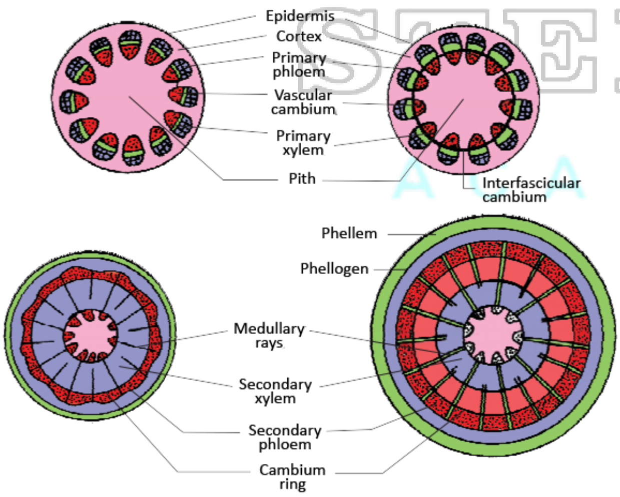


Fig. : Stages of secondary growth in a woody (dicot) stem; stages in transverse views

(b) Activity of the cambial ring: The cambial ring formed by the intra and interfascicular cambia becomes active and begins to divide to form new cells, both towards the inner and the outer sides by periclinal divisions.

As in a vascular bundle, xylem lies towards the pith and phloem lies towards the periphery, the cell cut off (separated) by cambial ring towards pith mature into the secondary xylem and the cells cut off towards periphery mature into secondary phloem. In this way, secondary xylem keeps on forming inner to cambial ring but outer to primary xylem and secondary phloem keeps on forming outer to cambial ring but inner to the primary phloem.

The cambium is generally more active on the inner side than on the outer and as a result, the amount of secondary xylem produced is more than secondary phloem (as secondary xylem is being produced on the inner side of cambium). Due to this, the cambium ring expands towards the periphery. The primary and secondary phloem get gradually crushed due to the continued formation and accumulation of secondary xylem. The primary xylem however, remains more or less intact, in or around the centre. Hence due to all these events, secondary xylem keep on increasing in amount and primary and secondary phloem's keep on gradually crushed (**obliterated**).

Due to newly formed secondary xylem and secondary phloem, the primary xylem and primary phloem which were near to one another earlier get separated far apart.

Secondary medullary rays: At some places, the cambium forms a narrow band of parenchyma which passes through the secondary xylem and the secondary phloem in the radial directions. These narrow bands are present in the form of continuous strips from secondary xylem to secondary phloem and are called the secondary medullary rays. These rays are arranged radially. Primary and secondary medullary rays conduct food, water and minerals from centre to the periphery of the organ. Secondary medullary rays are also called the **vascular rays.**

Growth Rings or Annual Rings (Spring wood and Autumn wood): The activity of cambium ring is not uniform throughout the entire year but markedly affected-by the variations in external environment i.e., climate as well as internal environment of the plant

(i) In temperate regions, like Asia, Central North America, etc. the climatic conditions are not uniform through the year and different seasons show different climates. The secondary xylem or the wood produced is different in different seasons due to differential activity of **cambium**.

(ii) In the spring season, cambium is very active and produces a large number of xylary elements i.e., vessels, tracheids, xylem fibres and xylem parenchyma. The vessels are produced with the wider lumens as more water is needed to meet the requirement by increased transpiring surface in spring season. The wood formed during this season is called the spring wood or early wood. In the winter, cambium is less active and as a result, fewer xylary elements are formed and the vessels have narrow lumens as less water is needed in this season. The wood formed during this season is called **autumn wood or late wood.**

(iii) The spring wood is lighter in colour and has a lower density whereas the autumn wood is darker in colour and has a higher density.

(iv) Transition from spring wood to autumn wood is gradual (slow) while transition from autumn wood to spring wood is sudden (fast). The two kinds of woods (spring and autumn wood) that appear as alternate concentric rings of light and dark colour constitute an annual ring. Hence, one annual ring includes one circle of spring wood and one circle of autumn wood. It is called annual ring because it represents one year of time span. It is also called growth ring because as the growth keeps on taking place these annual rings keep on increasing in number.

(v) Annual rings seen in a cut stem give an estimate of the age of the tree. The number of annual rings in the oldest part of the tree corresponds to its age. One ring shows the growth of one year so the age of a tree can be known by counting the number of these rings in the T.S of stem This study is known as Dendrochronology.

(vi) Annual rings are distinct in plants growing in temperate regions; however they do not develop in plants growing in areas where temperature and rains are uniform throughout the year, e.g., tropical areas. The cambium activity does not differ hence, different kinds of secondary xylem would not be formed in them.

Heartwood and Sapwood: As the tree continues to grow for several years and is undergoing secondary growth, the greater portion of its secondary xylem or wood turns dark brown in colour. These changes are more pronounced in the older parts of the stem. These areas are present in the central or innermost layers of the stem. These areas turn dark in colour due to progressive filling and deposition of organic compounds like tannins, resins, oils, gums, aromatic substances and essential oils in the vessels and tracheids of older secondary xylem. These 'depositions' results in the blockage of the xylary elements, i.e., vessels and tracheids and as a result they become non-functional. This region cannot conduct water hence, its primary role as a conductive tissue is lost. However, due to deposition of above-mentioned organic compounds, this region becomes **hard, durable and resistant to the attacks of microorganisms and insects. Such a modified and non-functional inner secondary xylem is called heartwood (duramen).** The heartwood comprises dead elements with highly lignified cell walls. It does not conduct the water but gives the mechanical support to the stem.

The conduction of water along with the minerals dissolved in it, from roots to leaf is performed by peripherally located younger areas of secondary xylem. **The peripheral region of the secondary xylem is lighter in colour and is known as sapwood (alburnum).** Sapwood is actively involved in the conduction of water and minerals from root to leaf in old trees. With the passage of time and addition of new outer rings of secondary xylem, more rings of the sapwood are changed into heartwood. Thus, the sapwood remains almost the same in thickness.

(c) Activity of cork cambium :

(i) As a result of the continued activity of vascular cambium, the girth of the stem goes on increasing. The continuous increase in the girth results in the rupture of outermost layer, i.e., epidermis and outer cortical layers (layers of cortex). Due to their rupturing, they need to be replaced to provide protection to the stem. New protective cell layers are provided by another lateral meristem, i.e., cork cambium. It is also called phellogen. It develops during the ongoing process of secondary growth. This meristematic tissue develops usually in the cortex region.

(ii) Due to its origin outside the stele, cork cambium is also called the **extra-stelar cambium** (stele comprises all tissues on the inner side of endodermis, i.e., pericycle, vascular bundles and pith).

(iii) Phellogen is a couple of layers thick and has two layers of the meristematic cells. These cells are thin-walled and nearly rectangular in shape. The **outer cells** of the phellogen differentiate into cork or phellem while the inner cells differentiate into the **secondary cortex** or phelloderm.

Cork or phellem: Cork is formed by the differentiation of the outer cells of the cork cambium. The cork cells are compactly arranged and have thin cellulosic walls in the beginning. As they mature, there is a gradual loss of living matter and their cell walls become thick due to deposition of a fatty substance called suberin. The suberin deposition in the cell wall makes the cork impervious to water.

Phelloderm: It is called secondary cortex because it is the cortex that develops during the secondary growth. It has thin-walled parenchymatous cells.

These are the living cells that possess cellulosic cell walls.

Periderm: Phellogen, phellem and phelloderm are collectively known as periderm. These all are the protective cell layers that grow after the rupture of epidermis and outer cortical layers of primary plant body. Hence secondary growth in the cortex with the help of cork cambium is the result of secondary growth by vascular cambium because latter caused rupture and therefore the need of replacement.

Due to the continuous activity of cork cambium, pressure builds up on the remaining layers peripheral to phellogen. Ultimately the layers peripheral to phellogen die and slough off.

Bark: All tissues outside the vascular cambium constitute the bark. Various kinds of cell constitute the bark are - Periderm (phellogen, phellem and phelloderm), primary cortex, pericycle, primary and secondary phloem. These all tissues are present the vascular cambium. Bark that is formed early in the season is called early or soft bark and that is formed towards the end of the season is called late or hard bark.

Fig: Bark

Lenticel: It is a small portion of periderm which is produced due to the activity of phellogen. The phellogen (cork cambium) is a meristematic tissue that develops during the secondary growth and normally produces suberized cork cells on outer side.

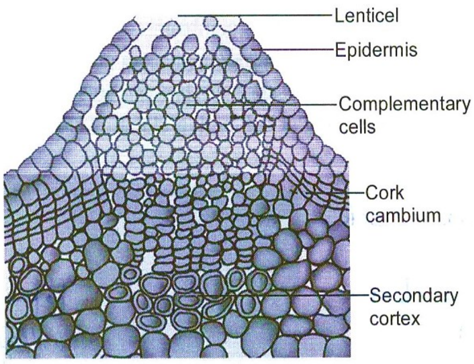


Fig: Lenticel

But, when the activity of phellogen increases at a certain point than elsewhere, then it starts producing loosely-arranged, thin-walled parenchymatous cells with numerous intercellular spaces, instead of thick-walled suberized cork cells. These thin-walled cells, which are now produced instead of thick-walled cork cells, are called complementary cells. As the number of complementary cells increases, it creates pressure on the epidermis which soon results in the rupture of epidermal cells. The small openings which are formed due to rupture in the epidermis are called lenticels.

Lenticels are the lens-shaped openings present on the bark that serve for exchange of gases between the internal tissue of the stem and the outer atmosphere. They occur in most woody trees and permit the exchange of gases in the woody areas of plants. They may also serve for the loss of water in the form of vapours. Lenticels are also called as **breathing pores**.

Secondary Growth in Dicot Roots

Like dicot stems, secondary growth occurs in dicot roots also. The root increases in girth by the activity of two lateral meristems, i.e., vascular and cork cambium. However, the vascular cambium is not present from the very beginning in the dicot roots. Vascular and cork cambium both arise during the secondary growth in a dicot root. The process of secondary growth in dicot roots can be summarised as -

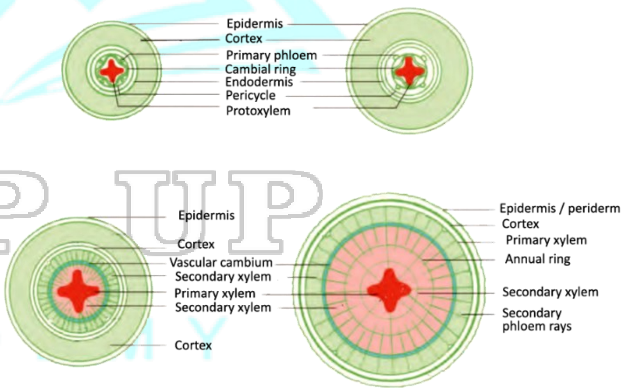


Fig. : Different stages in secondary growth of dicot root

(a) **Origin and Activity of Vascular Cambium:** In dicot roots, the arrangement of vascular bundles is radial and xylem is exarch. Vascular cambium is absent in the beginning but develops later at the time of secondary growth. Hence, the cambium is completely secondary in origin. Various tissues participate in the formation of vascular cambium.

In radial arrangement, xylem and phloem tissues lie along the different radii alternatively. Let us take an example of tetrarch root. In a tetrarch root, four different patches of primary xylem and four patches of primary phloem are present.

First of all, the parenchyma cells present just below the primary phloem (/.e., towards pith) become meristematic and give rise to four separate strips of cambia (as four patches of phloem's are present in a tetrarch root), (figure A). Till now, the cambia strips are separate and have not formed a continuous ring. Later on, as a result of the divisions of cells of pericycle, the complete cambial ring is formed. Only those cells of pericycle divide and form the cambium ring which lie above the protoxylem. This results in the formation of a complete and continuous wavy ring of cambium (figure B).

(i) This wavy ring is present below the phloem but above the xylem. The strips of cambia cut off the cells on their both sides. The cells cut off towards inner side mature into secondary xylem and the cells cut off towards outer side, mature into secondary phloem (see figure B and C). This wavy ring slowly becomes circular and cuts off secondary xylem at all places internally and secondary phloem at all places externally (see figures C and D).

(ii) Vascular cambium is completely secondary in origin in dicot roots and originates from the tissue, located just below the phloem bundles and a portion of pericycle tissue, located above the protoxylem; forming a complete and continuous wavy ring which later becomes circular.

(iii) Thus, after stelar secondary growth, *i.e.*, growth by vascular cambium, a central cylinder of wood (secondary xylem) surrounded by secondary phloem is formed.

(b) Origin and activity of cork cambium (phellogen): Cork cambium is also a meristematic tissue which arises as a result of the divisions of the cells of pericycle. Cork cambium gives rise to periderm, i.e, protective cell layers to replace the ruptured epidermis and outer cortical layers.

The activity of cork cambium in dicot roots is similar to that found in the dicot stem. It produces cork cells on the outer side and secondary cortex on the inner side. The cork cells have suberin in their walls and due to further deposition of suberin, these cells become dead.

Due to activity of the cork cambium, pressure builds up on the remaining layers peripheral to phellogen (cork cambium), i.e., primary cortex and epidermis. Ultimately, these layers die and slough off.

ADDITIONAL INFORMATION

- Tyloses are tracheal plugs found in heart wood thus making it non-functional. These are balloon-like swellings of xylem parenchyma cells in the lumen of vessels.
- Bottle cork is obtained from the bark of Quercus suber.
- Passage cells are cells of endodermis which are without casparian strips, thus help in water movement.

Chapter 7
Structural Organization in Animals

Introduction:

Life evolved on this earth in" the form of single-celled (unicellular) organisms. They were able to perform all the functions necessary for life such as digestion, respiration and reproduction. Even today, millions of such unicellular organisms are present, e.g., Amoeba, Paramecium, Euglena, etc. They can perform all the activities of life, but without much efficiency.

ANIMAL TISSUES

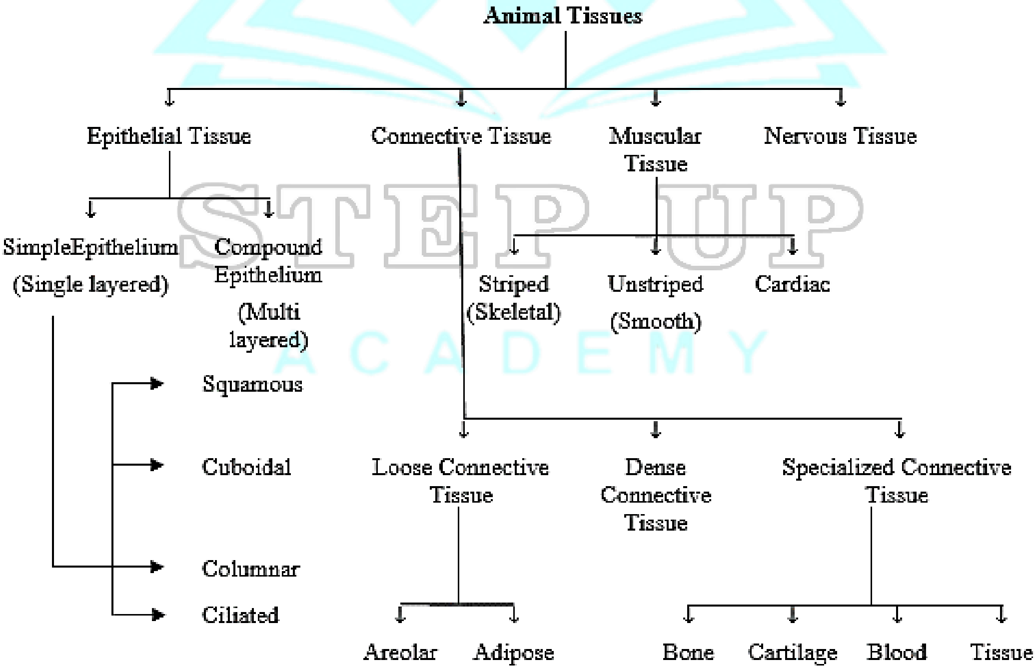
Tissue is a group of similar cells, having same origin and performing a specific function. The term tissue was given by Bichat. The term tissue had already been coined by N.Grew in connection with plant anatomy. The study of tissue is known as histology, a term introduced by Mayer. The tissue first evolved in Coelenterates.

Types of Animal Tissues

The structure of a cell varies according to its function. Therefore, different types of tissues are found in the body of animal at different locations. Depending on their location, structure and function; the animal tissues have been broadly classified into four types. These are:

1. Epithelial Tissue
2. Connective Tissue
3. Muscular Tissue
4. Neural/Nervous Tissue

These tissues are further differentiated as shown in the following chart:



EPITHELIAL TISSUE

Epithelial tissue is commonly referred to as epithelium (pl, epithelia). The term 'epithelium' was introduced by **Ruysch.** An epithelium is made up of one or more layers of cells, that covers or lines the external and internal surfaces of various body parts are also composed of epithelial tissue.

Structure: Epithelial tissue consists of variously shaped cells closely arranged in one or more layers. There is little intra-cellular material between the cells.

The epithelial tissue consists of a basal surface and a free surface. The basal surface lies in contact with a delicate **non-cellular layer called basement membrane**. The basement membrane provides elastic support and also anchors the epithelial tissue to the underlying connective tissue for obtaining nutrients. The free surface of epithelial tissue faces either a body fluid or the outside environment and thus, provides a protective covering to the external and internal exposed surfaces of the body parts.

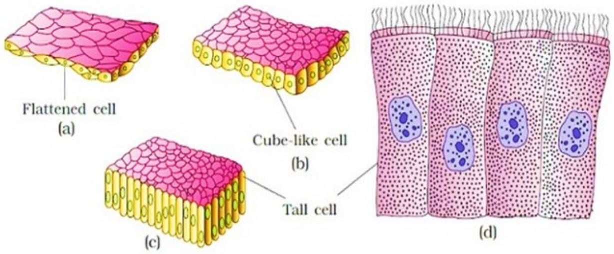


Fig. : Types of simple epithelium : (a) Squamous, (b) Cuboidal: (c) Columnar, (d) Columnar cells bearing cilia

Types of Epithelial Tissue

Classified into two groups – Simple and Compound epithelium.

1. Simple Epithelium :

It consists of a single layer of cell resting on a basement membrane. It functions as a lining for body cavities, ducts and tubes.

On the basis of structural modification of the cells, epithelium is further divided into the following types:

(i) Squamous
(ii) Cuboidal/cubical
(iii) Columnar
(iv) Ciliated
(v) Pseudostratified
(vi) Glandular

(i) Squamous Epithelium: It consists of a single thin layer of flattened cells with irregular boundaries. The cell are closely fitted like tiles in a floor. Hence, it is also known as **pavement epithelium.** If we see the cells from the surface, they seem to be polygonal in shape. The nuclei of the cells are flat and often lie at the centre of the cells. **Location :** This epithelium occurs in the **walls of blood vessels, air sacs (alveoli) of the lungs,** lymph vessels, wall of Bowman's capsule, loops of Henle of the nephrons of the kidneys, coelomic cavities etc.

Function:

1. Filtration in Bowman's capsule.
2. Exchange of materials between blood capillaries and tissue fluid.
3. Exchange of gases.

(ii) Cuboidal Epithelium : It consists of a single layer of cube-like (cubical) cells lying on a basement membrane. Nuclei are rounded and lie in the centre of the cells. Free surfaces of the cells may be smooth or bear minute finger-like projections known as **microvilli**. This gives a brush-like appearance to their free border and also increases the surface area to several times. Such an epithelium is known as **brush-bordered cuboidal epithelium.**

Location : It is generally found in the tubular parts of nephrons in kidneys, ducts of glands, thyroid follicles, ovaries and testes (germinal epithelium). The epithelium of proximal convoluted tubule (PCT) of nephron in kidney has microvilli (brush-bordered cuboidal epithelium).

Function:

1. Brush-bordered cuboidal epithelium present in the proximal convoluted tubule of nephron is responsible for reabsorption of useful substances.
2. Secretion and excretion by glands.

(iii) Columnar Epithelium : It consists of a single layer of tall and slender cells. Lying on a basement membrane.

The nuclei are somewhat elongated along the axis of the cells. Nuclei lie near the bases of the cells. Free surface may be smooth or bear microvilli for increasing the absorptive surface area. Some cells of this epithelium produce mucus and are called **goblet cells.** The epithelium containing mucus-secreting cells, along with underlying supporting connective tissue is called mucosa or mucous membrane. The intestinal mucosa bearing microvilli is called **brush-bordered columnar epithelium.**

Location : It is found in the lining of stomach and intestine.

Function :

1. Absorption
2. Secretion

(iv) Ciliated Epithelium : If the columnar or cuboidal cells bear cilia (hair-like outgrowths) on their free surface, they are called ciliated epithelium. The epithelium lies over a basement membrane. Number of cilia varies from one, a few to numerous. The cilia remain in rhythmic motion and create a current to transport the materials which come in contact with them. Their function is to move particles or mucus in a **specific direction** over them epithelium.

This epithelium is of two types :

1. **Ciliated cuboidal epithelium :** It consists of cubical cells which have cilia on their free surface. It occurs in smaller bronchioles.

2. **Ciliated columnar epithelium :** It consists of columnar cells which have cilia on their free surface. This epithelium occurs in the inner surface of hollow organs like fallopian tubes (oviducts) and most of the respiratory tract.

Function :

1. Ciliated columnar epithelium is responsible for the passage of ovum through fallopian tube.
2. In respiratory tract, it helps in expelling the mucus and particles trapped in it, towards the pharynx (throat).

(v) Pseudostratified Epithelium : A pseudostratified epithelium is a type of epithelium" that, though comprising only a single layer of cells, has its cell nuclei positioned in a manner suggestive of stratified epithelia. Hence, the name pseudostratified epithelium (pseudo means false, stratified means multilayered).

Structure: Its cells are columnar but unequal in size. The long. cells -extend- up to free surface. The short cells do not reach the outer free surface. The long cells have oval nuclei however, short cells have rounded nuclei. Mucus – secreting goblet cells also occur in this epithelium. The nuclei lie at different levels in different cells. Hence, it is called pseudostratified epithelium.

Location : Pseudostratified non-ciliated columnar epithelium tissue is found in urethra human male and in the large ducts of certain glands such as parotid salivary gland. Pseudostratified ciliated columnar epithelium is found in trachea and large bronchi.

(vi) Glandular Epithelium : Some of the cells of epithelium get specialized for secretion and are called glandular epithelium. Cells of glandular epithelium are **columnar** or **cuboidal** in outline. The glands are formed from the glandular epithelium. A gland may be made up of a cell, tissue or organ.

Types of glands : The glands are classified in different ways :

(i) Cell number : Based on cell number, glands are of two types : unicellular and multicellular.

(a) Unicellular glands : They consist of isolated single cells, which function as glands, e.g., Goblet cells of the alimentary canal. These glandular cells secrete mucus (a proteinaceous viscous and slimy substance) so they are also known as mucous cells or mucocytes.

(b) Multicellular glands : These glands are made up of a cluster of cells. A multicellular gland consists of a duct and secretory part, both made up of epithelial cells. For example, salivary glands, gastric glands, sebaceous (oil) glands etc. are multicellular in nature.

(ii) Mode of pouring of secretion : On the basis of the mode of pouring of their secretions, glands are of two types : **exocrine and endocrine glands.**

(a) Exocrine glands : These glands drain out their secretion to the body surfaces (exterior) and surfaces continuous with it, e.g., alimentary tract, respiratory tract etc. The secretion is passed out either by ducts or poured directly over the substrate. Exocrine glands secrete mucus, saliva, earwax, oil, milk, digestive enzymes and other cell products. These include salivary glands, gastric glands, intestinal glands, oil glands, mammary glands, tear glands etc.

(b) Endocrine glands : These glands lack ducts, so these glands are commonly called ductless glands. They secrete their products (hormones) directly into the fluid bathing the glands i.e., blood and lymph. The blood and lymph carry hormones to the target organs. Endocrine glands include thyroid, pituitary, adrenal, hypothalamus etc.

2. Compound Epithelium

It consists of more than one layer of cells. Only the cells of the deepest layer rest on the basement membrane. Being multilayered, compound epithelia have role in secretion or absorption, but they provide protection to underlying tissues against mechanical, chemical, thermal or osmotic stresses. Compound epithelia may be stratified or transitional.

(i) **Stratified Epithelium** has many layers of epithelial cells. The deepest layer is formed by columnar or cuboidal cells. But the morphology of the superficial layers varies in the different kinds of stratified epithelia. In stratified cuboidal epithelium, the superficial cells are cuboidal. It lines the inner surfaces of larger salivary and pancreatic ducts. **Stratified non-keratinised Squamous Epithelium covers moist surfaces such as those of buccal cavity, pharynx and oesophagus.** It has several superficial layers of living squamous cells and deeper layers of interlinked polygonal cells. **Stratified Keratinised Squamous Epithelium** covers the dry surface of skin. It has many superficial layers of horny, scale-like remains of dead squamous cells and several deeper layers of living-polygonal cells. Heavy deposits of the insoluble protein keratin in the dead superficial cells make the epithelium impervious to water and highly resistant to mechanical abrasions. In contrast, non-keratinised stratified epithelia cannot prevent water loss and afford only moderate protection against abrasions.

(ii) **Transitional Epithelium** is much thinner and more stretchable than the stratified epithelium. It has a single layer of cuboidal cells at the base, 2-3 middle layers of large polygonal or pear-shaped cells and a superficial layer of large, broad, rectangular or oval cells. **It lines the inner surface of the urinary bladder and ureters.** It allows considerable expansion of these organs to accommodate urine because stretching considerably flattens and broadens the cells of superficial and middle layers.

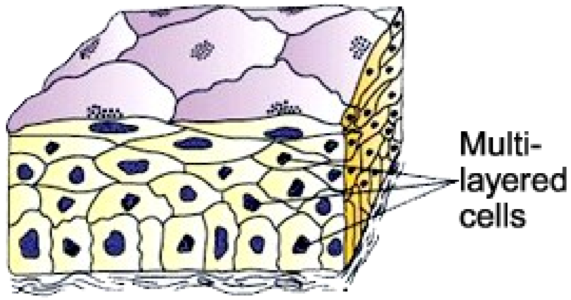


Fig. : Compound epithelium

Cell Junctions :

The cells are held together by specialised intercellular junctions, which serve as structural and functional links between them. Three types of cell junctions are found in the epithelium and other tissues as well.

These are :

1. **Tight junctions (Zonula occuludens) :** help to stop substances from leaking across the tissue. Plasma membranes in the apical parts of the adjacent epithelial cells become tightly packed together or are even fused to form the tight junctions.
2. **Inter digitations :** These are interfitting, finger like processes of the cell membranes of the adjacent cells. They increase the area of surface contact between the adjacent cells and therefore, their adhesion.
3. **Intercellular Bridges :** These are minute projections that arise from adjacent cell membranes. They make contact with one another.
4. **Gap Junctions :** Facilitate the cells to communicate with each other by connecting the cytoplasm of adjoining cells for rapid transfer of ions, small molecules and sometimes big molecules.
5. **Intermediate Junctions (Zonula adherens) :** These usually occur just below tight junctions. The intercellular space at these places contains a clear, low electron density fluid. These is a dense plaque like structure on cytoplasmic side of each plasma membrane from which fine microfilaments of actin (protein) extend into the cytoplasm. There is no intercellular filaments between the adjacent cell membranes. These is an adhesive material at this point. They probably serve anchoring functions.
6. **Desmosomes (Macula adherens) :** Perform cementing to keep the neighboring cells together. These are like zonula adherens but are thicker and stronger and are disc like junctions. They have intercellular protein. The plaque-like structures (protein plates) are much thicker. The microfilaments which extend from plaque-like structure into the cytoplasm are not of actin, but of a keratin like protein and these microfilaments are called **tone fibrils.** Desmosomes serve anchoring function.
7. **Hemidesmosomes** (single sided desmosomes) are similar to desmosomes but the thickening of cell membrane is seen only on one side. Hemidesmosomes join epithelial cells to basal lamina (upper layer of basement membrane).

CONNECTIVE TISSUE

Connective tissue is the most abundant and widely distributed tissue in the body of animals. It consists of living cells embedded in abundant non-living intercellular matrix which connects different tissues or organs and provides support to various structures of animal body. It forms packing around organs so that they do not get displaced by body movements.

Structure : Generally, a connective tissue is made up of three components : **Matrix, cells** and **fibres.**

The matrix (ground substance) is mainly a mixture of modified polysaccharides and proteins, which are secreted by the component cells of the tissue. Different types of cells such as fibroblasts, macrophages, mast cells, adipose cells etc. occur in the matrix. In all connective tissues except blood, the cells secrete fibres made of structural proteins called collagen or elastin. These fibres provide strength, elasticity and flexibility to the tissue.

Types : The connective tissues can be classified into three Types :

1. Loose connective tissues
2. Dense connective tissues
3. Specialized connective tissues

Each type is further divisible into sub-types :

Connective Tissues

- Loose Connective Tissues
  - Areolar Tissue
  - Adipose Tissue
- Dense Connective Tissues
  - Dense Regular Connective Tissue
    - Tendon
    - Ligament
  - Dense Irregular Connective Tissue
- Specialized Connective Tissues
  - Skeletal Connective Tissue
    - Bone
    - Cartilage
  - Fluid Connective Tissue
    - Blood
    - Lymph

1. Loose Connective Tissue

Loose connective tissue consists of cells and fibres loosely arranged in a semi-fluid ground substance (matrix). Examples of loose connective tissues are Areolar tissue and Adipose tissue.

(i) Areolar Tissue : It is the most widely distributed connective tissue in the animal body. It is present beneath the skin. Often it serves as a support framework for epithelium. It joins skin to muscles, fills spaces inside organs and is found muscles, blood vessels and nerves.

Structure : The areolar tissue consists of ground substance, the **matrix** which is made up of modified polysaccharides(mucopolysaccharides) ad proteins (glycoproteins).

Also scattered in the matrix are several kinds of irregular cells, which perform different functions in the body. Some example of these cells are :

(a) Fibroblasts : These cells produce and secrete fibres and matrix.

(b) Macrophages or Histiocytes : Ingest cell debris, bacteria and foreign matter.

(c) Mast Cells : Produce histamine (which dilates the walls of blood vessels in inflammatory and allergic reactions), heparin (which checks clotting of blood inside the blood vessels) and serotonin (which constricts blood vessels to check bleeding).

(d) Plasma Cells : Produce antibodies.

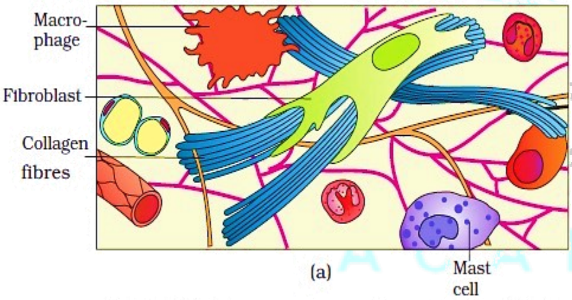


Fig. : Areolar tissue

Apart from these cells, the matrix contains two types of protein fibres :

1. **White Collagen Fibres :** These fibres are made up of collagen protein. These fibres occur in bundles and are unbranched and inelastic. Boiling of collagen fibres yields gelatin.
2. **Yellow Elastic Fibres :** These fibres are made up of elastin protein. These fibres are branched and elastic. These remain unaffected on boiling.

Function :

1. It acts as a supporting and packing tissue between organs lying in the body cavity.
2. It helps in repair of tissues after an injury.

(ii) Adipose Tissue : It is a fat-storing connective tissue.

Structure : Adipose tissue is basically an aggregation of fat cells or adipose cells (**adipocytes).** Each fat cell is rounded or oval and contains a large droplet of fat that almost fills it. The excess of nutrients which are not used immediately are converted into fats and are stored in this tissue. The protein fibres are few in number and form a loose network for supporting the fat-laden cells.

Location : It is located mainly beneath the skin and also around the heart, kidneys, eyeballs, etc., where fat is stored.

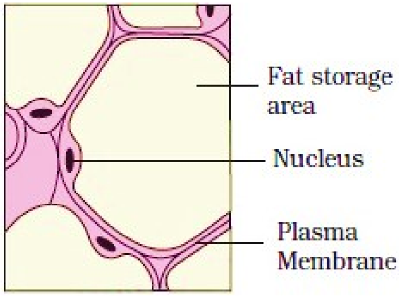


Fig. :Adipose tissue consisting of adipocytes

Function :

1. It serves as a fat reservoir.
2. It forms a shock-absorbing cushion around the eyeballs and kidneys.
3. It acts as an insulator. Being a poor conductor of heat, it reduces heat loss from the body.

2. Dense Connective Tissue

Dense connective tissue consists of fibres and fibroblast cells which are compactly packed in the matrix. It is the principal component of tendons and ligaments.

Orientation of fibres in the matrix show a regular or irregular pattern and thus there are two types of dense connective tissue : (i) Dense regular; (ii) Dense irregular connective tissue.

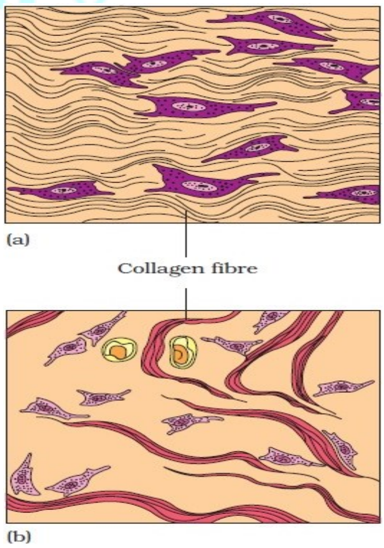


Fig. : Dense connective tissue : (a) Dense regular, (b) Dense irregular

(i) Dense regular connective tissue : In the dense regular connective tissue, the collagen fibres are present in rows between many parallel bundles of fibres. Examples are tendons and ligaments.

(a) Tendons : Tendons are cord-like, strong, inelastic structures that join skeletal muscle to bone. They consist of parallel bundles of collagen fibres.

(b) Ligaments : Ligaments are structures which connect bone to bone. They consists mainly of collagen fibres arranged in bundles with fibroblasts present in rows between bundles.

Differences between Tendon and Ligament

Tendons	Ligaments
1. Inelastic in nature.	1. Elastic in nature.
2. Join muscle to bone.	2. Connective bone to bone.
3. Made up of white collagen fibres.	3. Made up of bundles of elastic fibres and few collagen fibres.

Specialized Connective Tissue

This type of tissue include skeletal connective tissue like cartilage and bone and fluid connective tissue like blood and lymph.

(i) Skeletal connective tissue : In is the connective tissue in which the extracellular ground substance is solid. It forms the endoskeleton or internal framework of the vertebrates. It supports the body, protects various organs and helps in locomotion. It includes **cartilage and bone.**

(a) Cartilage : This tissue is elastic, harder than dense connective tissue but softer than bone. It is found more abundantly in vertebrate embryos because most of the bones forming skeleton of the adult are cartilaginous in the early stage. However, it is commonly found in the body of adult vertebrates.

Structure : The matrix (ground substance) of cartilage is solid and pliable and resist compression. In the are present fluid-filled spaces called lacunae. Lacunae contain cartilage-forming cells. Also, the matrix is produced and maintained by the cartilage cells.

Location : It is present in the tip of nose, outer ear joints, between adjacent bones of the vertebral column, limbs and hands in adults.

Function :

1. It provides support and flexibility to the body parts and resist compression.
2. It smoothens surface at joints and thus present the wear and tear of bones due to friction.

(b) Bone : It is the hard connective tissue. It is a very strong and non-flexible tissue. It is made up of 70% inorganic matter and 30% organic matter. If bone is put in HCI it gets decalcified and becomes soft and flexible and nothing is happened to it if put in KOH.

Structure : The matrix of bone is very hard and non-pliable because of the presence of salts, such as **calcium phosphate, calcium carbonate,** etc. and proteins like **ossein** and collagen fibers. Give bone its strength. In the solid matrix longitudinal canals are present called haversian canals. Each haversian canal contains an artery, a vein, a lymph vessel, a nerve and some bone cells, all packed within connective tissue.

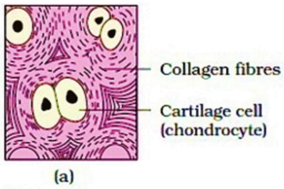
The matrix is present in the form of layers called **lamellae.** In these lamellae are present ring-shaped fluid-filled spaces called **lacunae.** The lacunae contain bone cells, **osteocytes.**

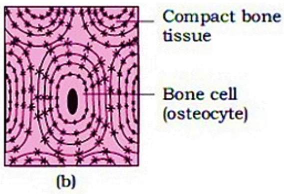
In long bones such as limb bones, a cavity called bone marrow cavity is present. This cavity is filled with a soft and semisolid fatty tissue termed as **bone marrow.** The bone marrow in some bones is the site of production of blood cells (such as RBCs, WBCs, Platelets etc.).

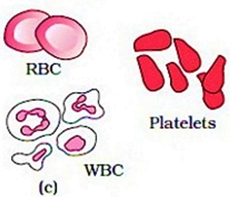
Location : It forms the endoskeleton of adult vertebrates.

Functions :

1. It provides structural framework to the body.
2. It support and protects softer tissues and organs, such as brain, lungs etc.
3. It provides surface for the attachment of muscles and thus help in locomotion/movement.
4. It serves as storage site of calcium and phosphate.







Specialised connective tissues : (a) Cartilage (b) Bone (c) Blood

Differences between Bone and Cartilage

S.No.	Bone	Cartilage
1.	**Matrix** is composed of tough inflexible material, called **ossein.**	Matrix is composed of a firm, but flexible material called **chondrin.**
2.	Matrix is impregnated with salts, chiefly calcium phosphate and carbonate.	Matrix is impregnated with calcium salts only in calcified cartilage.
3.	Matrix occurs in concentric lamellae.	Matrix occurs in a homogenous mass.
4.	Matrix contains **fibres,** but these are indistinguishable.	Matrix may contain **fibres,** which may or may not be distinguishable.
5.	Bone cells **(osteocytes)** lie in lacunae singly. Growth in bone is bidirectional.	Cartilage cells (chondrocytes) lie singly or in groups of two or four. Growth in cartilage is unidirectional.
6.	**Osteocytes** are irregular and give off branching processes.	**Chondrocytes** are oval and devoid of processes.
7.	**Lacunae** send out canaliculi for the processes of bone cells, which extend into these minute canals.	**Lacunae** lack canaliculi.
8.	There are outer and inner layers of special one forming cells, the **osteoblasts** that produce new osteocytes which secrete new lamellae of matrix.	Cartilage grows by division of **chondroblasts.**
9.	Bone is surrounded by a tough sheath, called **periosteum.**	Cartilage is surrounded by a firm sheath, called **perichondrium.**

(i) Fluid connective tissue: It is made up of fibre-free fluid matrix and specialized living cells that can neither divide nor secrete matrix. Vascular tissue regularly circulates in the body and helps in the transportation of various materials such nutritive elements, gases, excretory products, hormones, etc.

The two main fluid connective tissue present in animals are blood and lymph.

MUSCULAR TISSUE

All types of movements are brought about in the body with the help of muscular tissue. This tissue constitutes the muscles, which are made up of many long, cylindrical, fibre-like cells called **muscle fibres.** Muscle fibres in a muscle may be present in the form of sheets or bundles. The muscle fibers are held together by the connective tissue to form muscles, but they have no intercellular substance. The muscle fibres contain long thread-like proteinaceous fibrils called **myofibrils,** present in their cytoplasm known as **sarcoplasm.**

The muscle fibers are capable of contractions or relaxations. The cells of muscular tissue can contract (shorten) in response to a stimulus and then relax (lengthen) and return to their original uncontracted state in a coordinated manner. Their action moves the body to adjust the changes in the environment and to maintain the positions of the various parts of the body.

Types :

On the basis of their location, structure and function; there are three types of muscles:

1. Skeletal muscle
2. Smooth muscle
3. Cardiac muscle

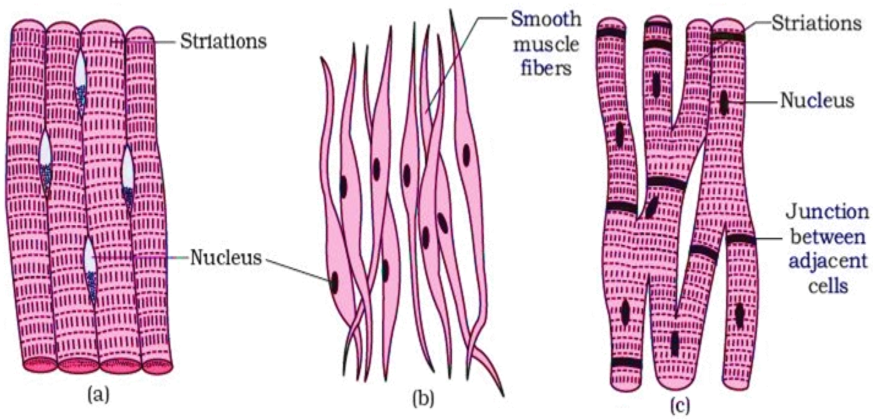


Fig. : Different types of muscle tissue : (a) Skeletal (striated) muscle tissue, (b) Smooth muscle tissue, (c) Cardiac muscle tissue

1. **Skeletal Muscle (Striated or Striped Muscle) :** These are the most abundant type of muscles fibers found attached to all the bones, hence, called skeletal muscle fibers. They are **voluntary** in their activity i.e., they are under the control of our will power, e.g., movements of arms, legs etc.

   Structure : In a typical muscle such as the biceps, striated skeletal muscle fibers are bounded form the outside by an elastic but tough covering called **sarcolemma.** Just beneath the sarcolemma in each fiber many nuclei occur at irregular intervals. Thus, these fibres are **multinucleated** and their nuclei are peripheral in position. The cytoplasm (sarcoplasm) of each fiber has a large number of myofibrils which are tightly packed. Each myofibril shows alternate dark and light bands giving a characteristic striped or striated appearance. Hence its name. These fibers are bundled together in a parallel fashion.

Location : It is found attached to the bones. But, the most common parts to fid such muscle are arms legs, body wall, face and neck.

Function :

1. Striated muscles provide the force for locomotion and all other voluntary movements of the body.
2. Striated muscles are powerful and undergo rapid contraction. These muscles can be tired and need rest.

2. **Smooth Muscle (Unstriated or Non-striated Muscle) :** Smooth muscles are found in the walls of the hollow visceral organs except that of the heart, that is why they are called **visceral muscles**.

They are **involuntary** in their activity i.e.; their functioning cannot be directly controlled.

Smooth muscles never connect with the skeleton.

Structure : Smooth muscle fibers or cells are elongated and spindle-shaped i.e., pointed or taper at the ends (fusi form) and broad in the middle. These cells are held together by the cell junctions and are bundled together in a connective tissue sheath. Each muscle cell is enclosed in a simple plasma membrane. There is a single centrally located oval nucleus in the centre of cytoplasm (or sarcoplasm). So, they are **uninucleate**. Delicate, contractile threads called **myofibrils** run longitudinally through the cell. These fibrils do not show any light and dark bands. That is why, they are called smooth or unstriped or non-striated muscles.

Location : They are found in the posterior part of oesophagus, stomach, intestine, lungs, urinogenital tract, urinary bladder, blood vessels, iris of eye etc.

Function : These muscles help in bringing about involuntary movements in the body such as peristalsis (movement of food in the alimentary canal), opening and closing of tubes etc.

Differences between Striated, Non-striated and Cardiac Muscles

Striated Muscle	Non-striated Muscle	Cardiac Muscle
1. Occur in the limbs, body wall, face, neck etc.	1. Occur in posterior part of oesophagus, urinogenital tract, iris of eye etc.	1. Occur in the walls of heart.
2. Cylindrical in shape.	2. Spindle shaped.	2. Cylindrical in shape.
3. Multinucleated muscle fibers.	3. Uninucleate muscle fiber.	3. Uninucleate muscle fiber.
4. Nuclei are peripheral.	4. Nucleus is central.	4. Nucleus is central.
5. Myofibrils show alternate light and dark bands.	5. Myofibrils are without light and dark bands.	5. Myofibrils show faint light and dark bands.
6. Fibers are unbranched.	6. Fibers are unbranched.	6. Fibers are branched.
7. Intercalated discs are absent.	7. Intercalated discs are absent.	7. Intercalated discs are present.
8. They soon get fatigued.	8. They do not get fatigued.	8. They never get fatigued.
9. Voluntary in action.	9. Involuntary in action	9. Involuntary in action.

NERVOUS (NEURAL) TISSUE

Neural tissue exerts the greatest control over the body's responsiveness to changing condition. Nervous tissue is specialized to transmit messages in out body Brain, spinal cord and nerves are all composed of nervous tissue. Nervous tissue contains highly specialized cells called **nerve cells** or **neurons**. The neuroglial cell which constitutes the rest of the neural system protects and supports neurons. Neuroglia make up more than one-half the volume of neural tissue in our body.

Neurons

Neurons are the structural and functional units of nervous tissue and are excitable cells. Each neuron has following parts :

1. **Cyton or Cell body :** It consists of a central nucleus and cytoplasm (called **neuroplasm**) with characteristic deeply stained particles, called Nissl's granules. **Nissl's granules** are large and irregular masses of ribosomes and RER.
2. **Dendrites :** These are short and branched processes arising from the cyton. They carry impulses towards the cell body.
3. **Axon :** It is a single long cylindrical projection of uniform thickness. The axon ends in a group of branches (axon endings), termed as terminal arborizations. Nissl's granules are absent in axon.

   The axon carries messages away from the cyton.

   Axon is surrounded by a sheath (called **Neurilemma**) of special connective tissue cells called **Schwann cells**. The unsheathed axon is called **Nerve fiber.**
4. **Synapse :** When a neuron is suitably stimulated, an electrical disturbance is generated which swiftly travels along its plasma membrane. Arrival of the disturbance at the neuron's endings, or output zone triggers events that may cause stimulation or inhibition of adjacent neurons and other cells. The terminal arborization of axon of one neuron is very closely placed to the dendrites of another neuron to carry impulses from one neuron to another neuron. This close proximity is called **synapse.**

   Nerve impulses pass between neurons through the synapse with the help of chemical called as **Neurotransmitters** (e.g., Acetylcholine).

Types of Neurons :

The neurons are of four types based on the number of nerve processes,

(a) **Unipolar neurons :** Which have only axon but no Dendron and are found only in early embryos.

(b) **Bipolar neurons :** Which have two processes, one axon and another Dendron, and are found in olfactory epithelium and retina of eye.

(c) **Multipolar neurons** : Which have many processes arising from cell body; out of them one is (longer) acts as an axon and the remaining as dendrons. Multipolar neurons are most common and are found in brain and spinal cord.

(d) **Pseudo-unipolar neurons :** They are actually bipolar but appear like unipolar. A single process arises first which divides to form dendrite and axon. This is found in dorsal root ganglion of the spinal cord.

Types of Nerves :

(i) **Sensory Nerve :** It is made up of only sensory nerve fibers surrounded by connective tissue membrane. It carries the impulse from the receptor to CNS.

(ii) **Motor Nerve :** It is made up of motor nerve fibers, which carry the impulse from CNS to the effector's organs i.e., muscles or glands to bring about their movement.

(iii) **Mixed Nerve :** It has both the sensory and motor nerve fibers. All the spinal nerves in our body are mixed.

Neuroglial cells/ Neuroglia

These are specialized cells found in the brain and spinal cord supporting the neurons. About more than 50% of all brain cells are neuroglial cells. These cells have different shapes and are thought to separate and insulate adjacent neurons, so that impulses pass from one neuron to the next only over the synapse, where the packing cells are missing.

Type of glial Cells : They are undifferentiated cells with no Nissl's granules.

(i) **Astrocytes / Macrocytes :** They are large in size with a number of protoplasmic processes. They form maximum number of glial cells. They help in repair of nerve tissue and form blood brain barriers.

(ii) **Oligodendrocytes :** They are with few protoplasmic processes and form myelin sheath in CNS.

There is no neurolemma inside the central nervous system. In the absence of Schwann cells myelin is formed by the spiral wrapping of the nerve fibers by processes of Oligo dendrocytes

(iii) **Microglial cells :** They are mesodermal in origin. They are smallest in size with few feathery processes and help in phagocytosis.

Functions of Nervous Tissue :

1. Nervous tissue controls all the body activities.
2. Nervous tissue coordinates between various body parts during any body function.
3. Dendrites carry nerve impulses towards the cyton whereas axon carries impulses away from the cyton.

Structural Organisation in Animals (Animal Morphology)

Introduction:

In multicellular organisms, tissues get arranged in a specific pattern to form various definite organs which in turn organize themselves to form different organ systems. Such a gradual and progressive organization is essential for efficient and better coordination of activities or processes taking place inside an organism which is basically composed of million of living cells.

In this chapter, morphology and anatomy of three organisms at different evolutionary levels us described to show the pattern of organization and functioning of them. These organisms include earthworm and cockroach which are non-chordates or invertebrates (as they lack notochord, a hollow dorsal nerve cord, pharyngeal gill slits and post-anal tall) and frog which belongs to phylum chordate, bears a notochord, pharyngeal gill slits and a hollow dorsal nerve cord. We will discuss their morphology, anatomy and organ systems like digestive system, respiratory system, reproductive system, etc.

Morphology refers to the study of form or externally visible features. In animals, it sometimes also refers to the study of external appearances of the organs or parts of the body, whereas Anatomy refers to the study of morphology of internal organs in the animals.

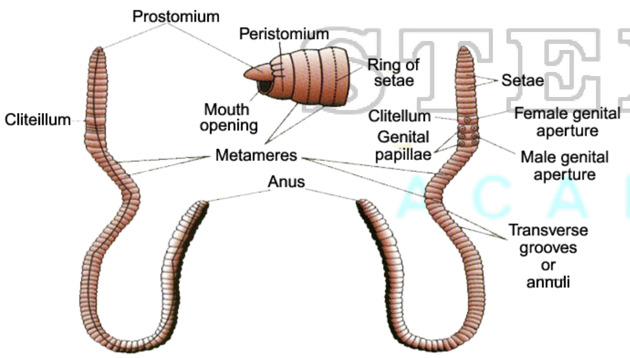


Fig. : Pheretima posthuma – A. Entire worm in dorsal view, B. Entire worm in ventral view, C. Anterior end in dorsal view, D. Anterior end in lateral view

EARTHWORM

- Earthworm is studied under Phylum Annelida of Kingdom Animalia
- There are about 500 species of earthworms out of which 13 are found in India.
- Some common species include Pheretima posthuma and Lubricous.
- Earthworm is a terrestrial animal of glistening deep-brown of reddish brown colour.
- They are found in wet soil containing rich organic matter, i.e., humus. They usually live in burrows found in upper layer of the soil.
- Mostly, they live in their burrows made by boring and swallowing the soil.
- During rainy season, they come out and can be seen in lawns, fields and gardens. In gardens, they can be traced by their faecal deposits known as **"worm castings".**

Morphology

- Earthworms have long, narrow, cylindrical body. Their body is divided into short and similar segments. These similar segments are known as **"Metameres"**. They are about 100 to 120 in number. These metameres divide body both externally and internally, such type of segmentation is called **metameric segmentation** or metamerism. These segments are separated from each other by distinct ring-like grooves or annuli.
- The dorsal surface of their body is recognized by a dark median line (mid-dorsal), which is in fact a dorsal' blood vessel beneath the skin. While their ventral surface can be recognized by the presence of genital; apertures (pores).
- The earthworms do not possess a distinct head nor any specialized sense organs like eyes or ears. Therefore, the anterior end of these worms consists of mouth and the prostomium. Mouth is a crescentric aperture at the anterior end of first segment. This segment is known as peristomium (or buccal segment). The dorsal edge of **peristomium** projects forward above the mouth, as a small fleshy lobe called "**prostomium**" which serves as covering for the mouth. It is used as a muscular probe in burrowing. It is also sensory in function.
- Other external features of earthworm include - presence of clitellum, setae and various apertures.

(a) Clitellum : In mature worms, a prominent dark circular band of glandular tissue is found from the 14th to 16"1 segments. This is known as the clitellum. This segment secretes material (i.e, mucus and albumen etc.) for the formation of the cocoon or egg capsule. This clitellum divides body into three prominent regions - pre-clitellar region, clitellar region and post-clitellar region.

(b) Setae : Each body segment, except the **first**, the **last** and clitellar **segments**, bears a ring of tiny, curved, chitinous structures known as setae or chaetae. They are embedded in the epidermal pits known as setigerous sac, in the middle of each segment. These pits or sacs have special muscle to move the seta in or out and to bend it forward or backward. Hence, they help in locomotion.

(c) Apertures : These include - **mouth, anus, spermathecal apertures, genital pores** and **nephridiopores**.

(i) Mouth : A crescentric, anterior aperture, surrounded by peristomium and overhung by prostomium.

(ii) Anus : A vertical slit-like aperture at the posterior end.

(iii) Spermathecal apertures : There are four pairs of spermathecal apertures situated on the ventro- lateral sides of the intersegmental grooves, i.e., 5th to 9th segments. They serve to receive sperms from another worm during copulation.

(iv) Female genital pore : A single median aperture is present in the mid-ventral line of 14th segments clitellar region. The ova are passed out by this aperture.

(v) Male genital pore : A pair of crescentric openings are present on the ventro-lateral sides of the 18th segment (one on each side). They serve for the exit of the sperms.

(vi) Nephridiopores : These are numerous very fine openings of the excretory organs. They are scattered irregularly over all the segments, except the first two.

(vii) Dorsal pores : These pores are present along the mid-dorsal line starting from groove of 12/13. A single pore is present in each groove up to last but one groove. Coelomic fluid exudes from these pores,

Anatomy

Body wall of earthworm is composed of four layers :

(a) Cuticle : Body wall of the earthworm is covered externally by a thin, non-cellular layer, secreted by the epidermis below it.

(b) Epidermis : It consists of a single layer of columnar cells that rest on basement membrane. It contains many gland cells and sensory cells scattered in it.

(c) Muscular layer : It further comprises two layers - outer thin layer of circular muscle fibres and inner thick layer of longitudinal muscle fibers. All muscle fibers are smooth.

(d) Coelomic epithelium : It is the inner-most single layer of thin cells. It forms the outer boundary of coelom.

A. Digestive System

Food : Earthworm feeds on dead organic matter and decaying leaves along with soil. It also feeds directly upon leaves, grasses, seeds, algae etc.

The digestive system of earthworm comprises of alimentary canal and various associated digestive glands.

Alimentary Canal :

- Alimentary canal in Pheritima is a complete and straight tube running along the entire length, i.e., between first to last segment of the body.
- It consists of following parts :

(a) Mouth : It is a terminal aperture in peristomium, overhung by prostomium.

(b) Buccal cavity : Mouth leads into a thin-walled, small tube called buccal cavity. It extends from the 1st to the middle of the 3rd segment.

(c) Pharynx : Buccal cavity is followed by the pharynx which is a small, pear-shaped sac. It extends from the middle of third segment to the end of segment four.

(d) Oesophagus : The pharynx leads into a small, narrow tubular structure. It extends from the 5^{th} segment to 7th segment.

(e) Gizzard : In segments 8th and 9th, oesophagus continues into a prominent, oval, hard and thick-walled muscular organ, the gizzard. Gizzard grinds the food i.e. the soil particles and decaying leaves etc., with the help of thick muscles and cuticle.

(f) Stomach : Gizzard is followed by a short narrow tubular stomach which extends from the 9th to the 14th segment. Its wall are highly vascular and glandular. In stomach wall, chalky secretion of calciferous glands neutralizes the humic acid present in humus.

(g) Intestine : The stomach leads into a wide thin-walled intestine which runs from the 15th segment to the last segment where it opens to the outside by means of anus.

- In 26th segment, the intestine gives off a pair of short, conical lateral outgrowths, the intestinal caecae which extend forward to 3 or 4 segments.
- The characteristic feature of the intestine between 26 to 95 segments is the presence of internal median fold of dorsal wall called "Typhlosole". These increase the effective area of digestion and absorption in the intestine.

(h) Anus : The alimentary canal opens to the exterior by a small-rounded terminal aperture called the anus.

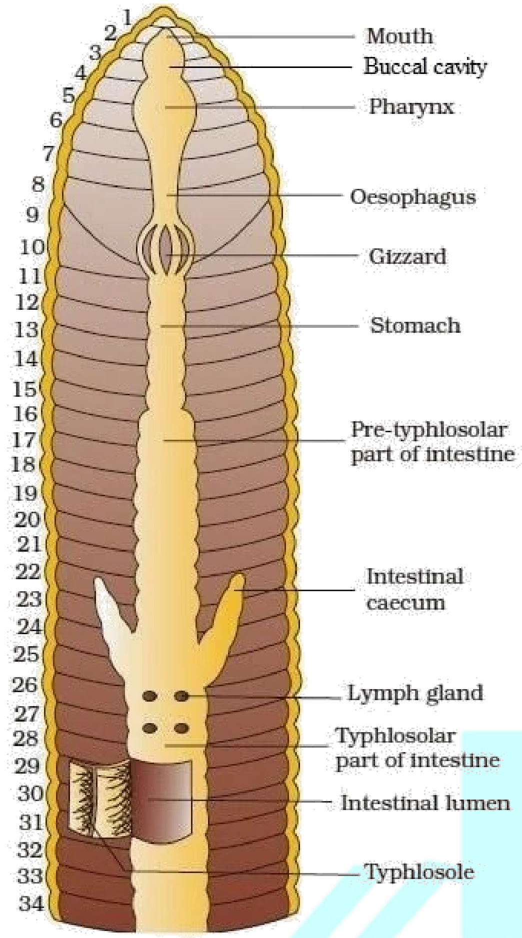


Fig. : Alimentary canal of earthworm

Process of Digestion :

- Earthworm ingests food, i.e., humus by the pumping action of its pharynx. Then this ingested organic-rich food passes through different parts of digestive tract, /.e., buccal cavity, pharynx, oesophagus, stomach, gizzard and intestine.
- In gizzard, food is grinded or pulverised thoroughly. Then in stomach, calciferous glands neutralise humic acid present in it. Intestine is the principal site of digestion. Intestinal wall consists of glandular cells which secrete digestive juice containing digestive enzymes which breakdown complex food into small absorbable units. These simpler molecules are absorbed through absorptive cells of intestinal epithelium, from here nutrients are passed to blood capillaries in the intestinal wall and are utilised inside body.
- The undigested food matter along with the soil is passed out through anus in the form of little heaps or pellets called worm castings.

B. Circulatory System

Pheretima exhibits a closed type of blood vascular system. It comprises of heart and blood vessels.

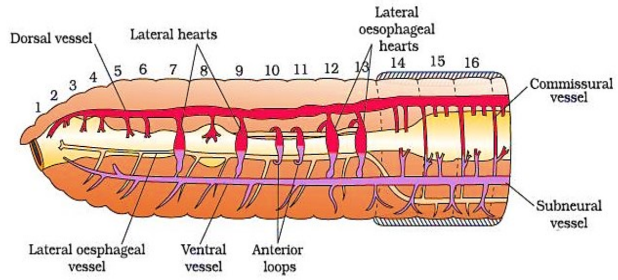


Fig. : Closed circulatory system

Heart and anterior loops : In earthworm, there are present four pairs of tubular hearts. These hearts are enlarged thick-walled pulsatile and provided with valves. The anterior two pairs of hearts known as **lateral heart** lie in the 7th and 9th segments. They connect dorsal blood vessel with ventral blood vessel. The posterior two pairs of heart are called **latero-oesophageal hearts** and are situated in the 12th and 13th segments. They are thick, muscular and rhythmically contractile vertical vessels. There is a pair of thin-walled, non-pulsatile, loop-like broad vessels without valves in each of the 10th and 11th segments. These vessels are known as **anterior loops.**

Blood vessels : Blood flows in well-organized vessels which run all along the body of earthworm. Some prominent blood vessels found in earthworm are :

(i) Dorsal blood vessel : It is the largest blood vessel of body running mid-dorsally above the alimentary canal, from one end of body to the other. It has valves which prevent the backflow of blood. It receives blood from various parts of earthworm through different connecting vessels.

(ii) Ventral blood vessel : It also extends from the one end to the other end of the body. It does not have any valves and flow of the blood is from anterior to the posterior end of the body. It is a main distributing blood vessel.

Blood : It is a mobile connective tissue which is composed of fluid plasma and colorless blood corpuscles. A coloured respiratory pigment, the haemoglobin is also present in the plasma. It gives a red colour to blood and aids in the transportation of oxygen for respiration. Only one type of blood corpuscles, the leukocytes are present in the blood of the earthworm. They are phagocyte in nature, i.e., they kill harmful germs which enter body.

Blood glands : In segments 4th, 5th and 6th lying above pharyngeal mass, are found small, red-coloured, follicular bodies called blood glands. They are considered to produce blood corpuscles and haemoglobin.

C. Respiratory System

The special respiratory organs are lacking in earthworm. Therefore, gaseous exchange takes place through general body surface (cutaneous respiration) which is kept moist by the secretion of epidermal cells (i.e., mucus) and coelomic fluid (i.e., milkish fluid filling the coelom). The body wall is thin and richly supplied with blood The blood carries an oxygen carrier protein, the haemoglobin dissolved in the plasma. The gaseous exchange, i.e., intake of O_2 and giving out of CO_2, take place between blood capillaries of outer epidermis and surface film of moisture as the atmospheric oxygen readily diffuses into the blood, and combines with haemoglobin to form oxyhaemoglobin. The latter circulated to the tissues, where it splits up into oxygen and haemoglobin. Oxygen oxidizes the food to form CO_2, water and energy. CO_2, again diffuses out from tissues to surrounding atmosphere through body surface. Earthworm respires through its skin surface; hence cutaneous respiration takes place in them.

D. Excretory System

- In Pheretima, excretion takes place by segmentally arranged, microscopic, coiled tubes called nephridial (sing.: nephridium).
- According to their location in body, these are distinguished into three types :

(a) Pharyngeal nephridia : These nephridia occur as paired tufts in the 4th, 5th and 6th segments on each side of the alimentary canal. Each tuft consists of large number of nephridia.

(b) Integumentary nephridia : These are attached to the inner surface of body wall in all segments, except the first two segments. They are microscopic and their terminal ducts open on the body surface independently through minute openings. They discharge waste matter directly to the exterior surface of worm.

(c) Septal nephridia : They are present on both the sides of each intersegmental septum behind 15th segment. The ducts of these nephridia open into intestine in each segment

Structure of Nephridia: A typical nephridium consists of:

(a) A ciliated funnel-shaped part (known as nephrostome) collects excess fluid from coelomic chamber in the coelom.

(b) This funnel-shaped region continues into a tubular part (i.e., main body) of nephridium where waste material is extracted from the blood.

(c) Finally, this tubular part terminates, passing all the excretory material to the surface in the body wall through a pore (known as nephridiopore) or terminal duct into the digestive tube.

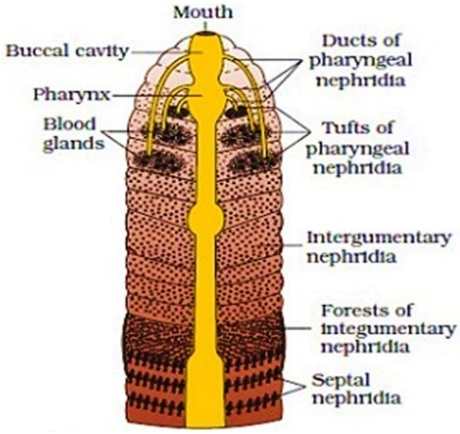


Fig. : Nephridial system in earthworm

Functioning of Nephridia : Nephridia regulate the volume and composition oi the body fluids, as they are abundant supplied with blood vessels. They bear gland cells which can extract excess of water and nitrogenous wastes from the blood. Integumentary nephridia discharge waste material to the outer body surface through pores. Pharyngeal and septal nephridia discharge them into gut lumen from where they are eliminated with faeces.

So, nephridia help in excretion and osmoregulation.

E. Nervous System

All the activities of earthworm are under the control of nervous system. Nervous system is well-developed and concentrated. Nervous system in earthworm basically comprises of:

(a) an anterior nerve ring, and

(b) a posterior ventral nerve cord

- **Nerve ring (brain-ring):** A pair of closely united white, pear-shaped cerebral ganglia, lying dorsally in the depression between buccal cavity and pharynx in the third segment. They elongate laterally giving rise to a pair of thick stout connectives which encircle the pharynx and meet ventrally into a pair of ganglia beneath the pharynx in 4th segment. In this way, a complete nerve ring is formed around pharynx.
- **Nerve cord :** From this ganglia (I.e., lying beneath pharynx) a nerve cord runs backward in mid-ventral line to the posterior of the body. This refers to the ventral nerve cord which bears, a slight enlargement, i.e., ganglion in each segment. These segmental ganglia give off nerves to various parts of the body. These nerves carry sensory information and also the messages to and for, i.e., from various parts of the body to nerve cord and vice-versa. Ventral nerve cord is double (paired) as it consists of two compactly united left and right cords. Each segmental ganglion also represents the fusion of a pair of ganglia.

F. Sensory System

Earthworms do not have special sense organs like eyes etc., but they have well-developed receptor cells which are quite simple in their structure. There are three types of receptors found in them. These are :

(i) Photoreceptors or light-sensitive organs : They are present on dorsal surface of the body and are numerous in anterior region. They enable worms to judge the intensity and duration of light.

(ii) Epidermal receptors or touch-sensitive organs : They are distributed all over epidermis but are more abundant on the lateral sides and ventral surface of the body. They are tactile (relating to touch) in function and also help worms to feel the vibrations in the ground.

(iii) Buccal receptors or taste receptors or chemoreceptors : They are specialized cells present in buccal chamber of earthworms. They are gustatory and olfactory (relating to taste and smell respectively).

E. Reproductive System

- Earthworms are monoecious or hermaphrodite, i.e., both male (testes) and female (ovaries) reproductive organs are present in the same individual.
- But self-fertilization does not occur as the male and female reproductive organs (testes and ovaries) do not mature at the same time.
- The testes mature earlier than the ovaries (such condition is known as protandry). So, cross-fertilization takes place. This fertilisation is followed by cocoon formation.

1. Male reproductive system : It consist of following parts :

(i) Testis sacs : There are two pairs of testis sacs in the 10^{th} and 11^{th} segments. Each sac encloses a testis and a spermiducal funnel.

(ii) Testis : There are two pairs of testis in 10^{th} and 11^{th} segments. Each testis arises from the anterior wall of each testis sac. Immature spermatozoa produced by the testes first enter testis sacs and then make their way into seminal vesicle where they undergo further development to become mature sperms.

(iii) Seminal vesicles : There are two pairs of seminal vesicles in 11th and 12th segments.

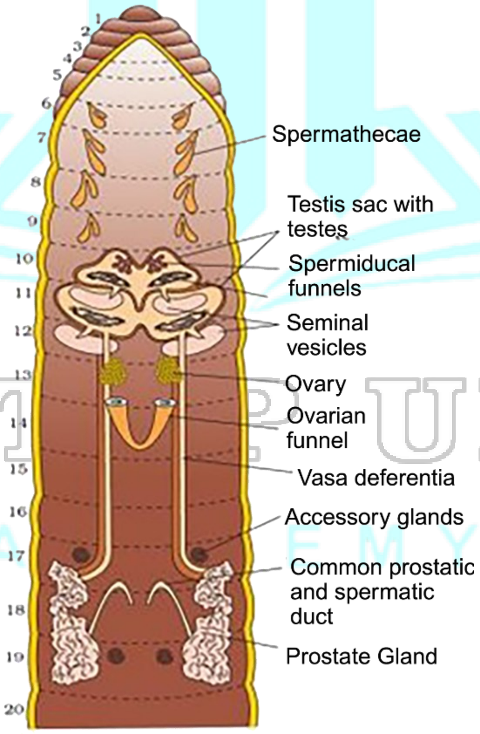


Fig.: Reproductive System of Earthworm

(iv) Spermiducal funnels : There are two pairs of spermiducal funnels, one in 10th segment and the, other in 11^{th} segment. Each spermiducal funnel leads into a fine tube, the vas deferens.

(v) Vasa differentia : There are present two pairs of vasa differentia. Each spermiducal funnel leads into a vasa deferens. Vasa differentia of each side run very close to each other up to the 18^{th} segment. In 18th segment, both the vasa differentia of each side are joined to the prostate duct coming from the prostate gland.

Two vasa differentia ducts and one prostate duct of each side are enclosed in a common thick muscular sheath, called the common prostate and spermatic duct. They open to the outside separately into male genital aperture.

(vi) Prostate glands : A pair of large prostate glands are present in earthworm. These glands are situated on either side of the intestine and extend from the 17th to 20th segment. They produce a secretion, which serves as a medium for transfer of sperms.

(vii) Accessory glands : There are two pairs of whitish glandular masses situated internally in 17th and 19th segments. The secretion of these glands is supposed to help in keeping the two worms close together during copulation.

During copulation, the sperms are passed onto the spermathecae of the earthworm.

2. Female reproductive system : It consists of following structures :

(i) Ovaries : There is a pair of white minute masses of the ovaries attached to the posterior surface of the septum present between the 12th and 13th segments. They produce ova.

(ii) Oviducts : They are two short tubes each lying immediately behind the respective ovary. The two ovarian tubes converge to meet in the body wall and open to outside by a female genital aperture on mid-ventral side of the 14th segment. The mature ova liberated by each ovary are received by the oviducts and are finally passed outside into the cocoon through a female genital aperture.

(iii) Spermathecae : There are present four pairs of spermathecae which lie in the 6th, 7th, 8th and 9th segments. They open to outside through the spermathecal pores situated ventro-laterally in the successive grooves separating the above-mentioned segments. They store the sperms received from another earthworm during copulation.

Copulation and Fertilization:

A mutual exchange of sperms occurs between two worms during mating. When one worm finds another worm they mate juxtaposing, i.e., worms apply to each other by their ventral surfaces with head ends pointing in the opposite directions, so that the male genital pores of each lie against a pair of spermathecal pores of other. In this position, they exchange packets of sperms called spermatophores. Mature sperms and egg cells and nutritive fluid, /'.e., prostatic fluid etc. are deposited in cocoons The cocoon or egg capsule is produce of by the gland cells of clitellum. Fertilization and development occur within the cocoons which are later deposited in soil. The ova (eggs) are fertilized by the sperm cells within the cocoon which then slips off the worm and is deposited in or on the soil. The cocoon holds the worm embryos. After about three weeks, each cocoon produces 2 to 20 baby worms with an average of four. In earthworms, **development is direct**, i.e., there no larva formed.

Importance to mankind :

Earthworms are simple, common place creatures of great economic importance to man. They are certainly small, but directly or indirectly very useful to us. They are well-known as "**Friends of Farmers**", because they make the soil loose and porous by their burrowing habit. The soil ploughed by their burrowing habit provides quick aeration to plant roots and also help in penetration of the developing plant roots. Earthworms also increase soil fertility as they upturn soil continuously, and they bring lower fertile soil on the surface. In this way, they plough the land, and share the work of the farmers. The large soil particles are ground up into finer ones by the gizzard (a grinding organ of their alimentary canal). This provides more surface to the soil for water absorption. Worm castings of the earthworms are of manurial value. The process of increasing fertility of soil by earthworms is called **vermicomposting**. They reduce both acidity and alkalinity of the soil, and thus create optimum conditions for plant growth. They are also used as bait for catching the fishes all over the world.

COCKROACH

- Cockroach are a group of nocturnal (i.e., more active at night), omnivorous and cursorial (running by legs) insects that are included in **Class-Insecta of Phylum-Arthropoda of Kingdom Animalia.**
- They are found in places where warmth, dampness and plenty of organic food is found. They have become residents of human homes and thus are serious pests and vectors of several diseases.
- They can feed on almost all kinds of food matter. For example, bread, fruit, paper, leather, cloth etc., and even dead bodies of their fellow.
- Periplaneta Americana is the common household cockroach.

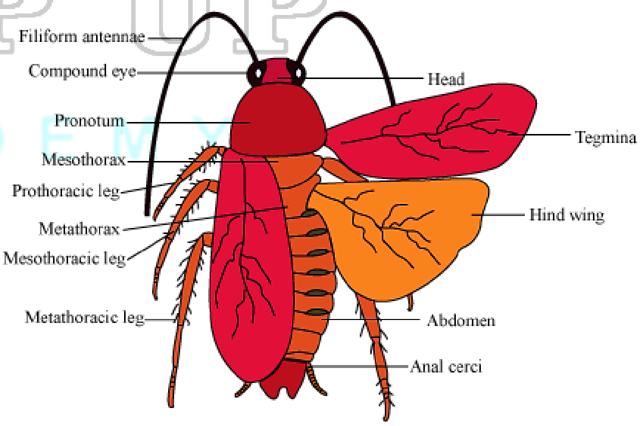


Fig. : External features of cockroach

External Morphology

1. Shape, size and colour :

- Body of cockroach is narrow, elongated and bilaterally symmetrical.
- Their colour is shining reddish-brown, sometimes black also, with a pale-yellow area at the last segment of the body.

- They have long antennae, legs and flat extension of the upper body wall that conceals head. Their size ranges from 1/4 inches to 3 inches (0.6-7.6 cm).
- Periplaneta species of cockroach are about 34-53 mm long with wings that extend beyond the tip of the abdomen in males.

2. Exoskeleton :

- The entire body is covered externally by a non-living brown-coloured hard, jointed and chitinous exoskeleton composed of several plates called sclerites.
- It is formed by the surface layer or cuticle of the body wall.
- Exoskeleton for each segment consists of a dorsal tergum, a ventral sternum and lateral pleura these plates are joined to each other by a thin and flexible articular membrane known as **arthrodial membrane** (articular membrane).

3. Division of body (Body divisions) : Body of cockroach is distinctly divided into three main segments or regions.

(a) Head
(b) Thorax
(c) Abdomen

(a) Head :

- Head is small and roughly triangular in shape. It lies anteriorly at right angles (perpendicularly) to the longitudinal body axis. It is formed by the fusion of six embryonic segments.
- Head is attached to thorax anteriorly by a short and narrow neck, which is supported by chitinous plates, i.e., sclerites. In adults, all the sclerites of the head fused to form a head capsule.
- Head shows greater mobility in all directions due to the flexible neck which is moved by muscles in different directions.
- Head region comprises of sense organs like eyes, antennae and mouth parts.

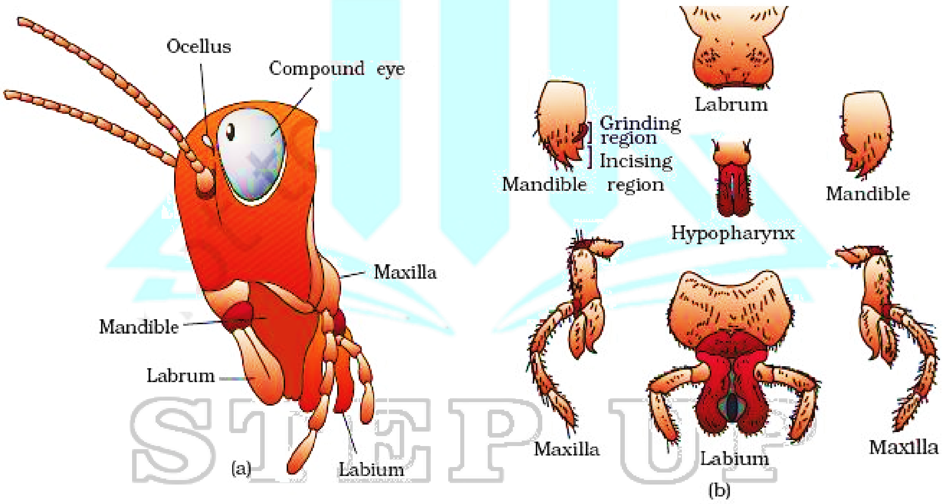


Fig. : Head region of cockroach : (a) parts of head region (b) mouth parts

(i) **Compound eyes :** Head bears a pair of large, black-coloured, kidney-shaped, dorsolaterally placed compound eyes which are formed by a large number of visual elements. They are the organs of sight.

(ii) **Antennae :** Just inner to each eye, a pair of long, slender and multi-segmented antennae are present. They arise from membranous sockets (i.e., antennal sockets) lying in front of eyes. The antennae bear tactile and olfactory receptors which are sensitive to touch and smell. They help cockroach in monitoring its surroundings (i.e., detecting, the presence of food and the object in front of it).

(iii) Mouth parts : Lower anterior end of head bears mouth, surrounded **by** mouth parts. Such a head with mouth parts directed downwards is called **hypognathous**. These mouth parts are used in searching and taking in food matter. These are of **biting and chewing type**, so that they enable cockroach to bite and chew hard stuffs, consume soft stuffs and lap up liquids. The mouth parts of cockroach consist of the labrum or upper lip, a pair of mandibles, a pair of maxillae, the labium or lower lip and the hypopharynx (tongue).

(b) Thorax : It consists of three segments:

(i) Anterior prothorax,
(ii) Middle mesothorax and
(iii) Posterior metathorax.

Each thoracic segment bears ventrally a pair of jointed walking legs, i.e., three pairs of legs, which are named, according to their respective positions on the body of cockroach, i.e., pro-legs (on prothorax), meso-legs (on mesothorax), meta-leas (on metathorax). All the three pairs of jointed legs are similar in s.

Two pairs of wings are also found in thoracic region in cockroach. The pair of wings arise from mesothorax (known as mesothoracic wings or fore wings) and the second pair of wings from meththorax region (i.e., metathoracic wings or hind wings).

- **Fore wings (Mesothoracic wings) :** They are thick, leathery, opaque and dark-coloured structures, which are somewhat narrow at distal end. They are larger than the second pair of wings. They are not used for flight, but cover and protect the metathoracic wings. Hence, also called wing covers or **tegmina** or **elytra**.
- **Hind wings (Metathoracic wings) :** They are delicate, thin transparent and membranous structures with broad terminal end. They are used for flight, but in the resting position, lie folded below the tegmina. Movements are due to special muscles attached to wing bases.

(c) Abdomen : The posterior region of body is called abdomen. It is broader than thorax and dorso-ventrally flattened. Abdomen in both males and females consists of 10 segments in adults (while embryo have 11 segments). A typical abdominal segment is enclosed by four sclerites. A dorsal tergum, one ventral sternum and two lateral pleura.

The posterior end of the abdomen bears the following appendages :

(i) Anal cerci : These are paired, jointed outgrowths, which arise from the 10th tergum. The anal cerci are long and thick structures found in both male and female cockroach and are sensitive to sound and other vibrations, ;

(ii) Anal styles : These are also paired but thin, small unjointed outgrowths, which project backwardly from the sides of the 9th sternum of the male cockroach only. They are sensitive to touch.

(iii) Gonapophyses : In both the sexes' the genital aperture is surrounded by some sclerites (i.e., chitinous plates) known as "**Gonapophyses**" or Phallomeres.

The abdomen bears the following apertures

(i) Anus : It lies in the 10th abdominal segment just below the tergum. The waste matter is expelled out through it.

(ii) Genital aperture : In male, it lies below anus between the 10^{th} tergum and 9^{th} sternum. Female genital aperture opens into the genital chamber. In both the sexes, genial is surrounded by gonapophyses.

Anatomy

A. Digestive System

The cockroach has well-developed digestive system comprising the alimentary canal and associated digestive glands.

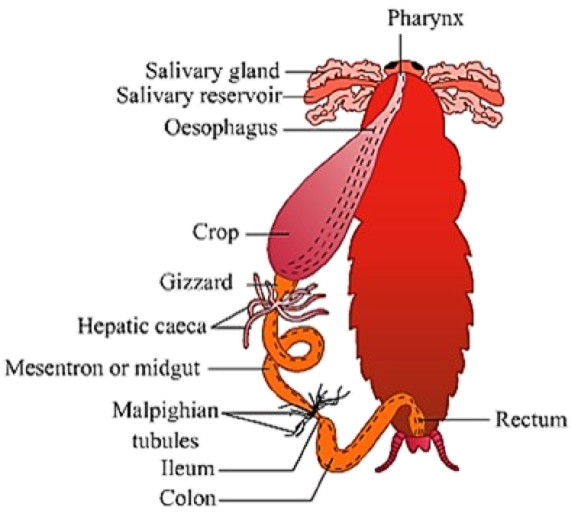


Fig. : Alimentary Canal of Cockroach

Its alimentary canal consists of three parts :

1. Foregut or stomodaeum.
2. Midgut or mesenteron.
3. Hindgut or proctodaeum.

The foregut and the hindgut are formed by ectoderm and are lined by cuticle internally, while the midgut is developed from endoderm of the embryo and is not lined by cuticle.

1. Foregut: It comprises the mouth, pharynx, oesophagus, crop and gizzard.

- **Mouth :** A narrow opening at the base of pre-oral cavity (/.e., space lying in front of the mouth to receive the food) which leads to pharynx and bounded by the mouth parts.
- **Pharynx :** It is short tube-like structure which lies in the head region and leads into the oesophagus.
- **Oesophagus :** It is a tubular thin-walled structure lying in the neck and continues into the crop. There are paired salivary glands lying one on each side of the oesophagus and crop. Their secretion is known as saliva which lubricates food and its digestive enzymes hydrolyse the starchy matter of food.
- **Crop :** The oesophagus dilates to form a large, thin-walled, pear-shaped sac, which extends up to 3rd or 4th abdominal segment. It is largest, part of foregut where, food stored. It opens into the gizzard.
- **Gizzard or Proventriculus :** Crop leads into a small, cone-shaped, muscular and thick-walled chamber called the gizzard or proventriculus. It has an outer layer of thick circular muscles which are needed by the gizzard for grinding. It also bears thick inner layer of cuticle which forms six highly chitinous plates called **teeth** (which are strong and sharp).

- **Midgut :** It is a thin-walled somewhat coiled tube with almost uniform thickness. Main digestion and absorption of food is carried out here from the junction of midgut and gizzard (i.e., foregut) arises six to eight finger-like structures called **hepatic caecae.** They are short, narrow, blindly ending hollow tubes which secrete digestive enzymes into midgut. The junction of midgut and hindgut is marked by the presence of another ring of 100-150 yellow fine thread-like structures, the ‚**Malpighian tubules.** They help in removal of excretory products from hemolymph.
- **Hindgut :** It comprises of ileum colon and rectum. It is broader than midgut. Rectum opens out through anus.

2. **Nutrition :** Cockroach is **omnivorous** animal which usually feeds at night. It searches food by the sweeping of antennae and taste it by maxillary and labial palps, and captures food by the help of forelegs, labrum and labium. In the mouth, food mixes with salivary secretion and is pushed into pharynx with the help of labium. Food now starts moving through alimentary canal by peristalsis. Food is partially digested, in crop. And upon entering gizzard, food is subjected to further mastication by internal teeth worked upon by muscles. In midgut partly digested food is mixed with enzymatic secretions of hepatic caecae and midgut itself. Epithelial cells of midgut are also absorptive, hence also they absorb digested food. Undigested food is passed first into ileum and then into colon. In rectum, water is absorbed from it and faeces is eliminated to outside through anus.

B. Circulatory System

The circulatory system or blood vascular system of cockroach is open **type, i.e.,** the blood does not flow in the vessels or capillaries, but moves through the internal open spaces and comes in direct contact with the body organs. This system comprises the **blood, haemocoel. heart** and **anterior aorta.**

1. **Blood or haemolymph :** The haemolymph of cockroach consists of a clear colourless plasma and numerous different types of cells, called haemocytes. Some haemocytes transfer food material from blood to the tissues while others act as phagocytes in removing the metabolic wastes from tissues. Haemolymph is devoid of a respiratory pigment, and hence does not assist in respiration.
2. **Haemocoel :** The body cavity of the cockroach is filled with blood and that is why it is referred to as a haemocoel. The blood-filled spaces are known as sinuses.
3. **Heart :** It consists of elongated muscular tube lying along mid-dorsal line of thorax and abdomen. The anterior end of the long narrow tube is open while posterior end is closed. It consists of 13 funnel-shaped contractile chambers.
4. **Anterior aorta :** The first chamber of the heart forms a single tubular **anterior aorta** leading into the sinuses (in head region).

❖ At the posterior end of each chamber, a pair of apertures, the ostia, are present laterally. The heart receives blood from the sinuses through ostia. Ostia are guarded by valves to check the flow of blood from the heart to the sinuses.

❖ All the chambers of heart are inter-connected and their openings are guarded by valves. This allows blood to be pumped (flow) anteriorly only.

❖ The blood from heart is pumped into sinuses anteriorly by the contraction and relaxation of fan-shaped paired muscles called “**Alary muscles**”.

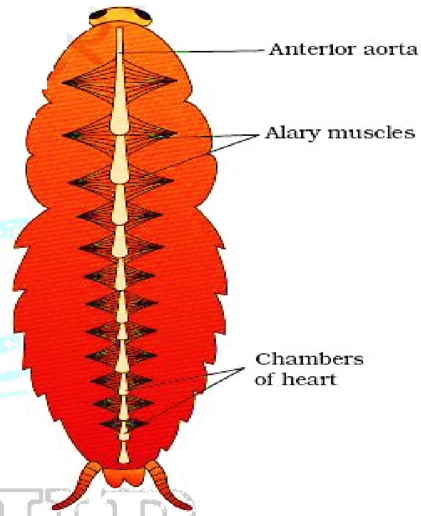


Fig.: P.americana : Heart in dorsal view

C. Respiratory System

The respiratory system of cockroach is more efficient than that of earthworm as there are definite respiratory organs. The atmospheric air directly comes in contact with the various organs of the body and therefore, the blood is not used for respiration. Their respiratory system of **spiracles** and a network of **trachea** and **tracheoles.**

1. **Spiracles :** There are 10 pairs of slit-like openings, called spiracles or stigmata present on the lateral side of the body. They are guarded by bristles or hair to keep out dirt. The opening of spiracles is also regulated by the sphincters. Each spiracle internally leads into a short tracheal chamber from which arises a main tracheal trunk.
2. **A network of trachea and tracheoles :** Haemocoel contains a network of elastic, closed and branching air tubes called tracheae. The trachea is profusely branched and penetrate to all parts of body.

Ultimately, it divides into fine branches known as tracheoles. They terminate in the tissues and contain a tissue fluid at the distal end which plays a significant role during the diffusion of gases.

D. Nervous System

The nervous system of cockroach consists of a series of fused, segmentally arranged ganglia joined by paired longitudinal connectives on the ventral side.

Brain is represented by supra-oesophageal ganglion which is a large bilobed mass located in head above oesophagus. It supplies nerves to antennae and compound eyes. The sub-oesophageal ganglion lies below oesophagus. These ganglions are connected together by paired longitudinal connectives on the ventral side. From sub-oesophageal ganglion, runs posteriorly a double ventral nerve cord along the mid-ventral line of thorax and abdomen. It bears 9 ganglion, 3 in thorax and 6 in abdomen.

The nervous system of cockroach is spread throughout the body. The head holds a bit of nervous system while the rest is situated along the ventral (belly-side) part of its body. So, now you understand that if the head of cockroach is cut-off, it will still live for as long as one week.

E. Sensory Organs :

The sense organs of cockroach are antennae, eyes, maxillary palps, labial palps, anal cerci etc. The most important sense organs in cockroach are a pair of large, sessile, **compound eyes** which are situated at the dorsal surface of the head. These eyes are black and kidney-shaped. Each eye consists of about 2,000 visual elements or units, called ommatidia (singular: ommatidium). They are transparent and more or less hexagonal biconvex areas, capable of forming an image in it.

With the help of ommatidia, a cockroach can receive several images of an object. The image received by them is compound and made up of large number of separate images each of which is contributed by single ommatidium. Thus, the image seen by the whole eyes is made up of many dark and light spots of light, each contributed by one ommatidium. This kind of vision is known as **mosaic vision** with more sensitivity but less resolution, being common during night, hence called **nocturnal vision**. Compound eyes are specially adapted to perceive movements of objects.

F. Reproductive System

Cockroach is **dioecious**, i.e., the sexes are separate. They exhibit sexual dimorphism, i.e., male and female individuals can be distinguished externally. Female cockroach bears broad abdomen, brood or genital pouch, but lacks anal styles, which are present in males.

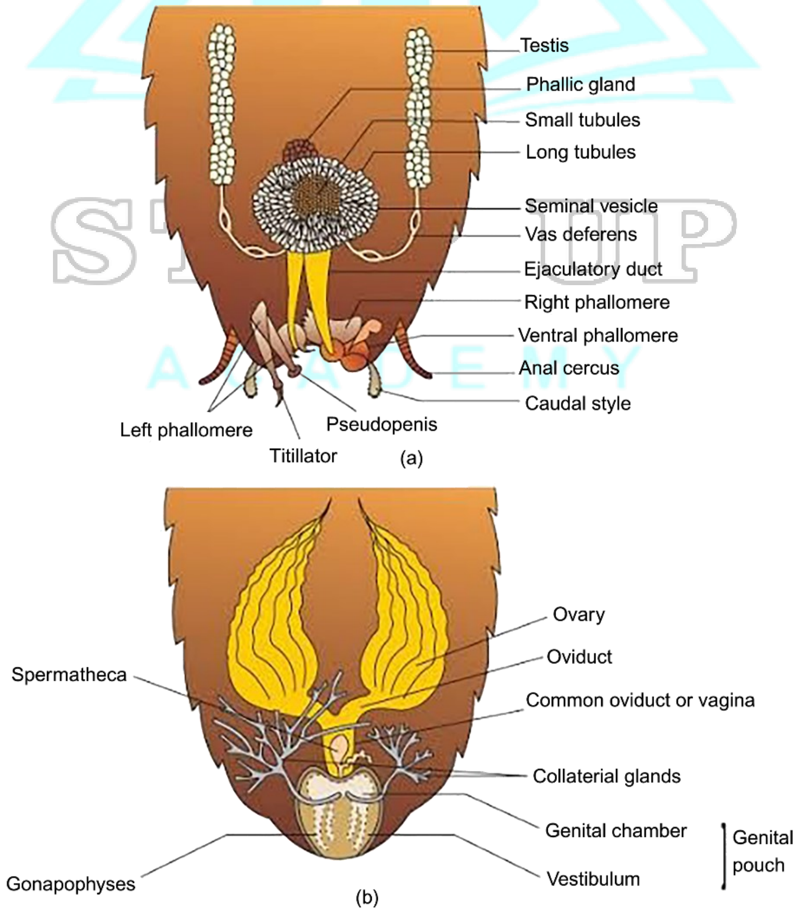


Fig.: Reproductive system of cockroach : A. Male and B. Female

1. **Male reproductive system :** All male reproductive organs are located in abdomen. They include :

(i) **Testis :** Male gonads are a pair of testes, lying one on either dorso-lateral side of 4th to 6th abdominal segments,

(ii) **Vasa deferentia :** The paired vasa deferentia one from each testis, run posteriorly and downwards towards the ejaculatory duct.

(iii) **Ejaculatory duct :** It is a single, median and muscular duct that extends posteriorly and opens into the genital pouch through the male genital pore (male gonopore), lying immediately below anus.

(iv) **Mushroom gland :** The junction of two vasa deferentia and ejaculatory duct is surrounded by an elaborate mushroom gland in 6th to 7th abdominal segments which consist of numerous compact, finger-like blind tubules. Their secretion nourishes the sperms.

(v) **Phallic or conglobate gland:** It is a large club shaped gland present below ejaculatory duct and reaching anteriorly up to 5th abdominal segment. Its narrow duct opens into the genital pouch by the side of male genital pore. Phallic gland secretes the outer layer of spermatophore.

(vi) **Seminal vesicles :** They are present on the ventral surface of anterior part of ejaculatory duct. They are numerous, small glistening white sacs which are meant for storage of sperms. The sperms are stored and glued together in the form of bundles called spermatophore which are discharged during copulation. Spermatophore is thus a pear-shaped capsule containing spermatic fluid with sperms.

(vii) **Genital pouch :** It lies at the hind end of abdomen bounded dorsally by 9th and 10th terga and; ventrally by 9th sternum. It contains the dorsal anus, ventral male genital pore and gonapophyses.

(viii) **External genitalia or gonapophyses :** In the genital pouch, surrounding the male genital pore, are present the gonapophyses which help in copulation. These consist of three small irregular chitinous plates (right, left and ventral) known as **phallomeres.**

2. **Female reproductive system :** All female reproductive organs are confined to abdomen. They include:

(i) **Ovaries :** A pair of yellow-coloured ovaries lie laterally in 2nd to 6th abdominal segments, one on either side of hindgut, and embedded in fat bodies. Each ovary consists of eight elongated, tapering and beaded blind tubes called Ovarian tubules or Ovarioles. Each ovariole contains a linear series of ova in various stages of development.

(ii) **Oviducts and vagina :** Posteriorly, all the ovarioles of an ovary unite to form a short and wide lateral oviduct. The two lateral oviducts in their turn unite in 7th segment to form a very short median common oviduct. Its posterior wider part is called vagina which opens into large genital chamber or pouch by a vertical slit-like female genital pore.

(iii) **Spermatheca :** A pair of spermatheca is present in the 6th segment which opens into the genital chamber. In a fertile female, spermatheca is found filled with spermatozoa, received during copulation from the male.

(iv) **Colleterial gland :** A pair of branched accessory or colleterial glands secrete the hard egg – case or ootheca around groups of fertilized eggs.

(v) **Genital pouch or chamber :** It is located at the hind-end of abdomen. In female cockroach, 7th sternum is large, boat-shaped and along with 8th and 9th sterna forms brood or genital pouch. Genital pouch can be divided into two parts - smaller anterior part containing female gonopore and pores of spermatheca and colleterial glands is termed genital atrium, while its larger posterior part in which ootheca is formed is called vestibulum or oothecal chamber.

(vi) **External genitalia or ovipositor :** There are three pairs of plate-like chitinous, gonapophyses present between female genital pore and anus.

Fertilisation and Development :

Spermatozoa produced by testes get stored in seminal vesicles of male. At the time of copulation, these pass into the ejaculatory duct where they get mixed with a nourishing fluid. During copulation, the spermatophore is deposited into female genital pouch, A spermatophore consists of a central chamber which contains spermatozoa in a spermatic fluid. Eggs from each ovariole usually descend into genital pouch, where they be- come fertilized by sperms ejected simultaneously from sperm theca.

Fertilized eggs become surrounded by the secretion of collateral glands, which hardens to form an egg case or ootheca. 14-16 eggs are arranged in two rows in one ootheca. On an average, about 9-10 ootheca are laid by the female cockroach. An ootheca is about 3/8" (8 mm) long. It is a dark reddish to blackish brown capsule the female cockroach carries the ootheca, protruding from tip of her abdomen, for several days, till it is deposited or dropped or glued to a suitable surface, usually in a crack or cervices of high relative humidity near a food resource. Each egg inside ootheca undergoes cleavage and finally results in the formation of nymphs. Freshly hatched nymphs are delicate, transparent and almost colourless with black eyes. The possess nearly all adult characters but differ in size and colouration, in being sexually immature and do not bear wings. The next to last nymphal stage has wing pads but only adult cockroaches have wings.

FROG

Frogs in general are found in or near fresh water and in very damp places on land.

They belong to class Amphibia of phylum Chordata and kingdom Animalia.

The most common species of frog in India is Rana tigrina.

Habits :

(a) Locomotion : It moves in two ways; by leaping or walking on land and by swimming in water. A frog may leap a distance of 1.5 to 2 meters in a single jump. On landing back, the forelimbs act like shock absorbers. The frog swims in water by powerful thrusts of its hindlimbs which act like propellers.

(b) Feeding : Adult frogs are carnivorous and their food consists mainly of living insects, worms, molluscs and tadpoles which are caught by a sudden flip of its large protrusible sticky tongue attached at the front end and free behind.

(c) Croaking : The characteristic noise or sound made by frogs is known as croaking. It is commonly heard in breeding season during rains.

(d) Hibernation and Aestivation : Frog is a cold-blooded or poikilothermous animal, /.e., the temperature of its body fluctuates with that of the environment. During adverse environmental conditions in cold winter or dry hot summer days, frogs are not seen. As they get burry in the soft damp bottom mud (i.e., deep burrow inside grounds) for protection. They become metabolically inactive and stop feeding, living only on the glycogen and fat stored in their bodies. Lung respiration is suspended and cutaneous respiration through damp skin alone is sufficient. This state of dormancy is called **hibernation** or "**winter sleep**" during winter and "**aestivation**" or "**summer sleep**" in summer. With the end of cold winter or hot summer season, the frogs come out to lead a normal active life once again.

(e) Mimicry : The ability of an organism to imitate others either by sound or appearance or to merge with their environment for protective purposes is known as mimicry. Frogs exhibit this property. As they are capable of changing their skin colour, though gradually with the change in its surroundings and climatic conditions. This colour change, i.e., protective coloration also known as camouflage enables them to resemble their surroundings, in order to hide themselves from enemies.

(f) Sexual dimorphism : Frogs exhibit sexual dimorphism, i.e., there are some differences in external features by which male and female can be distinguished. Males are generally smaller and darker in colour than females. Males croak loudly as they have vocal sacs which are absent in females. Males have swollen copulatory pads on inner fingers of forelimbs which are especially developed in breeding season for grasping the female during mating.

Morphology

- The body is dorsoventrally compressed and somewhat ovoid in shape having almost triangular head.
- The colour of frog's dorsal side of body is generally olive green with dark irregular spots. On the ventral side, the skin is uniformly pale yellow.
- The skin is thin, moist, slimy and smooth due to the presence of mucus. Mucus glands help them to maintain their skin in moist condition.
- The frogs never drink water through their mouths, but instead they absorb water through their skin.
- Body of a frog is divisible into head and trunk.
- A neck and tail are absent in mature frog

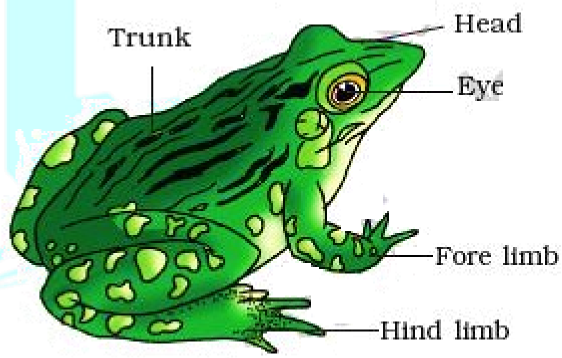


Fig.: Rana tigrina. External features of frog

Head :

- Head is flat, roughly triangular in outline and with a short blunt anterior snout terminating in a wide transverse mouth.
- Two small openings, the external nares or external nostrils, lie dorsally above the mouth, at the tip of snout and serve in respiration.
- Two very large, spherical and protruding eyes are situated dorsolaterally on top of head.
- Each eye has a thick, pigmented and almost immovable upper eyelid and a thin semi-transparent and freely movable lower eyelid.
- From the lower eyelid arises a transparent third eyelid or nictitating membrane, which covers and protects the eye during swimming and keep it moist in air.
- Behind and below each eye is a conspicuous, flat and deeply pigmented circular patch of skin, the eardrum or tympanum, that receives sound waves.

Trunk :

- Head is broadly joined behind with the flat ovoid trunk.
- The trunk bears two pairs of limbs, i.e., forelimbs and hindlimbs which help in swimming, walking, leaping and burrowing.

Forelimbs :

(i) They arise anteriorly from trunk just behind the head.

(ii) Each forelimb consists of the upper arm, forearm, wrist and hand bearing four digits without web.

(iii) Thumb is absent.

(iv) In male frog, the base of first inner finger (index finger) is thickened especially in breeding season forming the copulatory pad or nuptial pad for clasping the female.

Hindlimbs :

(i) They are much elongated and powerful, arise close together posteriorly from trunk.

(ii) Hindlimbs are larger and muscular than forelimbs.

(iii) The hindlimbs end in five digits which are connected by broad thin webs of skin which assist in swimming.

Anatomy

The large body cavity contains most of the internal organs which constitute different organs systems such as digestive, circulatory, respiratory, nervous, excretory and reproductive systems. All these organ systems are well-developed in frogs.

A. Digestive System

- It consists of alimentary canal and digestive glands.
- The alimentary canal is short because frogs are carnivores, and hence the length of intestine is reduced but it is complete, i.e., from mouth to cloaca.
- It is a long-coiled tube extending between mouth and cloaca. It consists of the following parts :

(i) Mouth : Mouth is a wide anterior-most opening leading to a spacious buccal cavity that leads to the oesophagus through pharynx.

(ii) Oesophagus : Because of the absence of neck in frog, the oesophagus is only a short tube that leads to the stomach.

(iii) Stomach : It lies on the left side in the body cavity. Its large broad anterior part is called cardiac stomach, while short narrow posterior part, the pyloric stomach. It also contains multicellular gastric glands which secrete the enzyme pepsinogen and unicellular oxyntic glands which secrete hydrochloric acid. Its posterior end opens into small intestine.

(iv) Intestine : It is the longest part of the alimentary canal and is divisible into :

Duodenum : It receives bile from gall bladder and pancreatic juice from the pancreas through a: common bile duct (i.e., hepatopancreatic duct).

lleum : The internal lining of the ileum is also thrown into a large number of finger-like branched projections known as villi which increase the absorptive surface area.

Rectum : The ileum leads into a broad, thin-walled, short but wider tube, known as rectum or large intestine. It opens outside by the cloaca.

(v) Digestive glands :

Liver : It is a reddish-brown, multilobed gland located close to the heart and lungs. Liver secretes a greenish alkaline fluid, the bile. The bile is transferred to the gall bladder for storage.

Pancreas : It is a branched flat elongated pale-yellow gland. It secretes pancreatic juice containing several digestive enzymes.

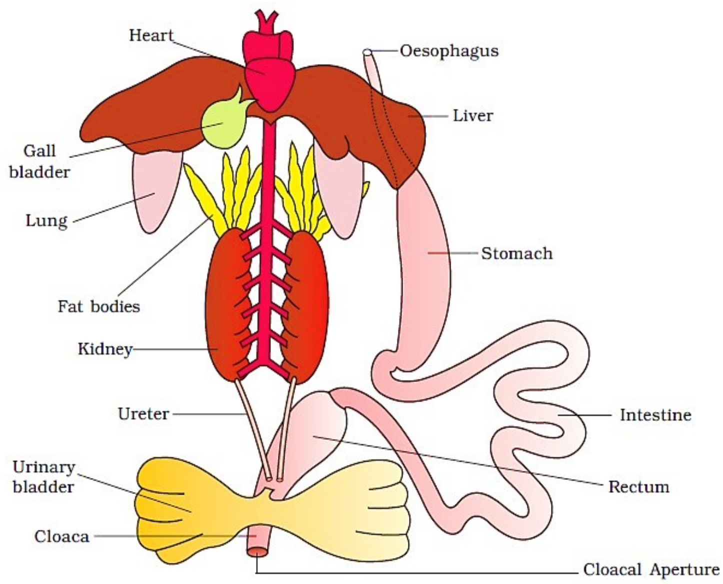


Fig.: Diagrammatic representation of internal organs of frog showing complete digestive system

Process of Digestion :

Frog feeds on insects, worms, molluscs etc. The prey is captured by rapid-flicking action of prehensile and bilobed tongue and swallowed whole. It passes down the oesophagus to reach stomach. Here the digestion of food takes place by the action of HCI and gastric juices secreted from walls of the stomach The liquefied semidigested acidic food is called chyme which passes down from stomach to the duodenum of small intestine. In duodenum, chyme is mixed with bile and pancreatic juices for further digestion to take place Bile neutralises the acidity of chyme and emulsifies fat. Pancreatic juices contain various type of enzymes to digest carbohydrates and proteins. The digestion is completed in the intestine only. This completely digested food is absorbed by numerous finger-like folds in the inner wall of intestine (i.e., ileum) The undigested solid waste moves into the rectum (where water reabsorption occurs) and finally it passes out through cloaca.

B. Respiratory System

Being amphibious in nature, the frog can utilise free oxygen and also oxygen dissolved in water. The adult frog, respires on land and in the water by following ways. These are :

1. **Cutaneous respiration :** The skin of frog provides an extensive surface for exchange of gases. It is thin richly supplied with blood and kept moist by the mucus and water. The cutaneous respiration is always, carried out. It is practically the only mode of respiration when the frog is under water. Dissolved oxygen in the water is exchanged through the moist surface of the skin by diffusion. During hibernation and aestivation, gaseous exchange takes place through skin.
2. **Pulmonary respiration :** On land, the buccal cavity, skin and lungs all act as the respiratory organs, breathing on land in atmospheric air with the help of lungs is called pulmonary respiration. It involves lungs and respiratory tract. The lungs are a pair of elongated, thin-walled, elastic, pink-coloured sacs present in the upper part of trunk region, i.e., thorax. The inner surface of each lung is divided by a series of partitions, the septa into many small cavities known as alveoli. Air enters through the nostrils into the buccal cavity and then into lungs.
3. **Buccal respiration :** On land, the frog fills its bucco-pharyngeal cavity with air through nostrils. Gaseous exchange occurs through the lining of buccal cavity and then expelled out.

C. Blood Vascular System

Blood vascular or circulatory system of frog is well-developed and closed type. It includes heart arterial system, venous system and blood. Frogs also have a lymphatic system. Its chief function is to transport all necessary liquid and gaseous materials to the living tissues of body and 9aseous wastes of metabolism to organs of elimination.

Heart :

- Heart is a muscular structure which lies mid-ventrally inside the anterior trunk region.
- It is enclosed within a thin, transparent, two-layered sac called the pericardium. It protects heart from friction or mechanical shocks.
- Heart is a three-chambered structure in frog, made of two anterior atria (right and left) and a single posterior ventricle.
- The heart of frog has two additional chambers - sinus venosus and truncus arteriosus (= conus artiosum).
- Sinus venosus is a thin-walled, triangular chamber attached dorsally to heart. It opens into the right larger atrium through an aperture.
- Truncus arteriosus arises anteriorly from the ventral side of ventricle. It is a tubular chamber present on the ventral side of heart. The opening of ventricle into truncus arteriosus is guarded by three semilunar valves which prevent backflow of blood from truncus into ventricle.

Blood Circulation: The right atrium receives deoxygenated blood through sinus venosus which in turn receives blood from the major veins called vena cava, while the left atrium receives oxygenated blood from pulmonary veins. Both right and left atrium pump blood into single ventricle which opens into truncus arteriosus the circulation of blood is achieved by the pumping action of heart. Various chambers of heart are separated by valves to keep the blood flowing in one direction.

- **Arterial system :** Arteries carry blood away from the heart. The arterial system in frog begins with the truncus arteriosus (= conus arteriosus). The truncus divides into left and right branches each of which sub-divides into vessels.
- **Venous system :** It includes veins or those blood vessels which carry the blood to the heart in frog it can be studied in four parts :

(i) Pulmonary veins : They collect oxygenated blood from two lungs and open directly into left auricle.

(ii) Vena cava : They carry deoxygenated blood from the body parts towards heart.

(iii) Renal portal vein : Renal portal vein carrying deoxygenated blood from lower part of body like hindlimbs, gonads etc., enters kidney. The blood from hind parts of the body containing urea and uric acid are first filtered in the kidneys before the blood goes to the heart. Thus, the blood going to the heart contains comparatively less impurities.

(iv) Hepatic portal vein : A large hepatic portal vein is formed by the confluence of several branches from stomach, intestine, spleen and pancreas. It carries blood of alimentary canal and its glands laden with digested foodstuffs, to the liver into which it breaks up into capillaries.

- **Blood :** Blood carries nutrients, gases and water to the respective sites in the body Hence it is the chief circulatory fluid of the body . It contains a clear liquid, called plasma, in which are suspended various types of free cells, called blood corpuscles.

(i) Plasma : It is largely water (90) in which are dissolved mineral salts, absorbed foods (sugars proteins), excretory wastes (urea), and other soluble substances.

(ii) Corpuscles : Three types of blood corpuscles are present in the plasma, viz., erythrocytes or RBCs (red blood corpuscles), leucocytes or WBCs (white blood corpuscles) and thrombocytes (spindle cells) or platelets.

RBCs are **nucleated**, oval and **biconvex** and have haemoglobin (respiratory pigment) which is yellowy to red colour, iron-containing protein. WBCs are amoeboid shaped and are protective in function Thrombocytes or platelets are spindle-shaped and help in blood clotting.

Lymphatic System : Lymph flows through the lymphatic system. Lymph is different from blood It is without KBCs and contains few proteins. It is colourless. Lymph is constantly produced from filtering of blood through1capillaries into intercellular spaces. Frog also has two pairs of lymph hearts which pump lymph.

D. Excretory System

- Frogs have well-developed excretory system which helps in elimination of nitrogenous wastes from its body.
- Frog is ureotelic as it excretes predominantly urea along with water.
- Excretory system consists of :
  (1) A pair of kidneys
  (2) Ureters
  (3) Urinary bladder
  (4) Cloaca

(1) A pair of kidneys : The two mesonephric kidneys, situated one on either side of the vertebral column in the posterior part of the body cavity. The kidneys are chief excretory organs which are oval, dorsoventrally flattened, dark, red and bean-like structures. Each kidney is a compact mass of innumerable (about 2000) highly twisted microscopic uriniferous tubules or nephrons and blood vessels embedded in connective tissue. These nephrons are the structural and functional units of kidney.

(2) Ureters : From posterior outer margin of each kidney leaves a urinary duct also called ureter. It is a fine, white tube extends backward to open into the dorsal wall of cloaca. In male frog, the ureters are called urinogenital ducts since they pass out sperms as well as urine.

(3) Urinary bladder: A large transparent, bilobed, thin-walled elastic, urinary bladder opens into the ventral wall of cloaca.

(4) Cloaca : It is a small median chamber into which open the anus, urinogenital apertures and urinary bladder. It receives faecal, genital products and urine.

Process of Excretion

Frog is ureotelic, it excretes urea along with water. Blood is filtered by nephrons in kidneys. All the wastes is filtered out and useful substances are reabsorbed into blood. The remaining fluid forms urine which is carried out of kidney by collecting vessels into ureter and passes down into cloaca. It is either stored temporarily in urinary bladder or eliminated through cloacal aperture.

Control and Coordination in Frogs :

- The system for control and coordination is highly evolved in the frogs.
- It includes both neural system and endocrine glands.

E. Endocrine system

The chemical coordination of various organs of the body is achieved by hormones which are secreted by the endocrine glands. The prominent endocrine glands found in frog are pituitary, thyroid, parathyroid, thymus, pineal body, pancreatic islets, adrenals and gonads.

F. Nervous System

The nervous system of frog is well-developed and is represented by :

1. Central nervous system comprising brain and spinal cord.
2. Peripheral nervous system including cranial and spinal nerves.
3. Autonomic nervous system comprises sympathetic and parasympathetic nervous system.

1. Central nervous system :

(i) Brain : It is enclosed in the cranial cavity of the skull called brain box. The brain is divisible into three parts:

(a) Forebrain : It comprises two olfactory lobes, two cerebral hemispheres and unpaired diencephalon.

(b) Mid-brain : It consists of optic lobes and crura cerebri (thick bands of nerve fibres which carry the stimuli between the cerebral hemispheres and medulla oblongata).

(c) Hind brain : The posterior part of brain includes cerebellum and medulla oblongata.

(ii) Spinal cord : The spinal cord extends posteriorly from medulla oblongata through foramen magnum and lies protected within neural canal of its vertebral column. It is short, thick, cylindrical, somewhat flattened and white in colour. It is mainly concerned with the reflex actions.

2. Peripheral nervous system :

(i) Cranial nerves : There are 10 pairs of cranial nerves which originate from brain of frog.

(ii) Spinal nerves : Frog has 10 pairs of spinal nerves. Every spinal nerve on either side arises from spinal cord.

3. Autonomic nervous system : It is a system of nerve fibers and ganglia which controls and coordinates the involuntary activities of the visceral organs, such as secretion of digestive fluid, action of heart etc.

Sense Organs

- Sense organs receive stimuli (i.e., changes in the environment) from outside or inside of the animals and pass impulses to the nervous system.
- Frog has five types of sense organs. They are :

(1) **Organs of touch (known as tango receptors) :** These are cellular aggregates around nerve endings, found in the skin as sensory papillae.

(2) Organs of smell (known as olfactory receptors) : They are also cellular aggregates found in the nasal epithelium of the nasal chambers.

(3) **Organs of taste (known as gustatory receptors) :** These are found as taste buds which are present in the epithelium of the tongue.

(4) **Eyes** are organs of sight.

(5) **Ears** are organs of hearing and balancing.

Out of these, eyes and internal ears are well-organized. They are described below :

(a) Eye : There are two large simple eyes. Each eyeball is roughly spherical and lodged inside an orbit in the dorso-lateral side of head protected by eyelids. A nictating membrane is present over the eyes which protects them inside water and also enables frog to see under water.

(b) Ear: A pair of ears are attached to skull, posterior-laterally in all vertebrates. They are statoacoustic organs as they help in both hearing and balancing of body. An ear of frog mainly consists of two parts - middle and internal ear. External ear is represented by tympanum.

G. Reproductive System

Frogs have well-organised male and female reproductive systems.

1. Male Reproductive System

It consists of two testes (attached to kidneys), several vasa efferentia and two urinogenital duct (copulatory organs are lacking).

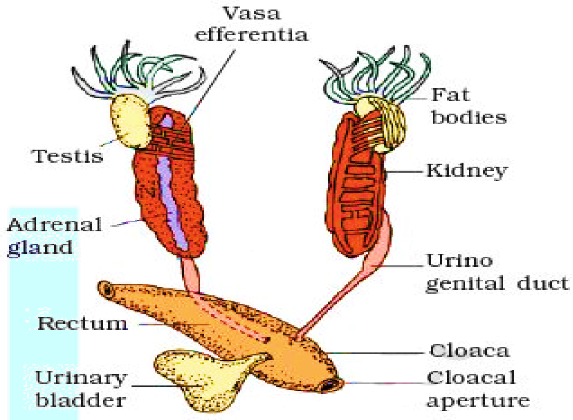


Fig. : Male reproductive system

(i) Testes : It is an elongated or ovoid light-yellow body, attached to upper part of kidney by a double fold of peritoneum, called **"mesorchium".** Each testis is a compact mass of much coiled seminiferous tubules, the epithelial lining of which produces spermatozoa.

(ii) Vasa efferentia : There are 10-12 very fine tubes connecting the testes to kidneys on each side. The vasa efferentia run transversely through the mesorchium enter the kidneys and cloaca open into the Bidder's canal. The sperm produced by testes are passed into Bidder's canal via vasa efferentia and then carried finally to the urinogenital duct.

(iii) Urinogenital duct: Duct arising from kidney in male frog is both a urinary duct and a sperm duct hence it is called a urinogenital duct. Each urinogenital duct runs posteriorly, and opens into cloaca. Cloaca is a common chamber which receives faecal matter, urine and sperms. All these are passed out through cloacal aperture.

2. Female Reproductive System

It comprises the following parts :

(i) A pair of ovaries : The ovaries are irregular-shaped, lobulated structures, situated near kidneys. They have no functional or internal connections with kidneys. Each ovary contains innumerable dark round ova in different stages of development. When ripe, the ova are shed into the body cavity from where they moved into the oviducts.

(ii) Oviducts : These are paired, white, glandular, long, coiled tubes lying one on either side of the body cavity. The posterior ends of oviducts are broad called ovisacs which open dorsally into cloaca. Eggs are temporarily stored in ovisacs. A mature female frog can lay 2500 to 3000 ova at a time.

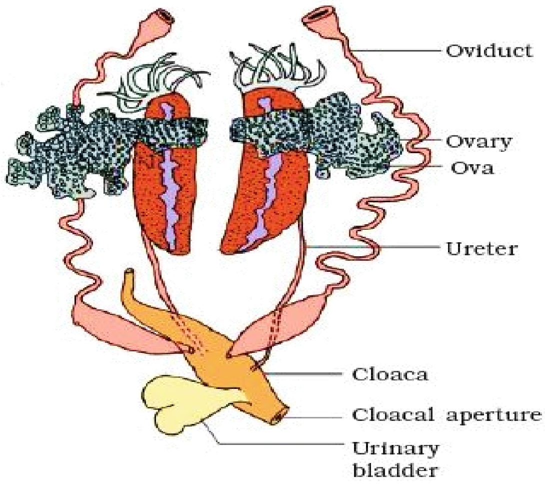


Fig.: Female reproductive system

Fertilization : With the onset of rainy season, frogs emerge out of aestivation and immediately start breeding. Male gather in shallow waters and starts croaking to attract females for mating. The male mounts upon the back of female and grasps her firmly with the help of copulatory pads. It is called **Amplexus**. Then, female deposits several hundred **(2500 to 3000)** ova or eggs through her cloaca at a time into water. The male discharges sperms over these eggs in order to fertilize them. So, **fertilization is external**. After this, male releases grip and leaves the female. Mass of eggs is embedded in a gelatinous material which on contact with water swells into a protective transparent jelly.

Development and Metamorphosis : Development is indirect. Within two weeks fertilized eggs or zygote develop into free-swimming aquatic larvae called **tadpoles**. It is small, fish-like creature which hatches out from the egg after completing the development. The tadpole swims freely in the water feeding on planktonic food, i.e., **herbivorous**. Initially, the tadpole have external gills which become replaced by internal gills later after metamorphosis. Limbs appear gradually and tail shortens. Along with these changes, a few other significant changes, like quick growth and movement of the eyes to higher up the skull and formation of eyelids, formation of skin glands, thickening of the skin and development of an eardrum to lock the middle ear take place. These changes transform the tadpoles into a young adult frogs. These changes together constitute metamorphosis. The disappearance of the tail is somewhat later (occurs at higher thyroxine level) and after the tail has been reabsorbed the animals are ready to leave the water).

After metamorphosis, young adults may leave the water and disperse into terrestrial habitats, or continue to live in the aquatic habitat as adults.

Importance to Mankind

Frog is useful animal for human being because it eats up insects which are harmful for the crops. Thus, it saves expenditure on insecticides. Frogs eat mosquitoes which can act as vectors for disease-causing parasites (e.g., malarial parasite) to man. Frogs help to maintain ecological balance in nature as they serve as an important link in food chain and food web. The muscles of the legs are used as food by man in some parts of India and many other countries. Frogs has been used as an experimental material for teaching and researches.

Chapter 8
Cell The Unit of Life

WHAT IS CELL?

Cell is the **fundamental structural** and **functional unit** of all living organisms.

Robert Hook studied and discovered the cell from a thin slice of cork but that was the 'dead cell'. **Anton Von Leeuwenhoek** was the first person who observed few **living cells** capable of moving, such as bacteria, protozoa, spermatozoa and red blood corpuscles under his own designed microscope. Later, **Robert Brown** discovered the nucleus of a cell. The invention of the microscope and its improvement leading to the electron microscope revealed all the structural details of the cell.

CELL THEORY

In 1838, **Matthias Schleiden,** a German botanist studied a large number of plants and observed that all plants are composed of different kinds of cells which form the tissues of the plant. At about the same time, another scientist. **Theodore Schwann** (1839), a British zoologist, studied different types of animal cells and reported that cells had a thin outer layer which is now known as the **'Plasma membrane'.** He also concluded, based on his studies on plant tissues, that the presence of cell wall is a unique character of the plant cells. On the basis of this, he proposed a .hypothesis that the bodies of plants and animals are composed of cells and their products. **Schleiden** and **Schwann** together formulated the **cell theory.** This theory however, did not explain as to how new cells were formed. **Rudolf Virchow** (1855) first explained that cells divided and new cells are formed from pre-existing cell (**Omnis cellula-e cellula).** He modified the hypothesis of Schleiden and Schwann to give theory a final shape.

Cell theory is understood as

(i) All living organisms are composed of cells and products of cells. ,

(ii) All cells arise from pre-existing cells.

(iii) Activities of an organism are the outcome of sum total of activities and interactions of its constituent cells.

You have earlier observed cells in an onion peel or human cheek cells under the microscope.

Cell That have membrane bound nuclei are called **eukaryotic** whereas cells that lack a membrane-bound nucleus are **prokaryotic.** In both prokaryotic and eukaryotic cells, semi-fluid matrix called cytoplasm occupies the volume of the cell. **The cytoplasm is the main arena of cellular activities** in both the plant and animal cells.

Besides nucleus, the eukaryotic cells have other membrane-bound distinct structures called **organelles** like the endoplasmic reticulum (ER), the Golgi complex, lysosomes, mitochondria, microbodies and vacuoles. The prokaryotic cells lack such membrane-bound organelles.

Ribosomes are non-membrane bound organelles found in all cells - both eukaryotic as well as prokaryotic. Within the cell, ribosomes are found not only in the cytoplasm but also within the two organelles - chloroplasts (in plants) and mitochondria and on rough ER. Animal. Cells contain another non-.membrane bound organelle called **centriole** which helps in cell division.

Mycoplasma, the smallest cell, are only 0.3 p-m in length largest isolated single cell is the egg of an **ostrich**.

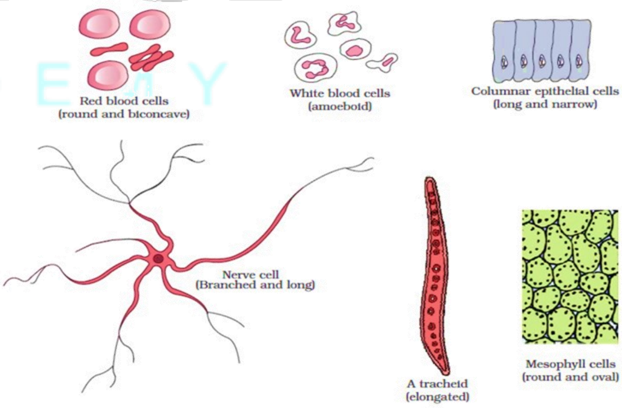


Fig. Diagram showing different shapes of the cells

PROKARYOTIC CELLS

The prokaryotic cells are represented by **bacteria, blue-green algae, Mycoplasma and PPLO** (Pleuro pneumonia- like organisms). They are generally smaller in size and multiply much faster than the eukaryotic cells.

They may vary greatly in shape and size but exhibit a similar basic cellular organisation.

The organisation of the prokaryotic cell is fundamentally similar even though prokaryotes exhibit a wide variety of shapes and functions. Most prokaryotic have a cell wall surrounding the cell membrane. The fluid matrix filling the cell is the cytoplasm. There is no well-defined nucleus. The genetic material is basically naked, not enveloped by a nuclear membrane. In addition to the genomic DNA (the single chromosome/circular DNA), many bacteria have small circular DNA outside the genomic DNA. These smaller DNA are called plasmids. The plasmid DNA confers certain unique phenotypic characters to such bacteria. One such character is resistance to antibiotics. The plasmid DNA is used to monitor bacterial transformation with foreign DNA. No organelles, like the ones in eukaryotes, are found in prokaryotic cells except for ribosomes.

Cell Envelope and its Modifications

Most prokaryotic cells, particularly the bacterial cells, have a chemically complex cell envelope. The cell envelope consists of a tightly bound three-layered structure i.e., the outermost **glycocalyx** followed by **the cell wall** and the **plasma membrane.**

Glycocalyx is the outermost layer comprising a coating of mucous or polysaccharides macromolecules, which protects the cells and also helps in adhesion. This layer differs in thickness and chemical composition in different bacteria. Some have a loose sheath called **slime layer,** which protects the cell from loss of water and nutrients. Others may have a thick and tough covering known as **capsule.** The capsule is responsible for giving gummy and sticky character to the cell. **It allows bacterium to hide from host's immune system.** The **cell wall** determines the shape of the cell and provides a strong structural support to prevent the bacterium from bursting or collapsing. This layer is rigid due to a special macromolecule called **peptidoglycan** (murein or mucopeptide). A number of antibiotics (e.g., penicillin) inhibits cross linking of peptidoglycan strands. Therefore, cells undergo lysis in the presence of these antibiotics.

Gram staining (developed by **Christian Gram)** a special technique, which is used to classify bacteria into two groups, viz. Gram-positive and Gram-negative bacteria. Those bacteria that take up the Gram stain are **Gram positive** and the others that do not are called Gram negative bacteria.

The plasma membrane is semi permeable in nature and interacts with the outside world. This membrane is similar structurally to that of the eukaryotes. A special membranous structure is the **mesosome** which is formed by the invagination of plasma membrane into the cell. These extensions are in the form of **vesicles, tubules** and lamellae. They help in the **cell wall formation, DNA replication and distribution to daughter cells.** They also help in respiration, secretion process, to increase the surface area of the plasma membrane and enzymatic content. **Mesosome is found in gram positive bacteria**. In some photosynthetic prokaryotes like cyanobacteria, and purple bacteria there are other membranous extensions into the cytoplasm called **chromatophores** which contain pigments.

Bacterial cells may be motile or non-motile. If motile, they have thin filamentous extensions from their cell wall called **flagella**. Bacteria show a range in the number and arrangement of flagella. The flagellum is composed of three parts – **filaments, hook and basal body**. The filament is the longest portion and extends from the cell surface to the outside. It is a hollow rigid cylindrical structure made up of the protein called **flagellin**. Basal body is a rod-like structure which consists of rings.

Besides flagella, **pili and fimbriae** are also surface structures of the bacteria but do not play a role in motility. The pili have been reported only in Gram-negative bacteria so far and in these forms, they are involved in mating process. During this process, usually partial transfer of DNA from one cell (donor cell) to another cell (recipient cell) takes place. Formation of pili is generally controlled and is specific for a cell type as conjugation takes place between compatible bacterial cells. The fimbriae are small bristle-like fibres sprouting out of the cell. These seem to be slender tubes composed of helically arranged protein subunits, which are 3-10 nm in diameter. In some bacteria, they are known to help in attaching the bacteria to rocks in streams and also to the host. tissues.

Ribosomes and Inclusions Bodies

In prokaryotes, ribosomes are associated with the plasma membrane of the cell. They are made up of two subunits - 50 S and 30 S units when present together form 70 S. prokaryotic prokaryotic ribosomes are the site of protein synthesis. Cytoplasmic ribosomes synthesizes proteins, which remain within cells but the ribosomes on the plasma membrane make proteins that are transported out. Several ribosomes may attach to a single mRNA and form a chain called **polyribosomes or polysome.** The ribosomes of a polysome translate the mRNA into proteins.

Inclusion bodies : Reserve material in prokaryotic cells are stored in the cytoplasm in the form of inclusion bodies. These are not bounded by any membrane system and lie free in the cytoplasm, e.g., phosphate granules cyanophycean granules and glycogen granules. Some other bodies may be surrounded by a single layer non unit membrane, which is 2-4 thick, e.g., poly β-hydroxybutyrate granules, Sulphur granules and gas vacuole. Gas vacuoles are found in blue-green algae, purple and green photosynthetic bacteria.

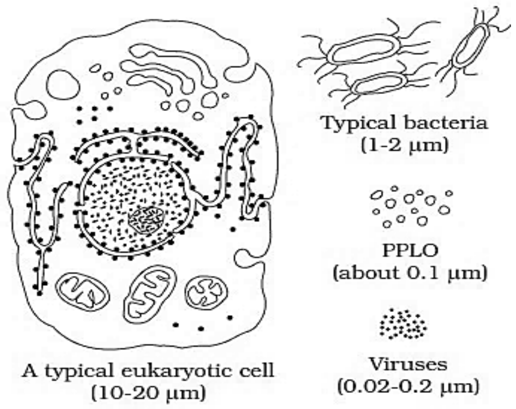


Fig. : Diagram showing comparison of eukaryotic cell with other organisms.

EUKARYOTIC CELLS

Eukaryotic cells are those cells which possess an organised nucleus with a nuclear envelope. Some of the important characteristics of eukaryotic cells are cytoskeletal structure, membrane-bound organelles and organisation of genetic material into chromosomes. These cells occur in protista, fungi, plants and animals. A eukaryotic cell like a prokaryotic cell is covered by a cell envelope. The cell envelope is formed of only plasma membrane in animal cells. It consists of plasma membrane and cell wall in plant cell, fungal cells and some protists. All eukaryotic cells are not identical due to many differences.

Table : Difference between Prokaryotic and Eukaryotic cell

Prokaryotic Cell		Eukaryotic Cell	
1.	The cell size is usually small.	1.	The cell size is comparatively larger.
2.	Nuclear region is poorly defined due to absence of nuclear envelope. Nucleoid (genetic material is in direct contact with the cytoplasm.	2.	Distinct nucleus is present. Nuclear material is surrounded by a nuclear membrane and is not in direct contact with cytoplasm.
3.	Nucleoid is equivalent to a single chromo-some or prochromosome. Hence the amount of DNA is comparatively low.	3.	Nucleus contains more than one chromosome Hence; the amount of DNA is comparatively very high.
4.	Nucleolus is absent.	4.	Nucleolus is present.
5.	Protein synthesis occurs only in cytoplasm.	5.	Protein synthesis takes place in cytoplasm, mitochondria and plastids.
6.	Membrane-bound organelles are absent.	6.	Membrane-bound organelles are present. (e.g., mitochondria, plastids, endoplasmic reticulum, Golgi apparatus, lysosomes etc.)
7.	Ribosomes are of 70S type.	7.	Ribosomes are of 808 type: 70S type ribosome occurs in mitochondria and plastids.
8.	Centrioles (centrosome, central apparatus) are absent.	8.	Centrioles are usually present.
9.	True sap vacuoles are usually absent. Instead gas vacuoles may be found.	9.	True or sap vacuoles are commonly found, e.g., plant cells.
10.	Thylakoids, if present, lie freely in cytoplasm.	10.	Thylakoids, if present are grouped inside chloroplast as granum.
11.	Additional small circular DNA segment or plasmids may occur.	11.	Plasmids are absent.
12.	Having single envelope system.	12.	Having double/two envelope system.

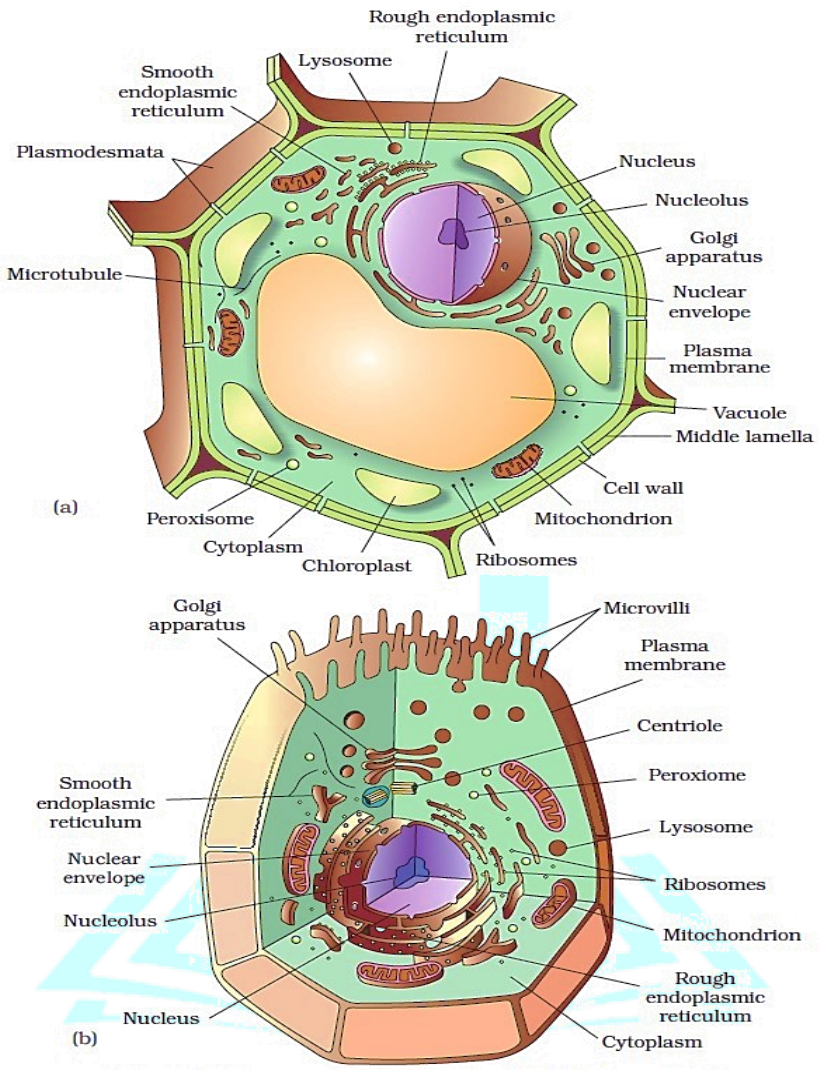


Figure 8.3 Diagram showing : (a) Plant cell (b) Animal cell

Table : Differences between Plant cell and Animal cell

Plant cell	Animal cell
1. Plant cells are generally larger than animal cells.	**1.** Animal cells are generally small in size.
2. Plasma membrane of plant cells is surrounded by a rigid cell wall made up of cellulose.	**2.** Cell wall is absent. The outermost covering of the animal cell is plasma membrane.
3. Plastids are present.	**3.** Plastids are absent.
4. Most mature plant cells have a permanent and large central sap vacuole.	**4.** Vacuoles in animal cells are many, small and temporary.
5. Plant cells have many simpler units of Golgi apparatus, called dictyosomes.	**5.** Animal cells have a single highly complex and prominent Golgi apparatus.
6. Almost all plant cells lack centrosome and centrioles.	**6.** Animal cells have centrosome and centrioles.

Plasma Membrane or Cell Membrane

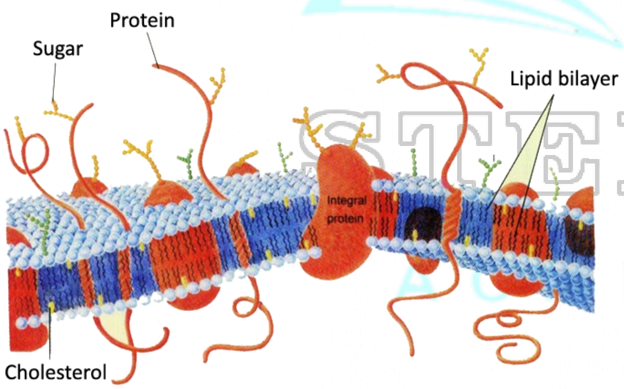
Plasma membrane is an absolute requirement for all living organisms as it is responsible for the relationship of a cell with the outside world. The detailed structure of the membrane was studied only after the invention of electron microscope in the 1950, Meanwhile, chemical studies on the cell membrane enabled the scientists to deduce the possible structure of the plasma membrane. The chemical studies done especially on the human red blood cells (RBCs), enabled the scientists to deduce the possible structure of plasma membrane.

On the basis of these studies, scientists found that the cell membrane is composed of lipids that are arranged in a bilayer. These lipids are arranged within the membrane with the polar head towards the outer sides and the hydrophobic (non-polar) tails towards the inner sides. The polar ends (head) interact with water and are called hydrophilic. This ensures that the non-polar tail of saturated hydrocarbons or hydrophobic tail is protected from the aqueous environment.

Later, biochemical investigation clearly revealed that the cell membranes also possess protein and carbohydrate. The ratio of protein and lipid varies considerably in different cell types. **In human beings, the membrane of the erythrocyte (RBC) has approximately 52 percent protein and 40 percent lipids.**

Depending on the ease of extraction, membrane proteins can be classified as integral or peripheral. The peripheral proteins lie on the surface of the membrane while the integral proteins are partially or totally buried in the membrane. The **integral proteins** which run throughout lipid bilayer are known **as tunnel proteins** (Trans membrane proteins). These proteins cannot be removed easily and their removal requires crude methods of treatment like detergents. Thus, the membrane has been described as **Protein icebergs floating in sea of phospholipids.** An improved model of the structure of cell membrane was proposed by **Singer** and **Nicolson)** (1972) widely accepted as **Fluid Mosaic Model.**

PLASMA MEMBRANE



According to this, the quasi-fluid nature of lipids enables lateral movement of proteins within the overall bilayer. This ability to move within the membrane is measured as its fluidity.

Functions :

1. The fluid nature of the membrane is important from the point of view of functions like cell growth, formation of intercellular junctions, secretion, endocytosis, cell division, etc.
2. Plasma membrane allows the transport of the molecules across it. The membrane is selectively permeable to some molecules present on either side of it. The passage of substances across cell membranes occurs by various methods such as passive transport, active transport.

(i) Passive transport: Many molecules can move across the membrane without any requirement of energy and this is called the passive transport. Neutral solutes may move across the membrane by the process of simple diffusion along the concentration gradient i.e., from higher concentration to the lower.

Water may also move across the plasma membrane from higher to lower concentration. The movement of water by diffusion through membrane is called osmosis. As the polar molecules cannot pass through the non-polar lipid bilayer, they require a carrier protein of the membrane to facilitate their transport across the membrane.

(ii) Active transport: It is an uphill movement of materials across the membrane where the solute particles move against their concentration gradient i.e., from their lower to higher concentration. Such a transport requires energy, which is obtained from ATP. Thus, it is an energy dependent process.

For example, Na^+/K^+ pump in animal cells.

Cell Wall

The cells of bacteria, fungi, algae and plants have an additional non-living, rigid structure called the cell wall that surrounds the plasma membrane. The composition of cell wall varies in different groups.

1. **Fungal cell wall :** The fungal cell wall is generally composed of **chitin,** a polymer of N-acetylglucosamine (NAG) units.
2. **Algal cell wall :** The algal cell wall is made up of **cellulose, galactans, mannans and minerals like calcium carbonate.**
3. **Plaint cell wall :** The plant cell wall is chiefly composed of the insoluble polysaccharides (**cellulose**). Certain other compounds, such as hemicellulose, pectin and proteins are also present in the cell wall.

The cell wall of plants consists of two regions : primary wall and secondary wall,

Primary wall : A young plant cell forms a single layer of wall material. This layer is known as the primary cell wall. The primary wall is thin, elastic and capable of expansion in a growing cell. It grows by addition of more wall material within the existing one. Meristematic and parenchymatous cells have primary cell wall only.

Secondary wall : In mature cell, more layers of wall material are added internal to the primary wall. These layers are called the secondary cell wall. Addition of secondary wall brings about thickening of the cell wall.

Thickening of cell wall occurs particularly in cells that form the harder woody parts of plants such as lignified and suberised cell wall.

Middle lamella : Adjacent cells in a plant tissue are held together by a thin, sticky, amorphous layer of **cementing material**. This layer is called the middle lamella. Middle lamella is chiefly made up of **calcium** and **Magnesium pectate.** In ripening fruits, the pectate compounds solubilize to a jelly-like material, making the fruits soft. The cell wall and middle lamella may be traversed by plasmodesmata which connect the cytoplasm of neighbouring plant cells.

Functions of Cell Wall :

The cell wall serves many functions :

1. It maintains shape of the cells.
2. It protects the cells from mechanical injury.
3. It wards off the attacks of pathogens like viruses, bacteria, fungi, etc.
4. It allows the materials to pass in and out of the cell.
5. It helps in cell-to-cell interaction and provides barrier to undesirable macromolecules.

Plasmodesmata : It forms the living component in the dead wall. A number of plasmodesmata or cytoplasmic strands are present in pit through which the cytoplasm of one cell is in contact with other. These are lined by plasma membrane and contains a fine tubule called desmotubule. Endoplasmic reticulum plays a role in origin of plasmodesmata. These form the symplastic system between two cells.

Endomembrane System

The interior of a eukaryotic cell is composed of many membrane bound organelles. Each of the membrane-bound organelles has a distinct structure and function. But some of these organelle's function in a coordinated manner and constitute an **endomembrane system**. The organelles included in this system are **endoplasmic reticulum, Golgi complex, lysosomes and vacuoles**. The functions of the mitochondria, chloroplast and peroxisomes are not coordinated with the above-mentioned organelles hence, these are not considered as a part of the endomembrane system.

1. **Endoplasmic Reticulum (ER) :** Electron microscopic studies of eukaryotic cells reveal the presence of a network of reticulum of tiny tubular structures scattered in the cytoplasm that is called the endoplasmic reticulum (ER).

   Ultrastructure : The endoplasmic reticulum is composed of the following three kinds of structures, viz, cisternae, tubules and vesicles.

(a) **Cisternae :** The cisternae are long, flattened, parallel, sac-like, interconnected structures. These are found in cells which are actively involved in protein synthesis. The cisternae usually occur in those cells which have synthetic roles, e.g., cells of pancreas and brain. They are usually associated with large subunit (60 S) of ribosomes.

(b) **Tubules :** The tubules are branched or unbranched structures forming the reticular system along with the cisternae and vesicles. They are free of ribosomes and are common in cells involved in lipid and sterol synthesis.

(c) **Vesicles :** The vesicles are oval, membrane bound vacuolar structures. They are also free of ribosomes. They are abundant in the pancreatic cells and these are the only ER structures found in spermatocytes.

ER divides the intracellular space into two distinct compartments:

(i) **Luminal compartment:** It is the internal space enclosed by ER membrane.

(ii) **Extra luminal compartment :** It is the space, present outside the ER in the cytoplasm.

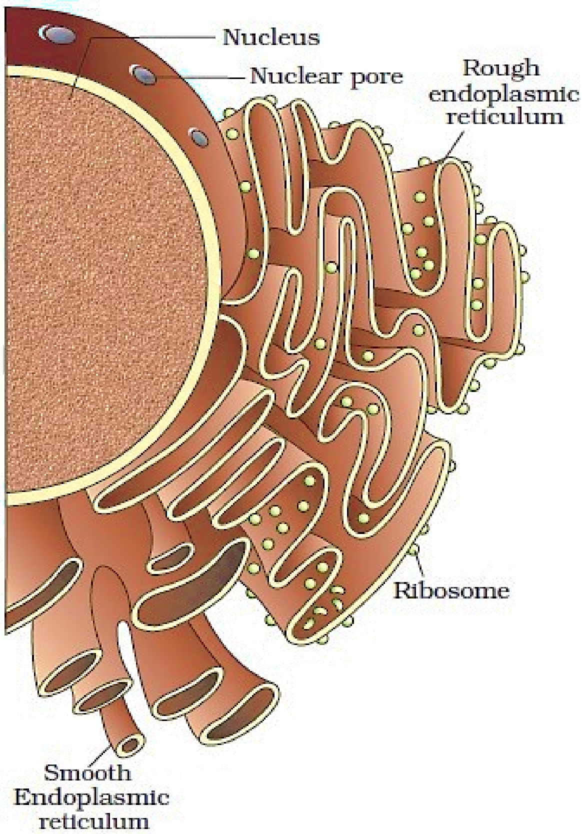


Fig. Endoplasmic reticulum

Types : On the basis of presence or absence of ribosomes on the surface of endoplasmic reticulum, it is of two types:

(i) **Smooth endoplasmic reticulum (SER) :** The endoplasmic reticulum which is free of ribosomes is known as SER. When it is observed under the electron microscope it appears as smooth tubular structures.

The muscle cells are also rich in smooth type of endoplasmic reticulum which is known as sarcoplasmic reticulum.

Function :

(a) It is specialised in the synthesis of lipids and steroids,

(b) Detoxification of drugs,

(c) Associated with muscle contraction by release and uptake of Ca ions.

(d) Synthetic products of RER pass onto Golgi complex through SER.

(ii) Rough endoplasmic reticulum (RER): The endoplasmic reticulum bearing ribosomes on its surface is called RER, it gives a rough granular appearance under the electron microscope. They are extensive and continuous with the outer membrane of the nucleus.

Function:

(a) Ribosomes are the site of protein synthesis and thus, RER are present in the cells which are actively involved in the protein synthesis and secretion.

(b) It provides precursors of enzymes for the formation of lysosomes in Golgi complex.

(c) It gives rise to SER.

2. Golgi Apparatus : Golgi apparatus was first observed by **Camillo Golgi** in 1898. He described it as a densely stained reticular structures present near the nucleus of the cell. Therefore, these were given the name Golgi bodies, after his name. It is present in eukaryotic cells, **except** in mature sieve tubes of plants, mature RBCs of mammals, sperm cells of bryophytes and pteridophytes, etc. It is also absent in prokaryotic cells. In plants, it is called **dictyosomes** as Golgi apparatus is made up of unconnected units.

Structure : There are four parts of Golgi complex, viz. cisternae, tubules, vesicles, Golgian vacuoles.

(a) Cisternae

(i) These are flattened sac-like structures stacked on one another. There are usually 4-8 cisternae present in a stack. These cisternae resemble with smooth endoplasmic reticulum.

(ii) Cisternae form an extensive network and are arranged near the nucleus in a concentric pattern.

(iii) The shape, size and number of cisternae may vary in different cells but have a similar organisation in one type of cells.

(iv) The Golgi cisternae are concentrically arranged near the nucleus with distinct convex cis or the forming face and concave trans or the maturing face. The cis and the trans faces of the organelles are entirely different, but interconnected.

(b) Tubules : These are small, flat, interconnecting structures arising from the periphery of cisternae due to fenestrations.

(c) Vesicles : These are large rounded sacs present at the edges of cisternae in clusters. These are pinched off from the tubules.

These are of two types:

(i) Smooth vesicles : These are smooth surfaced secretory vesicles and contain secretory granules,

(ii) Coated vesicles : These are rough surfaced, spherical protuberances arising from the tubules of cisternae.

(d) Golgian Vacuoles : These are large, spherical vacuoles produced at maturing face. These are filled with some granular or amorphous substances. Some of them function as lysosomes.

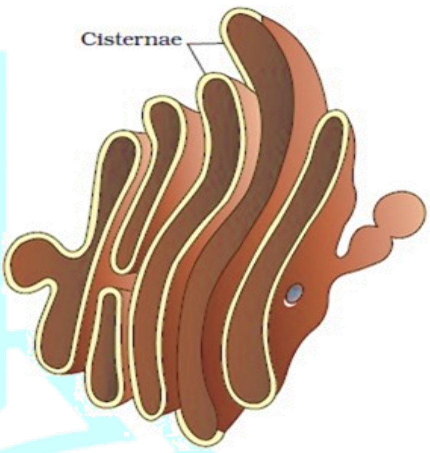


Fig. : Golgi apparatus

Functions :

(i) The important function of Golgi apparatus is to process, package and transport the materials for secretions. The packaged material is delivered either to the intracellular targets i.e., within the cell or secreted to extracellular targets i.e., outside the cell. The material to be secreted moves from ER to the Golgi apparatus in the form of transitional vesicles. These vesicles then fuse with the cis face and move towards the maturing face of the Golgi apparatus. Therefore, Golgi apparatus is closely associated with ER in structural as well as functional aspects.

(ii) A number of proteins synthesised by ribosomes present on the ER are transferred to Golgi apparatus. These proteins are then modified in the cisternae of Golgi apparatus before they are released from its trans face.

(iii) Golgi apparatus is the important site of formation of glycoproteins (glycosylation of proteins) and glycolipids (glycosidation of lipids).

(iv) Root cap cells are rich in Golgi bodies which secrete mucilage for the lubrication of root tip.

(v) Acrosome of the sperm is modified Golgi apparatus.

(vi) Formation of plasma membrane during cytokinesis.

3. **Lysosomes :** Lysosomes are simple tiny spherical sac-like structures evenly distributed in the cytoplasm. These are formed by the process of packaging in the Golgi apparatus. They are bounded by a single membrane. They are rich in hydrolytic enzymes (hydrolases - lipases, proteases, carbohydrase's).

Optimally active at the acidic pH : These enzymes are capable of digesting carbohydrates, proteins, lipids and nucleic acid. Acidic conditions are maintained inside the lysosomes by pumping of 1-T ions into them,

This organelle shows polymorphism : On the basis of morphology, their contents and functions, lysosomes are divided into following four forms :

(i) **Primary lysosomes :** These are small, vesicle-like newly formed structures produced from the Golgi apparatus, at trans face. Primary lysosomes contain inactive enzymes.

(ii) **Secondary lysosomes :** These are also called **heterophagosomes or digestive vacuoles.** Secondary lysosomes are formed when phagosomes fuse with already existing primary lysosomes. These contain the enzymes against the material to be digested.

(iii) **substances. Residual :** These are secondary lysosomes containing undigested substances. Residual bodies pass outwardly, come in contact with plasmalemma and throw their contents to the outside through **ephagy** or **exocytosis**. However, in certain cells the residual bodies do not discharge their contents to the outside. Instead, they load the cells and bring about ageing, e.g., liver cells, muscle cells. **Polynephritis** may occur due to absence of ephagy from residual bodies. A number of other diseases are linked to malfunctioning of lysosomes-**arthritic joints, gout and lung fibrosis**. Some 20 genetic or congenital diseases occur in human beings due to deficiency of certain lysosomal enzymes, e.g. Hunter's syndrome, Niemann-Pick disease, Farber's disease.

(iv) **Autophagic vacuoles:** They are formed by union of many primary lysosomes around old or dead organelles which surround them with vacuolar membrane and digest them by **autolysis** or autodigestion. These are also called suicidal bags. The disappearance of larval organs during metamorphosis (e.g., tail in frog) is due to autolysis.

4. **Vacuoles :**

(i) Vacuole is the membrane-bound space found in the cytoplasm. It contains water, sap, excretory products and other material not useful for the cell. These are also called sap vacuoles.

(ii) In plant cells, the vacuoles can occupy up to 90 percent of the volume of the cell. They are bounded by a single, semipermeable membrane called tonoplast. This membrane facilitates the transport of a number of ions and other materials against concentration gradients into the vacuole. Thus, their concentration is significantly higher in the vacuole than in the cytoplasm.

Types of vacuoles :

(a) Contractile vacuole : In Amoeba, it helps in excretion.

(b) Food vacuoles : In many cells, as in protists, food vacuoles are formed by engulfing the food particles.

(c) Gas vacuoles (Pseudovacuoles): These are membrane less vacuoles found in prokaryotes to provide buoyancy.

Mitochondria (Sing : Mitochondrion)

Mitochondria are cylindrical or sausage-shaped double membraned organelles distributed in the cytoplasm. They are not easily visible under the microscope. Thus, they are stained by a vital stain **Janus green** to make them visible for observation. Mitochondria show a great degree of variability in their shape, size and number.

Number : Their number also varies in different-cell types depending upon the amount of work done by the cell and its energy requirement.

Structure :

(i) Mitochondria are surrounded by two membranes designated as outer and inner membrane. The outer membrane is smooth and forms the continuous limiting boundary of the mitochondria whereas the inner membrane forms a number of infoldings called the cristae (sing : crista). Outer membrane is chemically 40 lipid and 60 proteins and the inner selectively permeable membrane has 80 protein and 20 lipids and is rich in cardiolipins. Due to the presence of two membranes, the organelle is partitioned into two distinct chambers filled with aqueous fluid.

(a) **Outer compartment or intermembrane space :** It lies between the two mitochondrial membranes. It is also called peri-mitochondrial space.

(b) **Inner compartment or matrix :** It lies inside the inner membrane. The cristae are infoldings of inner membrane and are formed towards the matrix which increase the surface area for enzyme action.

(ii) The matrix contains single circular dsDNA molecule (with high G = C content), a few RNA molecules, 70S ribosomes and the components required for the synthesis of proteins. The matrix also contains enzymes for TCA (Tricarboxylic acid) cycle.

(iii) The two membranes have their own specific enzymes associated with the mitochondrial function. The mitochondria divide by fission. **The enzymes and electron carriers for formation of ATP are present only in the inner membrane.**

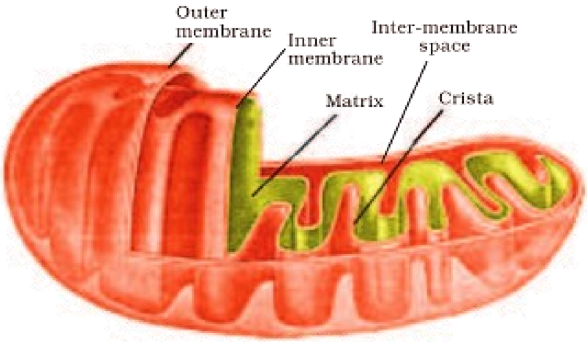


Diagram of Mitochondria

The cristae and the inner face of the inner membrane is studded with numerous spherical or knob like protuberances called **elementary particles or Particles of Fernandez and Moran** or **F1 particles or oxysomes.** Each oxysome is differentiated into base, stalk and head piece. The head piece contains enzyme ATP synthetase which brings about oxidative phosphorylation coupled with release of ATP.

Functions :

(i) Mitochondria are main sites of aerobic respiration. They are miniature biochemical factories where food stuffs or respiratory substrates are completely oxidized to carbon dioxide and water. The energy liberated in the process is stored in the form of ATP. These bring about the oxidation of carbohydrates, proteins and p-oxidation of fats.

(ii) The energy (ATP) produced in the mitochondria helps to perform various energy-requiring processes of the cell like muscle contraction, nerve impulse conduction etc. Because of the formation of ATP, mitochondria are called **power house of the cell.**

Plastids

Plastids are found in all plant cells and in euglenoids etc. These are easily observed under the microscope as they are large. Depending upon their colour and the pigments they contain, these are of three main types- leucoplasts, chromoplasts and chloroplasts.

1. **Leucoplasts :** They are colourless plastids which generally occur near the nucleus in non-green cells. They have variable size, form and stored nutrients. Granum is absent.

   There are three types of special leucoplasts:

   (i) Amyloplast: They are starch-containing leucoplasts, e.g., potato tuber, rice etc.

   (ii) Elaioplasts : They store fats and oils, e.g., castor.

   (iii) Aleuroplast : These leucoplasts store proteins e.g., aleurone cells of maize.

2. **Chromoplasts :** These plastids are yellow, orange or reddish in colour because of the presence of carotenoid pigments. Chromoplasts are formed either from leucoplasts or chloroplasts. Change of colour from green to reddish during the ripening of tomato and chilli is due to transformation of chloroplasts to chromoplasts. The orange colour of carrot roots is due to chromoplasts.

3. **Chloroplasts :** They are greenish plastids which possess photosynthetic pigments, chlorophylls and carotenoids and take part in the synthesis of food. Majority of the chloroplasts of the green plants are found in the mesophyll cells of the leaves. They vary in size, shape and number.

   Shape : They may be spherical, lens shaped, oval, discoid or even ribbon-shaped in some plants.

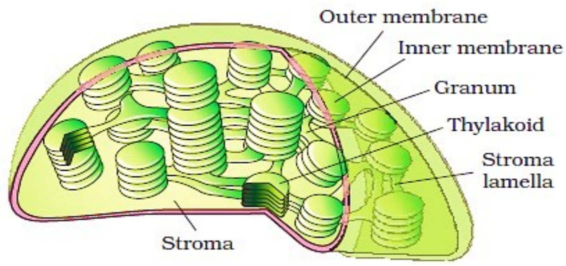
   Number: Their number varies from 1 per cell in Chlamydomonas, a green alga to 20-40 per cell in the mesophyll.

Structure of Chloroplast:

(i) Like mitochondria, chloroplasts are also double membrane-bound organelle having outer and inner membrane. The inner membrane is relatively less permeable to substances than outer membrane and thus, has more proteins including carrier proteins. The space enclosed by the inner membrane of the Chloroplast is called the stroma. Stroma contains a large number of organised flattened membranous sacs called **thylakoids** which are arranged in stacks like the piles of coins called **grana** (sing: granum) or the intergranal thylakoid.

(ii) The thylakoids of different grana are connected by flat membranous tubules called the stroma lamellae. The membrane of the thylakoids enclose a space called a lumen.

(iii) The stroma of the Chloroplast contains enzymes required for the synthesis of carbohydrates and proteins. It also contains small, double-stranded circular DNA molecules and ribosomes. The ribosomes of the chloroplasts (70S) are smaller than the cytoplasmic ribosomes (80S).



Sectional view of chloroplast

Functions : The chloroplasts perform various functions like

(i) Photosynthesis : Light reaction (in thylakoids), dark reaction (in stroma)

(ii) Storage of starch.

Ribosomes

Ribosomes were discovered by **George Palade** in 1953 in the animal cell. They were observed under electron microscope as dense particles present in the cytoplasm. They are composed of rRNA and proteins and are not surrounded by any membrane.

Structure of Ribosomes : The ribosomes are composed of two subunits. One ribosomal subunit is large in size and has a dome-like shape, while the other ribosomal subunit is smaller in size and occurs above the larger subunit and forms a cap-like structure.

The two ribosomal subunits remain united with each other due to a specific concentration of the Mg^{2+} ions. When the concentration of Mg+2 ions reduces below a critical level both ribosomal subunits get separated. But, by raising the concentration of Mg+2 ions in the matrix, the two ribosomes become associated with each other and is known as the dimer. During protein synthesis, many ribosomes form a chain on a common messenger RNA and form the **polyribosomes** or **polysomes,** or **ergasome.**

Ribosomes are of two types - 70S and 80S, where S represents the sedimentation coefficient which indirectly measures the density and size of the ribosomes. The ribosomes of prokaryotes are 70S while the eukaryotic ribosomes are 80S. In mitochondria and Chloroplast, ribosomes are 70 S.

(a) 70 S ribosomes 70 S ribosomes consist of:

30 S smaller subunit - 21 proteins molecules and 16 S rRNA.

50 S larger subunit - 34 proteins molecules and 23 S and 5 S rRNA.

(b) 80 S ribosomes 80 S ribosomes consist of:

40 S smaller subunit - with 33 protein molecules and a single 18S-rRNA.

60 S larger subunit - about 40 protein molecules and three types of **rRNAs -28S, 5.8S and 5S.**

Functions : Ribosomes are sites of protein synthesis. The free ribosomes synthesize non-secretory proteins, while ER bound ribosomes synthesize secretory proteins. Free ribosomes synthesise structural and enzymatic proteins for use inside the cell. The attached ribosomes synthesize proteins for transport. Thus, these organelles are also known as protein factories. Newly synthesized proteins are processed with the help of chaperones protein.

Cytoskeleton

It is made up of extremely minute, fibrous, filamentous and tubular proteinaceous structures which form the structural framework inside the cell. The cytoskeleton occurs only in eukaryotic cells and is involved in many functions such as mechanical support, motility, maintenance of the shape of the cell.

(A) Microtubules : The microtubules are found in the cytoplasmic matrix of all eukaryotic cells. They also occur in cilia, flagella, centrioles and basal bodies, mitotic apparatus etc. Prokaryotic cells lack microtubules.

The microtubules are hollow, unbranched cylinders, generally about 25 nm in diameter with a hollow core of about 15 nm. The boundary of a microtubule is composed of 13 parallel protofilaments. Each protofilament is made up of a and P subunits of tubulin protein (non-contractile protein). The assembly and disassembly of microtubules require GTP and Ca^{2+}.

Functions :

(i) These help in the spindles and astral rays formation during cell division.

(ii) These form the cytoskeleton of cilia and flagella.

(iii) These help in generating the shape, rigidity and form of the cell and cell motility.

(iv) Microtubules help in the anaphasic movement of chromosomes.

(v) Microtubules help in the intracellular transport of nutrients and inorganic ions.

(vi) Position of future cell plate is determined by microtubules.

(B) Microfilaments : The microfilaments are found in eukaryotic cells. The microfilaments are **solid**, unbranched, rod-like fibrils of indefinite length. They are mainly composed of a globular protein **actin**, but have filamentous protein myosin also. They form an extensive network in the cytoplasm of cells and may be associated with plasma membrane.

Functions :

(i) The microfilaments provide support to plasma membrane.

(ii) These represent the contractile system of the cell and are involved in cytoplasmic streaming and amoeboid movements.

(iii) Help in pseudopodia formation.

(iv) These help in the formation of cleavage furrow during cell division.

(C) Intermediate Filaments Centrosome and Centrioles

Centrosome is an organelle usually containing two cylindrical structures called centrioles, which are surrounded by a cloud of amorphous pericentriolar material called centrosphere or kinoplasm. These two centrioles called **diplosome**, are localised in the centrosome at right angles to each other.

The centrioles are found in almost all eukaryotic cells like animal cells, fungi and algae but not found in higher plant cells.

Structure of a Centriole:

(i) A centriole possesses a whorl of nine evenly spaced peripheral fibrils of tubulin. It is absent in the centre. Therefore, the arrangement is called 9+0.

(ii) Each fibril is made up of three sub-fibres. Therefore, it is called triplet fibril consisting of sub-fibres A, B, C.

(iii)The adjacent triplet fibrils are connected by proteinaceous linkers.

(iv) The centre of the centriole possesses a rod-shaped proteinaceous mass known as hub. From the hub, nine proteinaceous strands are developed towards the peripheral triplet fibrils. These strands are called radial spokes.

(v) Due to the presence of radial spokes and peripheral fibrils, the centriole gives a cartwheel appearance.

(vi) There is no membrane boundary for a centriole, but it is surrounded by pericentriolar satellites, also known as massulae (Microtubule generator)

Functions :

(i) Centrioles help in the formation of basal bodies which give rise to cilia and flagella.

(ii) Centrioles form the spindle fibres that give rise to spindle apparatus during cell division.

Cilia and Flagella

Cilia (sing : cilium) and flagella (sing : flagellum) are fine hair like outgrowths of the membrane. Cilia are smaller structures which work like oars. This activity of cilia causes the movement of either the cell or the surrounding fluid. On the other hand, flagella are comparatively longer and responsible for cell movement. Flagella are found in both prokaryotic and eukaryotic cells but, are structurally different.

Eukaryotic Cilia and Flagella :

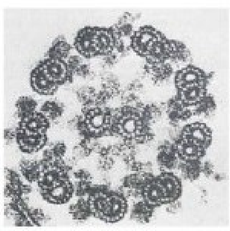
(i) Cilia and flagella are membrane-bound extensions of the plasma membrane. They arise from the centriole-like basal bodies present at their bases that anchor and control their movements.

(ii) They are cylindrical structures and their core is called axoneme which possess a number of microtubules running parallel to the long axis. The axoneme is made up of nine microtubule doublets arranged radially along the periphery and a pair of microtubules present singly in the centre. Such an arrangement of microtubules is referred as **(9 + 2)** organisation.

(iii) The pair of tubules present in the centre are connected to each other by a bridge and enclosed in common sheath called the central sheath.

(iv) The central sheath is connected to each peripheral doublet of microtubules by a radial spoke. Thus, there are total nine radial spokes.

(v) The peripheral doublets are also connected to each other via linkers made up of nexin protein.



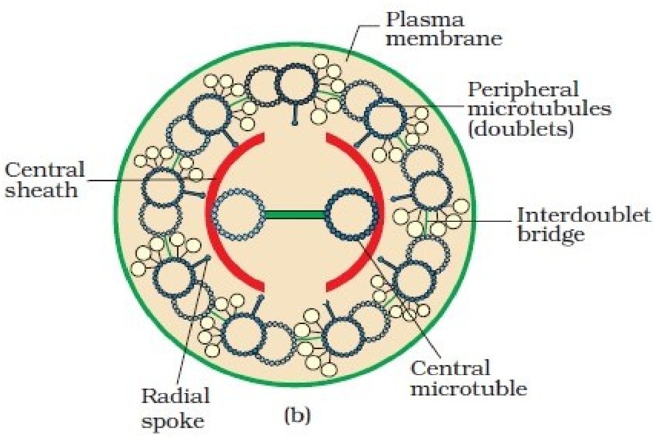


Fig. : Section of cilia / flagella showing different parts : (a) Electron micrograph, (b) Diagrammatic representation of internal structure

Table: Differences between Cilia and Flagella

Cilia	Flagella
1. The number of cilia per cell is usually very large.	1. The number of flagella per cell is usually 1-4.
2. They are smaller in size.	2. They are longer in size.
3. Cilia usually occur throughout or major part of the surface of cell.	3. Flagella are commonly found at one of the cell.
4. Cilia help in locomotion, feeding, circulation etc.	4. Flagella help in locomotion.

Nucleus

Nucleus as a cell organelle was first described by **Robert Brown** as early as 1831. Later, the material of the nucleus stained by the basic dyes was given the name **chromatin** by **Flemming**.

Nucleus is a relatively large organelle controlling all the activities of the eukaryotic cells. Some cells have more than one nucleus, e.g., **binucleate** cells have two nuclei per cell (**Paramoecnim**), while multinucleate ones have many nuclei, e.g. Opalina. However, some cells lack nucleus (**anucleate**) at maturity, such as, **mammalian RBCs and sieve tube cells.**

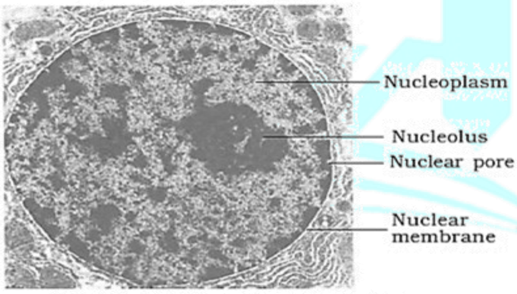


Fig. : Structure of nucleus

Structure: A nucleus in non-dividing phase is called interphase nucleus and a typical interphase nucleus is differentiated into nuclear envelope, nucleoplasm or nuclear matrix, nucleolus and chromatin.

Nuclear Envelope : It bounds the nucleus on the outside and separates it from the cytoplasm. It is made up of two membranes-outer and inner. The inner membrane is smooth whereas the outer membrane may be smooth or its cytoplasmic surface may bear ribosomes like the RER. The outer membrane is often connected to ER. These two membranes of the nuclear envelope are separated by a space known as perinuclear space. The space is 10 to 50 nm in width.

Nuclear envelope contains a large number of complex pores which are formed by the fusion of its two membranes. The nuclear pores control the passage of substances to inside or outside of the nucleus e.g., RNA, ribosomes, proteins.

Nucleoplasm : It is a transparent, semi-fluid and colloidal substance which fills the nucleus. It contains nucleolus and highly extended and elaborate nucleoprotein fibres called chromatin.

Nucleolus :

(i) It is a spherical structure found in the nucleoplasm.

(ii) It is not separated from rest of the nucleoplasm as it is not bounded by a membrane.

(iii) It is the site for ribosomal RNA (rRNA) synthesis. Thus, nucleoli are larger and more numerous in cells that are actively involved in protein synthesis.

Chromatin : (Gk. chroma - colour) The interphase nucleus contains a loose, extended and diffused network of nucleoprotein fibres called chromatin. These are named so because of their ability to get stained with certain basic dyes by Flemming in 1879. Chromatin fibres condense to form chromosomes.

(i) Chromatin is essentially composed of DNA and basic proteins called histones. It also contains RNA and some non-histone proteins. The histone proteins are the packaging proteins that are associated with packaging of DNA into compact structures called chromosomes. During different stages of cell division, cells show structured chromosomes in place of the nucleus.

Heterochromatin and Euchromatin : It was observed that when chromosomes are stained with basic dyes like acetocarmine or fuelgen stain, then two types of regions can be observed :

(a) Heterochromatin region : This region gets dark stain during interphase. This is **genetically** inactive and highly condensed region with tightly packed DNA.

(b) Euchromatin region : This region gets light stain during interphase. This portion is **genetically** active and rich in loosely packed DNA. Transcription occurs here.

(ii) In higher organisms, the well-organised nucleus contains a definite number of chromosomes of definite size and shape. For example, a single human cell has approximately two-meter-long thread of DNA distributed among its forty-six chromosomes (23 pairs of chromosomes).

Structure of a Chromosome

A chromosome consists of two identical halves, the chromatids which are held together at one point called centromere. The centromere appears as a narrow region called primary constriction, of the chromosome. On the sides of centromere, disc shaped structures are present known as kinetochores. Ends of chromosome are called telomeres. They seal the ends of chromosomes and prevent their shortening or chromosome loss.

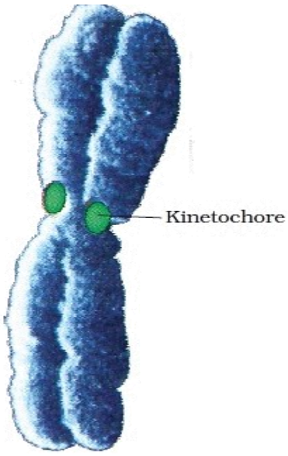


Fig. : Chromosome with kinetochore

Depending on the position of centromere, chromosomes can be classified into four types:

(i) Metacentric chromosome (median centromere): The centromere is present at the centre and thus during anaphase divides the chromosome into two equal arms (Isobrachial). They appear V-shaped,

(ii) Sub-metacentric chromosome (submedian centromere): The centromere is present slightly away from the centre of a chromosome or nearer to one end of the chromosome. As a result, chromosome is divided into one shorter and one longer arm (Heterobrachial). They appear L-shaped during anaphase.

(iii) Acrocentric chromosome (subterminal centromere): The centromere is present very close to one end of the chromosome. Thus, it forms one extremely short and one very long arm. They appear J-shaped during anaphase.

(iv) Telocentric chromosome (terminal centromere): The centromere is present at the terminal end of the chromosome and thus, chromosome appears to have a single arm. They appear l-shaped during anaphase.

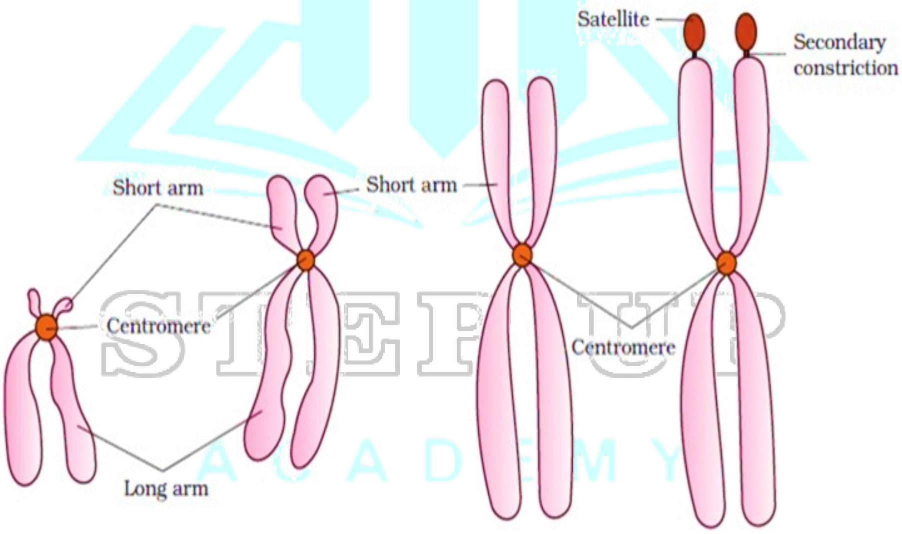


Fig. : Types of chromosomes based on the position of centromere

A few chromosomes may have additional constrictions termed as nonstaining secondary constrictions or NOR (nucleolar organiser) near their ends. The part of the chromosome beyond the secondary constriction is called satellite. A chromosome having satellite is called SAT-chromosome and these are considered as marker chromosome. In humans, 5 pairs of SAT chromosomes are present.

Special types of Chromosomes or Giant Chromosomes

In some organisms, the chromosomes assume special structures in some specific tissues, e.g.,

1. **Lampbrush chromosomes :** These were described by Ruckert (1892). These are present in primary oocyte nuclei of vertebrates as well as invertebrates. These are diplotene bivalent chromosomes joined at certain points called chiasmata.

Their main axis is formed by DNA. Each of the bivalents bear rows of large number of chromomeres. Many of the chromomeres give out lateral projections or loops.

Loops are extended parts of chromosomes, participating in transcription, the hairs on loops are actually nascent RNA molecules. These hairs are bound to proteins, giving it a fibrillar granular appearance. Some of these are stored as informosomes (mRNA + proteins) for future use (development of embryo).

2. **Salivary gland chromosomes or Polytene chromosomes :** In salivary gland cells of insects of order Diptera (dipteran insects), some special chromosomes were reported by E.G. Balbiani (1881). It is due to the presence of these giant chromosomes that maximum cytological studies have been made in Drosophila. Another example is **Chironomus.**

In Drosophila, salivary gland chromosomes up to 2000 urn (2 mm) have been observed. The name polytene chromosome has been given to them as there occurs polytene i.e., number of chromonemata or fibrils increases up to 2000 or more per chromosome. A characteristic feature of these chromosomes is that **somatic pairing** occurs in them and hence, their number appears half of normal somatic cells.

Microbodies

Many single membrane-bound minute vesicles called microbodies that contain various enzymes are present in both plant and animal cells. They are associated with oxidation reactions other than those of respiration.

These include :

A. Peroxisomes

B. Sphaerosomes

C. Glyoxysomes

ADDITIONAL INFORMATION

- Proteins due to their large size cannot show flip-flop movement.
- Cytochrome P_{450} is associated with ER membrane and is involved in breakdown of foreign compounds (Xenobiotics).
- SAT chromosomes produce nucleoli for ribosome synthesis.

Mitochondria provide intermediates for synthesis of cytochromes, chlorophylls, pyrimidines, alkaloids etc.

Chapter 9

Biomolecules

HOW TO ANALYSE CHEMICAL COMPOSITION?

- By performing a chemical analysis, the various biomolecules that are found in living tissues (a vegetable or a piece of liver etc.) can be studied. When a living tissue is grinding in trichloroacetic acid (**CCl_3COOH**) using a mortar and a pestle, a thick slurry is formed. This slurry when strained through cheese cloth or cotton gives two fractions, one is the filtrate which is called acid-soluble pool where thousands of organic compounds are found. The other fraction is called the retentate or the **acid-insoluble pool** where compounds like proteins, nucleic acids, polysaccharides etc. are found.
- However, inorganic elements and compounds are also present in the living organisms, which can be known with the help of a technique called **'ash'** analysis. A small amount of a living tissue (say a leaf or liver and this is called wet weight) is weighed and dried. All the water evaporates. The remaining material gives dry weight.
- When this tissue is fully burnt, the carbon compounds are oxidised to gaseous forms like CO_2, water vapour and are removed and the remnant is called 'ash'. This ash contains many inorganic elements like calcium, magnesium etc.

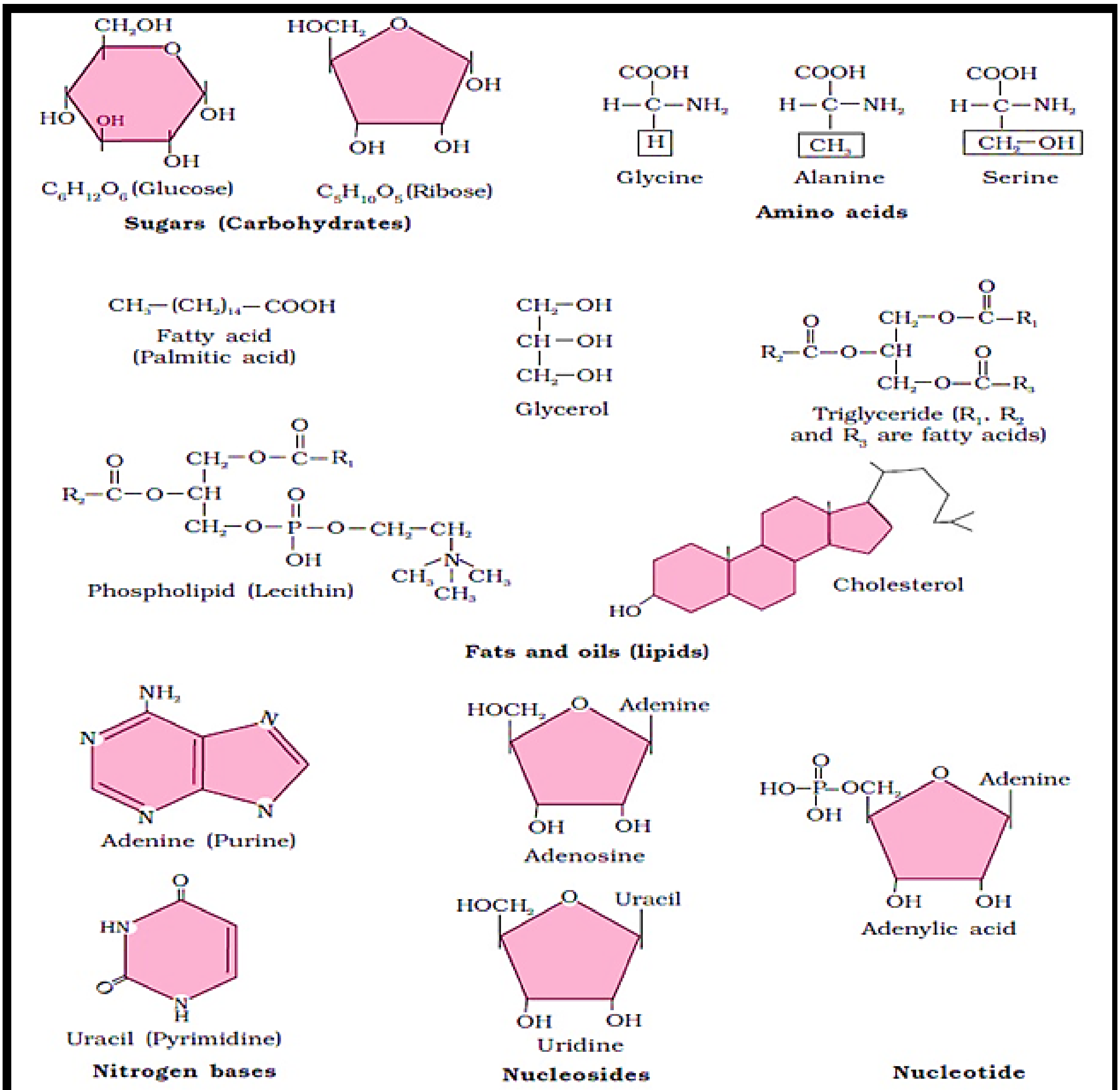
Table : A comparison of elements present in non-living and living matter

Element	% Weight of	
	Earth's crust	Human body
Hydrogen (H)	0.14	0.5
Carbon (C)	0.03	18.5
Oxygen (O)	46.6	65.0
Nitrogen (N)	Very little	3.3
Sulphur (S)	0.03	0.3
Sodium (Na)	2.8	0.2
Calcium (Ca)	3.6	1.5
Magnesium (Mg)	2.1	0.1
Silicon (Si)	27.7	Negligible
Adapted from CNR Rao, Understanding Chemistry, Universities Press, Hyderabad.		

- In the acid-soluble fraction, inorganic compounds like sulphate, phosphate etc. are also present.
- From a chemistry point of view functional groups like aldehydes, ketones, aromatic compounds etc. can be identified.
- From a biological point of view can classify the biomolecules into **micromolecules** and **macromolecules.**

Biomolecules

- Micromolecules (acid soluble fraction)
  - Amino acids
  - Simple sugar
  - Nucleotides
- Macromolecules (acid insoluble fraction)
  - Polysaccharides
  - Proteins
  - Nucleic acid



Diagrammatic representation of small molecular weight organic compounds in living tissues

The acid soluble pool contain chemicals with small molecular mass of 18 - 800 daltons approximately. They are called **micromolecules** or **biomicromolecules**. They include amino acids, sugar, nucleotides etc.

The acid insoluble fraction, has only four types of organic compounds, /.e., proteins, nucleic acids, polysaccharides and lipids. These classes of compounds with the exception of lipids, have molecular weights in the range of ten thousand daltons and above. For this very reason, biomolecules, i,e., chemical compounds found in living organisms are of two types. One, those which have molecular weights less than one thousand Dalton and are usually referred to as micromolecules or simply biomolecules while those which are found in the acid insoluble fraction are called macromolecules or **biomacromolecules.**

Lipids are not strictly macromolecules. Their molecular weight does not exceed 800 Da, but they come under the acid insoluble fraction because when we grind a tissue, cell membrane and other membranes are broken into pieces and form vesicles which are not water soluble (lipids are also present in structures like cell membrane and other membranes). Therefore, these membrane fragments in the form of vesicles get separated along with the acid insoluble pool.

The acid-soluble fraction represents roughly the cytoplasmic composition (without organelles), while the acid- insoluble fraction represents the macromolecules of the cytoplasm and cell organelles. The two fractions together represent the entire chemical composition of living tissues or organisms.

Table : Average composition of cells

Component	% of the total cellular mass
Water	70-90
Proteins	10-15
Carbohydrates	3
Lipids	2
Nucleic acids	2
Longs	1

- Water is most abundant chemical in living organisms.

PRIMARY AND SECONDARY METABOLITES

Living organisms produce thousands of organic compounds (biomolecules) including amino acids, sugars, chlorophylls, haems etc. These are required for their basic or primary metabolic processes like photosynthesis, respiration, protein and lipid metabolism etc. These organic compounds are called **primary metabolites.**

Many plants, fungi and microbes of certain genera and families synthesize a number of organic compounds (biomolecules) which are not involved in primary metabolism and seem to have no direct function in growth and development of organisms. Such compounds are called **secondary metabolites.**

Thus, primary metabolites have identifiable functions and play known roles in normal physiological processes. The functions or role of secondary metabolites in host organisms are not understood. However many of them are useful to human welfare (e.g., rubber, drugs, spices, scents and pigments).

Some secondary metabolites have ecological importance. For example, some cyanobacterial secondary metabolites exhibit toxic effects on living organisms. A diverse range of these cyanotoxins may have ecological roles as herbicides and insecticides.

Table : Average composition of cells

Pigments	Carotenoids, Anthocyanins, etc.
Alkaloids	Morphine, Codeine, etc.
Terpenoides	Monoterpenes, Diterpenes etc.
Toxins	Abrin, Ricin
Lectins	Concanavalin A
Drugs	Vinblastin, Curcumin, etc.
Polymeric substances	Rubber, Gums, Cellulose

CARBOHYDRATES

Carbohydrates are mainly compounds of carbon, hydrogen and oxygen. These are also known as **saccharides** because their basic components are sugars. They are of two types, small and large (complex). Small carbohydrates (biomicromolecules) are further divided into **monosaccharides, derived monosaccharides** and oligosaccharides. Large carbohydrates (biomacromolecules) are called polysaccharides.

1. **Monosaccharides :** They are those sugars or simple carbohydrates which cannot be hydrolysed further into smaller components. These are composed of 3-7 carbon atoms and are biomicromolecules.

   Example - Ribose, glucose, fructose etc.
2. **Derived monosaccharides :** Monosaccharides are modified variously to form a number of different substances.

- **Deoxy sugar :** e.g. Deoxygenation (removal of oxygen at 2nd carbon) of ribose produces deoxyribose.
- **Amino sugar.:** e.g. glucosamine
- **Sugar acids** : e.g. glucuronic acid, ascorbic acid
- **Sugar alcohol :** e.g. mannitol (present in brown algae).

3. **Oligosaccharides :** They are small carbohydrates which are formed by condensation (a chemical reaction in which two molecules combine to form one molecule with loss of a small molecule usually water) of 2-9 monosaccharides and are biomicromolecules. The monosaccharide units are joined together by **glycosidic** bond. It is formed between the aldehyde or ketone group of one monosaccharide and the alcohol group of another. This bond is also formed by dehydration. It is normally formed between carbon 1 of one monosaccharide unit and carbon 4 of second monosaccharide unit. Depending upon the number of monosaccharide molecules condensed to form Oligosaccharides, they can be **disaccharides** (e.g., sucrose, maltose, lactose, trehalose (present in haemolymph of insects), **trisaccharides** (e.g., raffinose -made up of glucose, fructose and galactose), **tetrasaccharides** (e.g., stachyose) etc.

Reducing sugars : They are those sugars which can reduce Cu^{2+} ions to Cu^{+} ions. This property is the basis of **Benedict's and Fehling's test** to detect the presence of glucose in urine. The property is found in all those saccharides which possess free aldehyde or ketone groups. All monosaccharides have this ability. Amongst disaccharides, **sucrose** (glucose + fructose is **non-reducing** because both aldehyde group of glucose and ketone group of fructose participate in formation of glycosidic bond between the two. However, some other disaccharides like, lactose, maltose possess the reducing groups.

4. **Polysaccharides :** Polysaccharides are polymers or chains of monosaccharides and are **macromolecules.** They are threads (literally a cotton thread) containing different monosaccharides as building blocks and are branched or unbranched. In a polysaccharide the individual monosaccharides are linked by a glycosidic bond. **The right end of a polysaccharide is reducing end while the left end is non-reducing end.** Depending upon the composition, polysaccharides are of two types, **homopolysaccharides and heteropolysaccharides.**

(i) **Homopolysaccharides :** Homopolysaccharides consist of only one type of monosaccharide monomer. Starch and glycogen both are polymers of glucose and serve as a storage form in plants and animals respectively.

(a) **Glycogen:** Glycogen is made up of about 30,000 glucose residues. It is a branched structure having a1,4 linkage at unbranched part and the branching points have a 1, 6 linkage. **It gives red colour with iodine.**

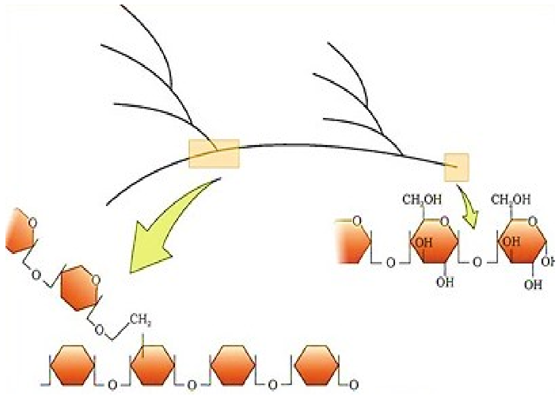


Fig. : Diagrammatic representation of glycogen

(b) **Starch** form helical secondary structure i.e., the chain of glucose molecules folds in the form of a helix. Starch gives a characteristic blue colour with iodine molecules due to the ability of the latter to occupy a position in the interior of a helical coil of glucose unit.

In plants **cellulose** serves as structural elements in plant cell wall. Paper made from plant pulp is cellulose. Cotton fibre is also cellulose. Cellulose does not contain complex helices and hence cannot hold I_2.

(c) **Inulin** is a polymer of **fructose**. It is a storage polysaccharide of roots and tubers of dahlia and related plants. Inulin is not metabolised in human body and is readily filtered through the kidney. It is therefore used in testing of kidney function.

(d) **Chitin :** It is the second most abundant organic substance. In chitin the basic unit is a nitrogen containing glucose derivative known as N-acetyl glucosamine. The exoskeletons of arthropods have chitin.

(ii) **Heteropolysaccharides :** Heteropolysaccharides consists of more than one type of monosaccharide monomer i.e., they are heteropolymers and are more complex polysaccharides. Some of the heteropolysaccharides are :

(a) **Peptidoglycan :** In peptidoglycan, the heteropolysaccharide chains are made up of two alternate amino-sugar molecules i.e., N-acetyl glucosamine and N-acetyl muramic acid.

(b) **Hyaluronic acid :** It is a heteropolymer composed of D-glucuronic acid (a carboxylic acid) and D-N-acetyl glucosamine (a monosaccharide derivative of glucose). Hyaluronic acid accounts for the toughness and flexibility of cartilage and tendon.

AMINO ACIDS

Amino acids are organic compounds, having amino group ($-NH_2$) and carboxylic group (-COOH) attached to the same carbon i.e., the a-carbon (a-carbon is the carbon to which functional groups are attached). The alpha-carbon also bears hydrogen and a variable R group. They are

substituted methane's as there are four substituent groups occupying the four valency positions of carbon. Since both the functional groups are attached to the α carbon so they are called α-amino acids.

- Based on the nature of R groups there are many amino acids.
- Amino acids which occur in proteins are only of twenty types. The R group in these proteinaceous amino acids could be a hydrogen (glycine), a methyl group (alanine), hydroxy methyl (serine), etc.
- Humans are incapable of synthesizing half of the 20 standard amino acids and these are known as **essential amino acids**. They must be obtained from food. e.g., Lysine, methionine, phenylalanine, tryptophan, valine,
- isoleucine, leucine, threonine.
- **Semi essential amino acids :** They can be synthesised very slowly by human beings, e.g., Arginine and histidine.
- The amino acids that are synthesized in our body are called **non-essential amino acids** to denote the fact that they are not needed in the diet.

  e.g., Alanine, cysteine, glutamate, glycine, proline etc.
- Physical and chemical properties of amino acids are mainly due to the amino, carboxyl and R functional groups. Based on comparative number of amino and carboxyl groups, amino acids can be acidic, basic and neutral.

(i) **Acidic amino acids :** The amino acids have an extra carboxylic group.

Example - Glutamic acid (glutamate), aspartic acid (aspartate).

(ii) **Basic amino acids :** They have an additional amino group.

Example - Lysine, arginine etc.

(iii) **Neutral amino acids :** Amino acids have one amino group and one carboxylic group.

Example - Valine, alanine, glycine, leucine, isoleucine.

(iv) **Sulphur containing amino acid :** Have sulphur.

Example - Cysteine, cystine and methionine.

- A particular property of amino acids is the ionizable nature of NH_2 and COOH groups. These fully ionized species known as Zwitter ions have both a positive and a negative charge. Every amino acid has a carboxyl group and an amino group and each group can exist in an acidic form or a basic form depending on the pH of the solutions in which the amino acid is dissolved. Notice that an amino acid can never exist as an uncharged compound regardless of the pH of the solution. Therefore, at isoelectric point, an amino acid exists as a dipolar ion, called a Zwitterion. A zwitterion is compound that has a negative charge on one atom and a positive charge on a non-adjacent atom. (The name comes from Zwitter, German for "hermaphrodite" or "hybrid"). Hence in solutions of different pHs, the structure of amino acid changes.
- Two amino acids can join through amino group of one and carboxylic group of the other forming **peptide bond** by loss of water molecule. When a few amino acids are joined in this fashion, the structure is called an **oligopeptide.** When many amino acids are joined, the product is called a **polypeptide.**

PROTEINS

Proteins are large-sized **macromolecules** having one or more polypeptides (chains or polymers of amino acids linked by peptide bond). The term polypeptide is often used interchangeably with protein. However, a single polypeptide must be at least 50 amino acid long in order to qualify for the term.

As there are 20 types of amino acids, **a protein is a heteropolymer.** A homopolymer has only one type of monomer repeating 'n" number of times. Collagen is the most abundant protein in animal world. It is the main component of connective tissue of animals. **Ribulose bisphosphate carboxylase-oxygenase (RuBisCo)** is the most abundant protein in the whole of the biosphere. RuBisCo is an enzyme involved in carbon fixation (photosynthesis), a process by which atmospheric CO_2 is converted by plants to energy rich molecules i.e., glucose.

Structure of Proteins

Biologists describe the protein structure at four levels - primary, secondary, tertiary and quaternary.

1. Primary structure

The sequence in which amino acids are arranged in a polypeptide chain of a protein is called its primary structure. it gives the positional information of amino acids in a protein i.e., which is the first amino acid, which is the second, and so on.

- In this chains of amino acids which constitute protein, the amino acid present at the left end is the first amino acid, whereas the one at the right end is the last amino acid of the protein.
- The first amino acid is known as **N-terminal** amino acid and the last is known as **C-terminal** amino acid.

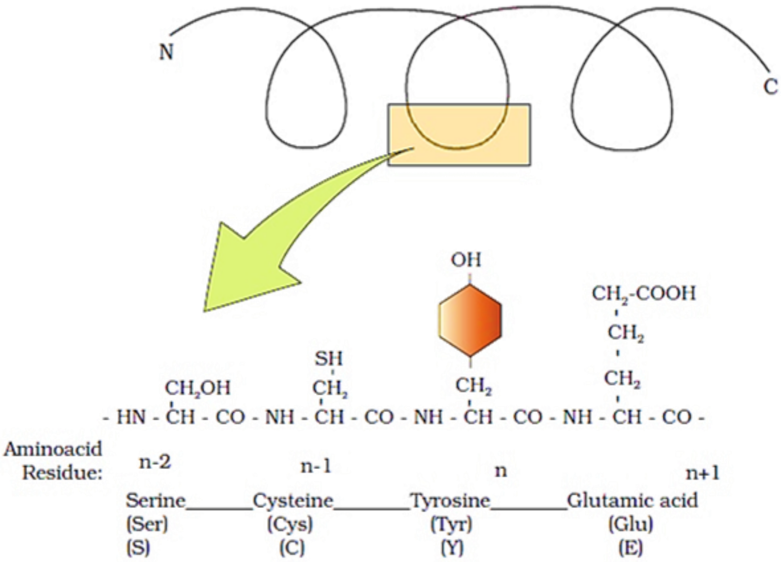


Fig. : Primary structure of portion of a hypothetical protein. N and C refer to the two termini of every protein. Single letter codes and three letter abbreviations for amino acids are also indicated.

2. Secondary structure

- A protein thread does not exist throughout as an extended rigid rod. Some portion of the protein thread are folded either in the form of a helix (similar to a revolving staircase) or β-pleated sheet. The α-helix β -pleated sheet are two types of secondary structures. In a-helix, there is interaction between every fourth amino acid by the formation of intramolecular hydrogen bond. The polypeptide gets a helical shape (α -helix). The intramolecular hydrogen bond is a bond formed between the hydrogen atom and the highly electronegative atom such as nitrogen, oxygen and fluorine of same molecule.
- In proteins, **only right-handed helices are observed.** Example - **Keratin protein present in hair.**

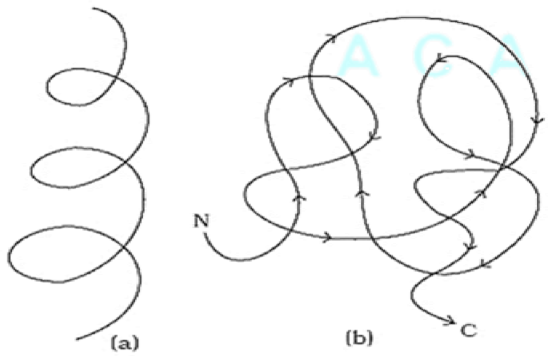


Fig. : Cartoon showing : (a) A secondary structure and (b) A tertiary structure of proteins

When two or more polypeptide chains are held together by intermolecular hydrogen bonds, the structure is described as **β-pleated sheet.** The intermolecular hydrogen bond is the bond formed between the hydrogen atom of the molecule and the highly electronegative atom (such as nitrogen oxygen, fluorine) of the other molecule.

Example – **Fibroin** protein of silk

Collagen helix : The polypeptide coil of collagen helix is strengthened by establishing hydrogen bond and locking effect also occurs with the help of proline and hydroxyproline amino acid.

3. Tertiary Structure

- The long protein chain or the polypeptide chain usually folds upon itself, like a hollow woolen ball. This is termed as **tertiary structure**. This structure gives a 3-dimensional view of a protein.
- Tertiary structure is absolutely necessary for the many biological activities of proteins for example, this structure brings distant amino acid side chains closer forming the active site (the site to which a substrate gets attached) of proteins i.e. **enzymes.**

  Example –**Myoglobin** (protein found in muscle cell).

4. Quaternary structure

Quaternary structure is formed when a protein has more than one subunits (individual polypeptide chains of a quaternary protein are called subunits) or polypeptide chains and each polypeptide has a primary, secondary or tertiary structure of its own. The way in which these individual folded polypeptides are arranged with respect to each other (e.g., linear string of spheres, spheres arranged one upon each other in the form of a cube or plate etc.) gives the architecture of the quaternary structure of a protein.

For example, haemoglobin has such structure. Haemoglobin has four helical polypeptide chains, tow α-chains and two β-chains.

Functions :

1. **Enzymes :** All enzymes (except a few) are built up of proteins alone or in conjugation with some non-protein materials called cofactors. Enzymes catalyse all the chemical reactions that occur in the living world. Example – Trypsin (present in the pancreatic juice)

Table : Some proteins and their functions

Protein	Functions
Collagen	Intercellular ground substance
Trypsin	Enzyme
Insulin	Hormone
Antibody	Fights infectious agents.
Receptor	Sensory reception (smell, taste, hormone, etc.)
GLUT-4	Enables glucose transport into cells

LIPIDS

Lipids are all made of carbon, hydrogen and little oxygen and are water insoluble but get dissolved in organic solvents like ether, benzene, acetone etc. The **lipids are not polymers** but they are assembled from smaller molecules by dehydration.

Lipids could be simple **fatty acids or glycerol (which is trihydroxy propane**). Many lipids have both glycerol and fatty acids. Some lipids have phosphorus and a phosphorylated organic compound in them. Some lipids have more complex structures.

Classification

The lipids are classified into sub-groups as follows :

Lipids
- Simple lipids
  - Neutral or true fats
  - Waxes
  - Cutin and suberin
- Compound or conjugated lipids
  - Phospholipids
  - Glycolipids
  - Lipoproteins
  - Chromolipids
- Derived lipids

A. Simple lipids : These are esters (organic acids and alcohols react to form esters) of fatty acid with various alcohols. They are of two types :

(i) Neutral or true fats : These are esters of fatty acid with glycerol. They are also called glycerides. A fat molecule consists of one molecule of glycerol and one to three molecules of the same or different long-chain fatty acids.

(a) Glycerol : A glycerol molecule has 3 carbons, each bearing a hydroxyl (-OH) group.

$$\begin{array}{l} CH_2-OH \\ | \\ CH_2-OH \\ | \\ CH_2-OH \end{array}$$

Glycerol

(b) A fatty acid molecule is an unbranched chain of carbon atoms having a carboxylic group attached to an R group. The R group could be a methyl ($-CH_3$) or ethyl ($-C_2H_5$) or higher number of $-CH_2$ groups (1 carbon to 19 carbons). For example, **palmitic acid** has 16 carbons including carboxyl carbon. **Arachidonic acid** has 20 carbon atoms including the carboxyl atom.

Fatty acids are of two types :

1. **Saturated fatty acids :** Fatty acids without double bond.

   Example – **Palmitic acid , stearic acid**

$CH_3-(CH_2)_{14}-COOH$
Fatty acid
(Palmitic acid)

$CH_3-(CH_2)_{16}-COOH$
Fatty acid
(Stearic acid)

2. **Unsaturated fatty acids :** Fatty acids with one or more double bonds.

   Example - Oleic acid, linoleic acid, linolenic acid, arachidonic acid

$$CH_3(CH_2)_7\,CH=CH\,(CH_2)_7\,COOH$$
Oleic acid

$$CH_3(CH_2)_4\,CH=CH\,CH_2\,CH=CH(CH_2)_7\,COOH$$
Linoleic acid

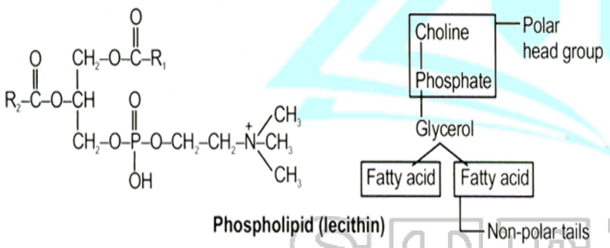
- Neutral or true fats may be monoglyceride if there is only one molecule of fatty acid attached to a glycerol molecule. If the number of fatty acids attached to a glycerol happens to be two, it is called diglyceride, or triglyceride if the number of fatty acids is three.

Glycerol (1 molecule)		Fatty acid (3 molecules)		Triglyceride (1 molecule)
CH_2-OH | $CH-OH$ | CH_2-OH	+	$HOOC-R_1$ | $HOOC-R_2$ | $HOOC-R_3$	→	$CH_2-O-OC-R_1$ | $CH-O-OC-R_2$ $+ 3H_2O$ | $CH_2-O-OC-R_3$

- Based on the melting point triglycerides can be called as fats or oils. Fats have high melting point and remain as solids at room temperature, e.g., butter, ghee while oils have low melting point and remain as liquids/oil at room temperature. e.g., gingelly oil, sunflower oil, etc.

B. Compound or conjugated lipids : These are esters of fatty acids with alcohol, but contain some other substances also. They are :

(i) Phospholipids : The phospholipids are composed of a molecule of glycerol or other alcohol having (a) a phosphate group joined to one of its outer -OH groups, (ii) two fatty acid molecules linked to the other two -OH groups, and (iii) a nitrogen-containing choline molecule, bound to the phosphate group. Phospholipids are found in cell membranes. Lecithin is one example of phospholipid.



Phospholipid (lecithin)

(ii) Glycolipids : Glycolipids contain fatty acids, alcohol sphingosine and sugar (galactose). The sugar replaces one fatty acid molecule. The glycolipids are present in myelin sheath of nerve fibres and in the outer surface of cell membrane of chloroplast.

(iii) Lipoproteins : Lipoproteins contain lipids (mainly phospholipids) and proteins in their molecules. Membranes are composed of lipoproteins.

(iv) Chromolipids : These contain pigments such as carotenoids e.g. Carotene, vitamin A.

C. Derived lipid

Steroids : The steroids do not contain fatty acids, but are included in the lipids because they have fat-like properties. Instead of straight chain they are composed of four fused carbon rings. The various steroids differ in the number and position of double bonds between carbon atoms and in the side groups linked to the ring. The most common steroids in the animal tissue. Food rich in animal fats contain cholesterol. It is also synthesized in the liver.

- Cholesterol is an essential component of animal plasma membrane.

Prostaglandins : It is a group of hormone like unsaturated fatty acids which function as messenger substance between cell. They are derived from arachidonic acid and related C_{20} fatty acid.

Another steroid compound, diosgenin produced by the yam plant (Dioscorea) is used in the manufacture of antifertility pills.

NUCLEIC ACIDS

Nucleic acids are polymers of nucleotides and are macromolecules. There are two types of nucleic acids namely - deoxyribonucleic acid (DNA) or ribonucleic acid (RNA). Nucleotide serves as the building block of nucleic acid. A nucleotide is composed of:

(i) A phosphate group :

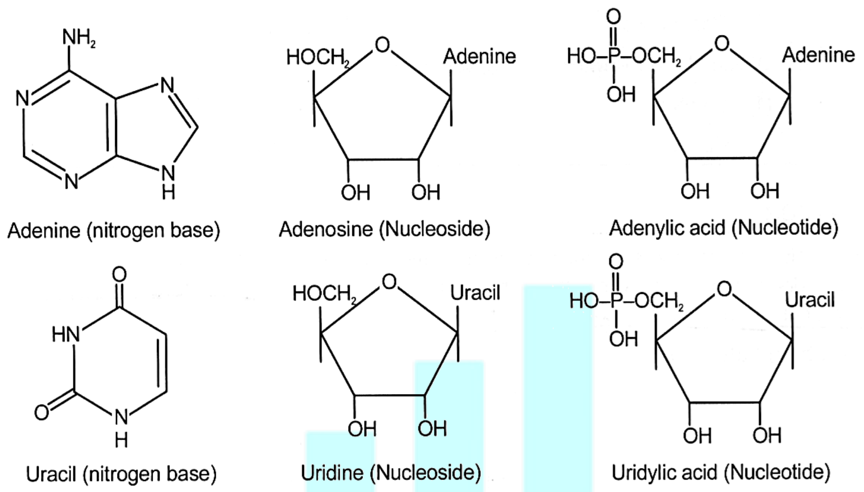
O ‖ H – O – P – O – H | OH Phosphoric Acid	O ‖ O – P – O | O Phosphate ion

(ii) A five-carbon sugar or pentose sugar (monosaccharide) : In RNA the sugar is ribose (thus the name ribonucleic acid) and in DNA the sugar is **deoxyribose** (thus deoxyribonucleic acid).


β-ribose β-deoxyribose

(iii) A heterocyclic nitrogen-containing compound called base : There are four different bases commonly found in DNA : **adenine (A), guanine (G), thymine (T) and cytosine (C).** RNA also contains adenine guanine, and cytosine but instead of thymine it has uracil (U). Adenine and guanine are double-ring bases called **purines**. Cytosine, thymine and uracil are single-ring bases called **pyrimidines**.

Nitrogenous Base	Nucleoside	Nucleotide
1. Adenine	Adenosine	Adenylic acid
2. Guanine	Guanosine	Guanylic acid
3. Cytosine	Cytidine	Cytidylic acid
4. Thymine	Thymidine	Thymidylic acid
5. Uracil	Uridine	Uridylic acid



- In a nucleic acid a phosphate moiety (moiety is a part of a larger molecule or structure) links the 3' carbon of one sugar of one nucleotide to the 5' carbon of the sugar of the succeeding nucleotide. The bond formed between the phosphate and hydroxyl group of sugar is an ester bond. As there is one such ester bond on either side, it is called **phosphodiester bond.**
- DNA is the genetic material and forms molecular basis of heredity (the transmission of genetic characters from parents to offspring) in all organisms. In certain viruses, such as tobacco mosaic virus (TMV), RNA is the genetic material.
- Nucleic acids exhibit a wide variety of secondary structures for example, one of the secondary structure exhibited by DNA is the famous **Watson-Crick model.**

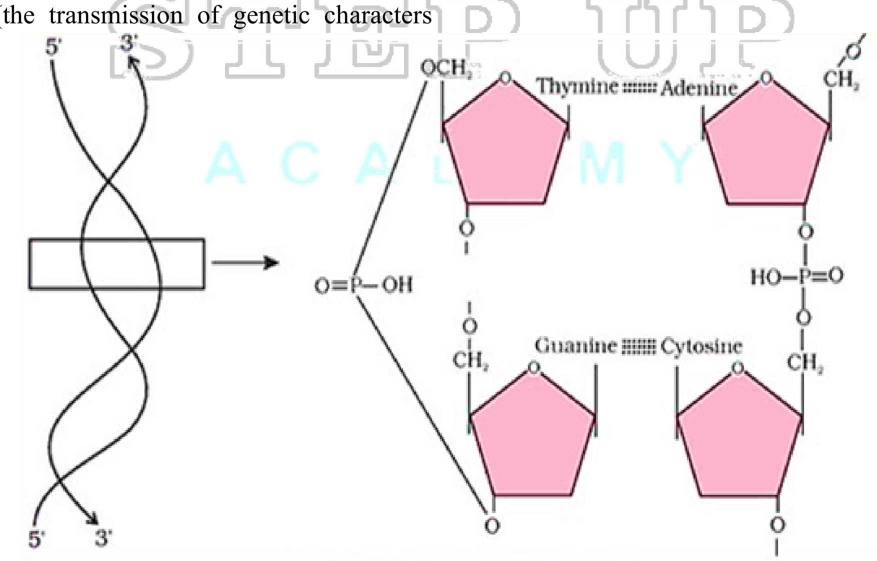


Fig. : Diagram indicating secondary structure of DNA

Watson-Crick Model of DNA

- This model says that DNA exists as a double helix. A DNA molecule has two unbranched polynucleotide strands. Each polynucleotide strand or chain consists of a sequence of nucleotides linked together by phosphodiester bonds. The polynucleotide strands are **antiparallel**, i.e., run in the opposite direction.

- The two strands are not coiled upon each other but the double strand is coiled upon itself around a common axis like spiral staircase with base pairs forming steps while the backbones of the two strands form railings. The backbone is formed of sugar and phosphate.
- The nitrogen bases are projected more or less perpendicular to the sugar phosphate backbone but face inside.
- The base-pairing is specific. Adenine is always paired with thymine and guanine is always paired with cytosine. Thus, all base-pairs consist of one purine and one pyrimidine. Once the sequences of bases in one strand of a DNA double helix is known, the sequence of bases in the other strand is also known because of the specific base pairing. The two strands of a DNA double helix are thus said to be complementary (not identical). This is known as complementary base pairing.
- The two polynucleotide strands are held together in their helical structure by **hydrogen bonding** between bases in opposing strands. Adenine and thymine form two hydrogen bonds. Guanine and cytosine form three hydrogen bonds.
- One end of the strand is called **5' end** where the fifth carbon of the pentose sugar is free and the other end is called **3' end** where the third carbon of pentose sugar is free.
- At each base pair the strand turns 36°. One full turn of the helical strand (360°) would involve **ten base** pairs i.e., one turn of 360° of the helical strand has about 10 nucleotide on each strand of DNA. The base-pairs in DNA are stacked 3.4 A apart. Thus, pitch of the DNA is 34 A as ten base pairs occupy a distance of about 34 Å.
- This form of DNA with the above mentioned salient features is known as B-DNA.

DYNAMIC STATE OF BODY CONSTITUENTS - CONCEPT OF METABOLISM

- Living organisms contain thousands of organic compounds or biomolecules (also known as **metabolites)** that are present in certain concentrations (expressed as mols/cells or moles/liter etc.) All these biomolecules **have a turn** over which means they are constantly being changed into some other biomolecules and also made from some other biomolecules. Through chemical reactions, this breaking and making occurs constantly in living organisms. Together all these chemicals reactions are called **metabolism.**
- Biomolecules get transformed due to metabolic reactions that occur in a living cell/organism.
- A few examples of metabolic transformations are : removal of CO_2 from amino acids making an amino acid (contain -COOH and $-NH_2$) into an amine (contain NH_2 only as functional group), removal of amino acid in a nucleotide base; hydrolysis (cleavage of a bond by the addition of element of water, yielding two or more products) of a glycosidic bond in a disaccharide such as **lactose**, yields two monosaccharide molecules namely **glucose** and **galactose**.
- Metabolites are converted into each other in series of linked reaction **called metabolic pathways.** These pathways resemble the automobile traffic in a city. They are either linear or circular and criss-cross each other i.e., there are traffic junctions.
- Flow of metabolites through metabolic pathway has a definite rate and direction like automobile traffic. This metabolic flow is called the **dynamic state of body constituents**.
- In healthy conditions, this interlinked metabolic traffic is very smooth and without a single reported mishap.
- In metabolic reactions, every chemical reactions that occurs is a **catalysed reaction** (reactions that occur in the presence of a catalyst). Catalyst which accelerates the rate of a given metabolic conversations (reactions) are known as enzymes. Almost all enzymes are proteins with catalytic power. Thus, enzymes are biocatalyst which accelerates the rate of a given metabolic reactions.
- There is no uncatalysed metabolic reaction. Even COg dissolving in water is a catalysed reaction in living systems.

$$\underset{\text{Carbon dioxide}}{CO_2} + \underset{\text{Water}}{H_2O} \xrightarrow[\text{(Enzyme}]{\text{Carbonic anhydrase}} \underset{\text{Carbonic acid}}{H_2CO_3}$$

- All chemical reactions occurring in the living systems are mediated through the **biocatalyst** called **enzymes**.

Metabolic Basis for Living

- Metabolic pathways can lead to a more complex structure from a simpler structure for example, acetic acid becomes cholesterol. Acetic acid is the primary precursor in the production of body cholesterol. The acetic acid is converted to cholesterol in the liver through a series of biochemical reactions. Such metabolic pathways are called **biosynthetic pathways** or **anabolic pathways.** Another example is formation of proteins from amino acids. **Anabolic pathways consume energy.**

- Metabolic pathways can also lead to a simpler structure from a complex structure for example glucose (6 carbon compound) becomes lactic acid (3 carbon compound). In every living cell glucose is converted into pyruvate through 10 metabolic steps called **glycolysis**. In vigorously contracting muscles, due to lack of oxygen, the pyruvate gets converted into lactic acid (converted acetyl CoA which further breaks down into CO_2 and H_2O). This constitute degradation and are called **catabolic pathways**. Catabolic pathways leads to release of energy.
- Living organisms trap the energy liberated during degradation and store it in the form of chemical bonds of molecules like ATP (adenosine triphosphate). When needed, the chemical bonds breakdown and energy is liberated. This liberated energy is utilised for biosynthetic, osmotic (related to osmosis i.e., movement of solvent from a region of diluted solution to a region of concentrated solution through a semipermeable membrane) and mechanical work that we perform.
- Adenosine triphosphate (ATP) a nucleotide, is called **universal energy carrier** as well as **energy currency of the cell**. ATP is formed of an adenine (a purine), a ribose (pentose sugar) and a row of three phosphate attached to ribose.
- ATP molecules are produced during cellular respiration. The second and third phosphates of ATP are attached by high energy bonds. Breakdown of these bonds liberate energy to perform the various cellular activities. ATP is found in all living cells.

THE LIVING STATE

- In a living organism tens and thousands of metabolites or biomolecules are present at concentrations characteristic of each of them for example, **glucose is 4.5-5.0 mM in blood,** hormones in nanograms/ml.
- The most important fact of biological systems is that all living organisms exist in a **steady state**. Steady state is a non-equilibrium state in which all the biomolecules remain at constant concentration. These biomolecules are in a **metabolic flux.**
- Metabolic flux is the rate of turn over of molecules through a metabolic pathway. Flux (the act of flowing) is regulated by the enzymes involved in a pathway within cells. Regulation of flux is vital for all metabolic pathways to regulate the metabolic pathways activity under different conditions.
- Any chemical or physical process moves spontaneously to equilibrium but at equilibrium no work can be done. Living organisms cannot afford to reach equilibrium as they work continuously. Therefore, **the living state is a non-equilibrium steady-state to be able to perform work.**
- Living process is a constant effort to prevent attaining equilibrium. This is done by energy input (absorption of energy). Metabolism provides a mechanism for the production of energy. Hence the living state and metabolism are synonymous. Without metabolism there cannot be a living state.

ENZYMES

- Almost all enzymes are proteins that catalyse the biochemical reactions in living cells, hence called biocatalysts.
- Enzymes are proteinaceous in nature (Sumner 1926) with the exception of recently discovered two RNA enzymes.

(i) Ribozyme : Cech et al, 1981 isolated ribozyme from Tetrahymena.

- An **active site** of an enzyme is a crevice or pocket into which the substrate fits. A substrate is a specific compound acted upon by an enzyme. Thus enzymes, through their active site, catalyse reactions at a higher rate.
- Enzymes are organic catalysts, there are inorganic catalysts also, which do not occur in living cells.

Table : Differences between enzymes and inorganic catalysts

Enzymes	Inorganic catalysis
1. Almost all enzymes are proteins and have a complex molecular organization.	1. They are usually small and simple molecular like nickel, platinum etc.
2. They occur in living cells.	2. They do not occur in living cells.
3. An enzyme catalyses only a specific reactions.	3. They are not specific for any one reaction and can catalyse a number of reactions.
4. They get damaged at high temperatures (above 40°C).	4. They work efficiently at high temperatures and pressures.
5. They are highly efficient.	5. They are less efficient.

- Enzymes isolated from thermophilic organisms who normally live under extremely high temperatures (e.g., hot vents and sulphur springs), are thermally stable and retain their catalytic power even at high temperatures (up to 80º-90ºC). Thus **thermal stability** is an important quality of such enzymes isolated from thermophilic organisms.

Chemical Reaction

- Chemical compounds undergo two types of changes. A physical change simply refers to a change in shape without breaking of bonds. This is a physical process. Another physical process is a change in state of matter. When ice melts into water, or when water becomes vapour.
- This is an inorganic chemical reaction as it involves inorganic compounds.
- Hydrolysis of starch into glucose is an organic chemical reaction as both compounds are organic in nature.
- Rate of a physical or chemical process refers to the amount of product formed per unit time. It can be expressed as :

$$\text{Rate} = \frac{dp}{dt}$$

- Rate can also be called velocity if the direction is specified. One of the factor that influences the rates of physical and chemical processes, is **temperature**. A general thumb rule is that rate doubles or decreases by half for every 10ºC change in either direction. Reactions that occur in the presence of catalyst proceed at vastly higher rates or the catalysed reactions occurs very fast as compared to the uncatalysed ones.

For example---

$$\underset{\text{Carbone dioxide}}{CO_2} + H_2O \xrightleftharpoons{\text{Carbonic anhydrase}} \underset{\text{Carbonic acid}}{H_2CO_3}$$

- In the absence of the enzyme carbonic anhydrase, this reaction is very slow producing 200 molecules of H_2CO_3 in an hour. But when the reaction occurs in the presence of carbonic anhydrase (present in the cytoplasm), the reaction speeds dramatically with about 600,000 molecule.
- There are various types (thousands of types) of enzymes, each catalyse a unique chemical or metabolic reaction. A multistep chemical reaction, when each of the steps is catalysed by the same enzyme complex or different enzymes, is called a metabolic pathway. For example, glycolysis is a metabolic pathway in which glucose is converted into pyruvic acid through ten different enzyme catalysed metabolic reactions.

$$\text{Glucose} \rightarrow 2 \text{ pyruvic acid}$$

$$C_6H_{12}O_6 + O_2 \rightarrow 2C_3H_4O_3 + 2H_2O$$

- This metabolic pathway (glycolysis) with one or two additional reactions give rise to a variety of end products in different conditions.
- In our skeletal muscles, under anaerobic conditions the pyruvic acid gets converted into lactic acid. Under normal aerobic conditions pyruvic acid is converted into Acetyl CoA which in turn is converted into CO_2. and H_2O. In yeast, during the anaerobic conditions pyruvic acid is converted into alcohol by the process of fermentation.

How do enzymes bring about such high rates of chemical conversions?

- In order to understand how enzymes bring about such high rates of chemical conversions, we need to study them a little more. We have already learnt about the active site. Now, the chemical which is converted into a product is called a **'substrate'**. Thus, enzymes are proteins with three dimensional structures including an active site are capable of converting a substrate (S) into a product (P). This can be shown as :

$$\underset{\text{(substate)}}{S} \longrightarrow \underset{\text{(product)}}{P}$$

- The substrate 'S' binds to the active site of the enzyme for which it has to diffuse towards the active site. There is an obligatory formation of an 'ES' (Enzyme Substrate) complex. This complex formation lasts only for a short time and is a **transient phenomenon**.
- When substrate binds to the active site of enzyme a new structure of the substrate called transition **state structure** is formed.
- The molecules of the substrate undergo chemical changes i.e., breaking or making of bonds finally the product is formed and is released from the active site. Hence, enzyme trans formed the structure of substrate into product.
- The pathways of this transformation of substrate into product must go through the so-called **transition state structure**. There could be many more **'altered structural states'** between the stable substrate and the product. In this formation of substrate into product, all other intermediate structural states are unstable. Stability is something related to energy status of the molecule or the structure.
- For a reaction to start an external supply of energy is needed. It is called **activation energy.**

- Activation energy required for such a large number of reactions cannot be provided by living systems, Enzymes lower **the activation energy required for a reaction.**

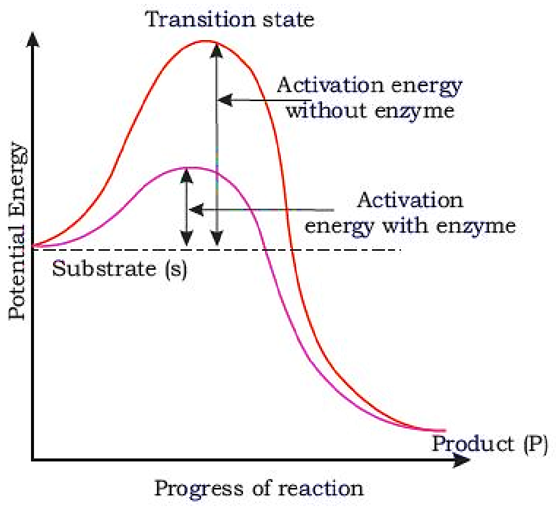


Fig. : Concept of activation energy

- In the given graph Y-axis represents the potential energy content. Potential energy of a body is it stored energy. The X-axis represents the progression of the structural transformation of substrate into product or states through the 'transition state', or we can say it represents the progress of reaction.
- If the energy level difference between S and P is such that P is at a lower level than 'S', the reaction is exothermic. In exothermic reactions, the energy content of the product is lower than that of this substrate as heat is released. External supply of energy is not required to form the product.
- When 'S' is at lower level than P, the reaction is endothermic. In endothermic reactions the energy content of products is higher. As, heat is absorbed in this reaction.
- The difference in the energy level of substrate (S) and transition state is the activation energy require to start the reaction.

Nature of Enzyme Action

Each enzyme has an active site to which substrate binds and forms a short lived highly reactive enzyme substrate complex. This is followed by formation of the enzyme-product complex (EP). Finally the enzyme product complex dissociates into product (P) and the enzyme, remains unchanged and is able to bind more substrate molecules.

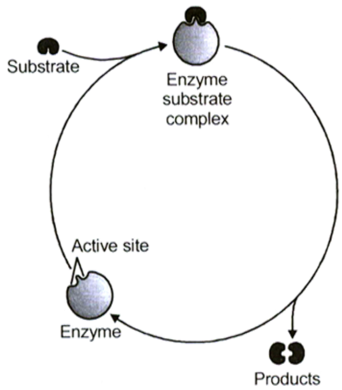


Fig. : The method by which the same enzyme molecule can be used again and again

The formation of the ES complex is essential for catalysis.

$$E + S \rightleftharpoons EP \rightarrow E + P$$

Factors Affecting Enzyme Activity

Enzymes are proteins with tertiary structures. Any change in the tertiary structure would affect the activity/action of enzymes. Factors which can affect the enzyme action are as follows :

(i) Temperature

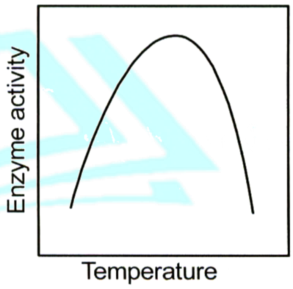


Fig: Effect of change in temperature on enzyme activity

(ii) Hydrogen ion concentration (pH)

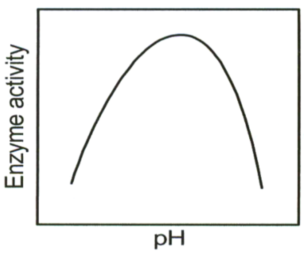


Fig. : Effect of change in pH on enzyme activity

(iii) Concentration of substrate

Increase in substrate concentration, increases the velocity of the enzymatic reaction. The reaction ultimately reaches a maximum velocity (V_{max}) which is not exceeded by any further rise in concentration of the substrate. This is because, at this stage the enzyme molecules become fully saturated and no active site is left free to bind additional substrate molecules.

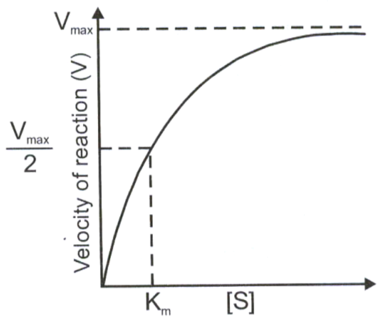


Fig. : Effect of change in : Concentration of substrate on enzyme activity

- **K_m (Michaelis constant)** is a mathematical derivation or constant which indicates the substrate concentration at which the chemical reaction catalysed by an enzyme attains half its maximum velocity or we can say that the concentration of the substrate at which half the maximum velocity) of the enzyme reaction is attained, is the K_m (**Michaelis constant)**.
- Allosteric enzymes do not show a typical Michaelis Menten constant.

Mechanism of Enzyme Action :

Two hypothesis have been put forward to explain the mode of enzyme action.

1. **Lock and Key Hypothesis :** This hypothesis was given by **Emil Fischer.**
2. **Induced Fit Hypothesis :** This hypothesis was proposed by **Koshland**

Inhibition of Enzyme Activity

Any substance that can diminish the velocity of an enzyme-catalyzed reaction is called an **inhibitor**. Reversible inhibitors bind to enzymes through non-covalent bonds. Dilution of the enzyme-inhibitor complex results in dissociation of the reversibly-bound inhibitor and recovery of enzyme activity. Irreversible inhibition occurs when an inhibited enzyme does not regain activity upon dilution of the enzyme-inhibitor complex. Some irreversible inhibitors act by forming covalent bonds with specific groups of enzymes; for example, the neurotoxic effects of certain insecticides are due to their irreversible binding at the catalytic site of the enzyme **acetylcholinesterase**. The two most commonly encountered types of inhibition are competitive and noncompetitive.

A. **Competitive inhibition :** This type of inhibition occurs when the inhibitor binds reversibly to the same site that the substrate would normally occupy and, therefore, competes with the substrate for that site.

1. **Effect on V_{max} :** The effect of a competitive inhibitor is reversed by increasing [S]. At a sufficiently high substrate concentration, the reaction velocity reaches the V_{max} observed in the absence of inhibitor.
2. **Effect on K_m :** A competitive in that in the presence of a competitive inhibitor more substrate is needed to achieve 1/2 V_{max}. e.g., **Inhibition of alcohol dehydrogenase by ethanol in methanol poisoning, sulpha drugs for folic acid synthesis in bacteria and inhibition of succinic dehydrogenase by Melonate and oxaloacetate.**

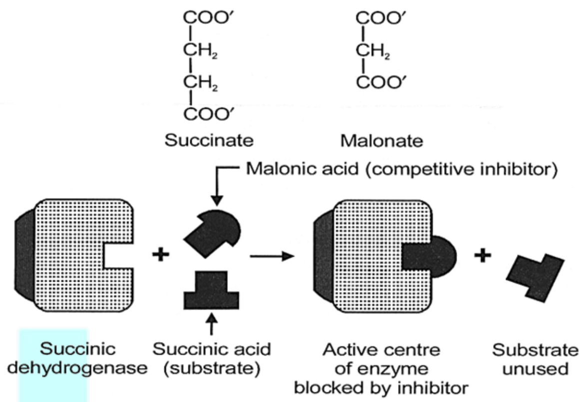


Fig. : Competitive inhibition of enzyme action

Classification and Nomenclature of Enzymes

Enzymes are divided into six classes :

(i) Oxidoreductases / dehydrogenases : Enzymes which catalyse oxidation-reduction reactions involving transfer of electrons/H^+ from one molecule to another. In these reactions one compound is oxidised and other is reduced.

Example - dehydrogenase, oxidases, reductases, catalase, peroxidase.

$$\text{Alcohol} + \text{NAD} \xrightarrow{hv} \text{Aldehyde} + \text{NADH}_2$$

(ii) Transferases : These enzymes catalyse the transfer of specific groups other than hydrogen from one substrate to another.

Example - Transaminase (transfers amino group), Kinase (catalyse the phosphorylation of substrate by transferring phosphate group usually from ATP).

$$S - G + S' \text{------}\rightarrow S + S' - G$$

$$\text{Glucose} + \text{ATP} \xrightarrow{E} \text{Glucose 6 phosphate} + \text{ADP}$$

(iii) Hydrolases : These enzymes catalyse the breakdown of larger molecules into smaller molecules with the addition of water. They catalyse hydrolysis of ester, ether, peptide, glycosidic, C – C, C-halide or P – N bonds.

Example - Proteases, amylases, lipases, maltase, nucleases and other digestive enzymes.

$$\text{Sucrose} + H_2O \xrightarrow{E} \text{Glucose} + \text{Fructose}$$

(iv) Lyases : These enzymes catalyse the cleavage of substrate into two parts, without the use of water or removal of groups without hydrolysis. A double bond is formed at the place of removal of group.

Example - Aldolase, decarboxylase, carbonic anhydrase etc.

$$\begin{array}{ccl} X & Y & \\ | & | & \\ C - & C & \dashrightarrow X - Y + C - C \end{array}$$

Fructose 1, 6, diphosphate $\longrightarrow$ Dihydroxy acetone phosphate + Glyceraldehyde phosphate

(v) Isomerases : These enzymes catalyse the rearrangement 'of molecular structure to form isomers. Isomers are molecules or molecular compounds that are similar in that they have the same molecular formula however have different arrangements of the atoms or group of atoms involved.

They catalyse inter- conversion of optical, geometric or positional isomers.

Example - Isomerase

Glucose-6-phosphate $\xrightarrow{E}$ Fructose 6-phosphate

(vi) Ligases : These enzymes catalyse covalent bonding of two substrates to form a large molecule. They catalyse joining of C-O, C-S, C-N, P-O etc. bonds by using energy of ATP.

Example - RUBP carboxylase, ligase, Phosphoenol pyruvate (PEP carboxylase) etc.

Chapter 10
Cell Cycle and Cell Division

CELL CYCLE

The sequence of events by which a cell duplicates its genome, synthesizes other constituents of the cell and eventually divides into two daughter cells is termed as cell cycle. It is a genetically controlled series of changes that occur in a newly formed cell by which it duplicates its contents, undergoes growth and division to form two daughter cells.

When a cell enters the cell cycle, it goes through various phases which prepare it for cell division. Synthesis of DNA, duplication of cell organelles, synthesis of various proteins are the various requirements of a cell which is about to enter mitosis. The cell synthesizes these constituents in a sequential pattern to ensure that proper division and distribution of components occurs within the two daughter cells. This ensures that proper intact genome enters the two daughter cells and progenies formed are functionally and structurally intact. The daughter cells then grow and again at maturity undergo cell division.

Growth is a continuous process which occurs throughout the life of a cell but duplication of organelles, DNA replication etc. occurs during a specific stage of the cell cycle.

Thus, the cell cycle is the period (time) between the formation of new daughter cells and their further division.

PHASES OF THE CELL CYCLE

Cell cycle basically consists of two phases namely :

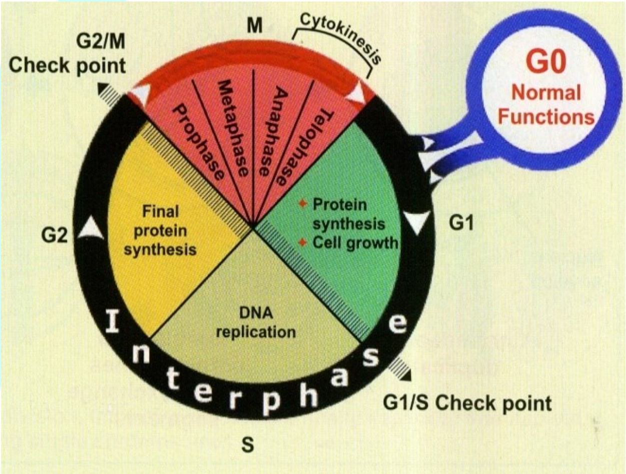
(i) Interphase

(ii) M or Mitotic phase

Interphase is a phase between two successive M phase, where the cell prepares itself for cell division. It is a biosynthetic phase in which the cell duplicates its organelles and replicates its DNA (genetic material). It constitutes more than 95% duration of the cell cycle.

M phase or Mitosis is the phase where the actual cell division occurs. In this phase, the cell utilizes the constituents formed during interphase and divide into two daughter cells.

Period of cell cycle varies from organism to organism and also from cell to cell, e.g., a yeast cell divides once in 90 minutes, a typical human cell divides approximately every 24 hours.



INTERPHASE

It is a long, non-dividing, growing phase of the cell cycle, where the cell prepares itself for division. It represents the most active stage of the cell cycle where both cell growth and DNA replication occur in an orderly manner. It is the period of intense growth and synthesis in which a cell stocks all the biomolecules required during cell division. It is called the **resting phase** because there is no apparent activity related to cell division rather, it deals with the changes that occur in a cell and the nucleus, before it enters into cell division. It is further divided into three stages:

(i) G_1 Phase

G_1 phase is the interval between mitosis and initiation of DNA replication. In this phase, cell does not synthesize or replicate DNA but remains metabolically active. The cell grows in size continuously and synthesizes nucleotides, ATP, proteins, amino acids, RNA etc. (required during S phase). **Most of the organelles duplication occurs in this phase.** The length of the G_1 phase varies from one cell to another. If a cell divides frequently, then it has a shorter G_1 phase and if a cell does not divide frequently, then it has a longer G_1 phase.

Some cells in an adult animal do not divide, e.g. nerve cell, whereas many cells divide occasionally just to replace the cell lost due to injury or cell death. Such type of cells remain in G_0 phase.

G_0 Phase: The non-dividing cell enters the quiescent stage or G_0 stage of the cell cycle. In this phase, the cell remains metabolically active but do not proliferate unless they are called on to do so.

(ii) S Phase

'S' or synthesis phase is a phase in which synthesis or replication of DNA takes place. It is the phase in which cell doubles its DNA. For example, if the initial amount of DNA is denoted by 2 C, then after the S phase the amount of DNA would become 4C. The amount of nucleic acid, i.e., DNA (genetic material) doubles but the number of chromosomes remains the same. For example, if a diploid cell has 2n number of chromosome at G., phase, then even after S phase, the number of chromosome would remain 2n. The existing DNA molecule acts as a template to synthesize new DNA molecule. The new DNA molecule forms the new chromatin fibres which remain attached in pairs, the chromatin material condenses to form two sister chromatids which remain attached to each other through a centromere. It holds the two sister chromatids together.

In animal cell, during the S phase, DNA replication begins in the nucleus, and the centrioles duplicate in the cytoplasm. Centrioles are required during the M phase. The centrioles are absent in the plant cell.

(iii) G_2 Phase

G_2 phase or Gap_2 phase is the second gap phase present between S and M phase. Tubulin protein synthesis take place. **Mitochondria, Chloroplast and Golgi bodies duplicate in this phase.**

The DNA synthesis stops at this phase but cell synthesizes RNA, proteins etc. required during the next phase. In animals, mitotic division is only seen in a diploid somatic cells, whereas in plant cells, mitotic division is seen in both haploid and diploid cells.

M PHASE

M phase or mitotic phase is the phase where actual cell division occurs. It is the most dramatic period of the cell cycle. Prior to this, cell duplicates its components and during this phase, distribution of the already duplicated components occurs in an orderly manner. It consists of two processes.

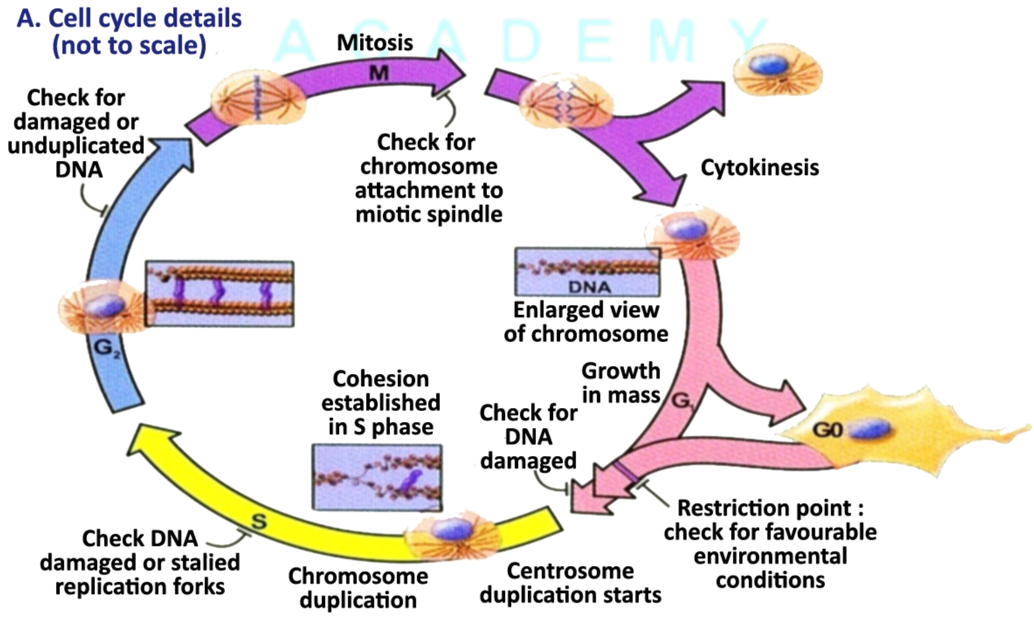
(i) Karyokinesis - where division of nucleus occurs

(ii) Cytokinesis - where division of cytoplasm occurs

Table: Difference between Cytokinesis and Karyokinesis

	Cytokinesis	Karyokinesis
1.	Cytokinesis is a biological process which involves division of the cytoplasm during mitosis or meiosis.	Karyokinesis is a biological process involving the division of a cell's nucleus during mitosis or meiosis.
2.	It is not divided into four stages.	Stages such as prophase, metaphase, anaphase and telophase are present in karyokinesis.

Therefore, during M phase reorganisation and separation of all the components of the cell occur.



MITOSIS

Definition : Mitosis is a process in which a parent cell divides into two identical daughter cells. These cells are identical to each other as well as to the parent cell. It is a type of division in which already duplicated chromosomes are distributed into two daughter cells equally, so that both the cells have the same number of chromosomes. Mitosis is called **equational division** because the two daughter cells have the same number of chromosomes as that present in the parent cell.

Occurrence : Mitosis is also called somatic cell division because it occurs in the somatic cells (body cells) of the animals. It also occurs in the gonads for the multiplication of undifferentiated germ cells. In plants, it occurs in the dividing meristematic tissue and also in leaves, flowers and fruits during growth.

Mechanism of Mitosis

Mitosis is an elaborate process, which involves a series of important changes in the nucleus as well as in the cytoplasm. There are two major events that occur during mitosis.

(I) Karyokinesis

(II) Cytokinesis

(I) Karyokinesis : Karyon means "nucleus" and kinesis means "movement", therefore karyokinesis is the division of the nucleus. Karyokinesis is a continuous process in which a parent nucleus divides into two daughter nuclei. There is no pause during the process but for our convenience, mitosis has been divided into four stages. Clear cut lines cannot be drawn between two stages because karyokinesis is a progressive process.

The four stages of mitosis are :

(1) Prophase : 'Pro' means first and 'phase' means stage, therefore prophase is the first stage of mitosis which follows the interphase phase of the cell cycle. The following events occur during prophase :

(i) The condensation of chromatin material takes place and during condensation, the DNA strands get untangled to form compact mitotic chromosomes.

(ii) Each chromosome appears double and consists of two coiled sister chromatids joined by a centromere. Their ends are not visible in early prophase. Therefore, the chromosomes appear like a ball of wool.

(iii) The centrioles in the animal cells, begin to move towards the opposite poles of the cell.

(iv) Initiation of the assembly of mitotic spindle occurs during prophase.

(v) Cells at the end of prophase, when viewed under the microscope, do not show Golgi complex, ER, nuclear membrane and nucleolus.

(2) Metaphase : 'Meta' means second and 'phase' means stage, hence metaphase is the second stage of mitosis. The following events occur during metaphase

(i) The disintegration of the nuclear envelope marks the beginning of the metaphase. The nuclear envelope disappears, and chromosomes spread through the cytoplasm of the cell.

(ii) The chromosomes contain two chromatids attached to each other through the centromere. The chromosomes during this stage are the thickest and shortest and hence, it is easy to study their morphology. The chromosomes condense to assume short rod-like forms during mitosis because it is easier for short, compact chromosomes to move through the cytoplasm in anaphase than it is for long, slender, twisted interphase chromosomes.

(iii) Mitotic spindle formation is complete. The phenomenon of bringing the chromosomes on the equator of spindle is called congression.

(iv) All the chromosomes align themselves at the equator. The plane of alignment of centromeres of all the chromosomes of the cell, at metaphase is referred as metaphasic plate.

(v) The centromere joins the two sister chromatids together. The surface of the centromere which holds the two sister chromatids of a chromosome is surrounded by a small disc-shaped structure called kinetochore.

(vi) The spindle fibres are made up of microtubules. The kinetochores present around the centromere forms the site of attachment of these microtubules. The microtubules of the spindle fibres attach to the kinetochore during metaphase.

(3) Anaphase : Ana means up and phase means stage. Anaphase is the phase where chromatids move towards the pole. Following events occur during anaphase :

(i) The centromere which holds the two chromatids together splits and separated daughter chromatids are now referred to as chromosomes of the future daughter nuclei.

(ii) The spindle fibres attached to the kinetochore now shorten and daughter chromosomes begin to migrate towards the opposite poles. Formation of interzonal fibres occur.

(iii) During migration, chromosomes always move away from the equatorial plate. The centromere of the daughter chromosome move towards the pole and the arms of chromosomes trail it. The anaphase ends when the chromosomes reach the poles. It is the **best stage to study shape of chromosomes (V, L, J, I).**

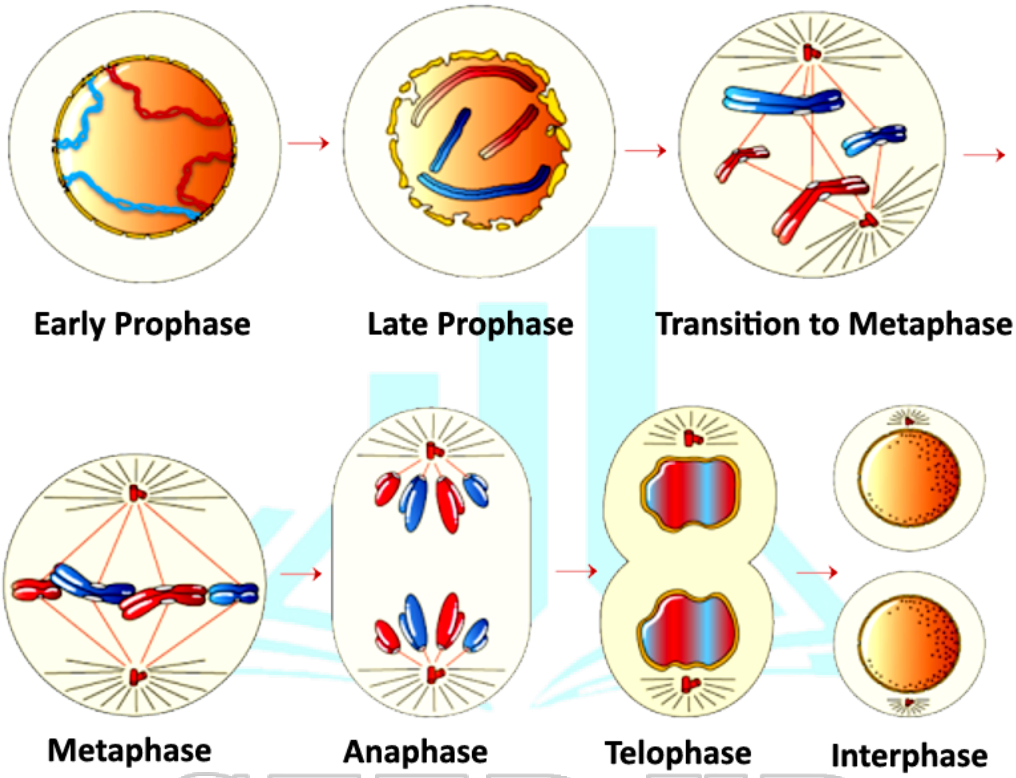
(4) Telophase : Telo' means end and 'phase' means stage, hence, telophase is the end stage of mitosis. The following events occur during telophase :

(i) The chromosomes (sister chromatids) reach their respective poles. The mitotic spindle disappears.

(ii) After reaching the poles, the chromosomes gradually uncoil and become thin, slender, long and lose their identity. The decondensation of chromosomes occur and finally they become indistinguishable mass and collect at the poles.

(iii) Nucleolus, endoplasmic reticulum, Golgi bodies, and other organelles reappear in the daughter cells.

(iv) The nuclear envelop assembles around the chromatin cluster.



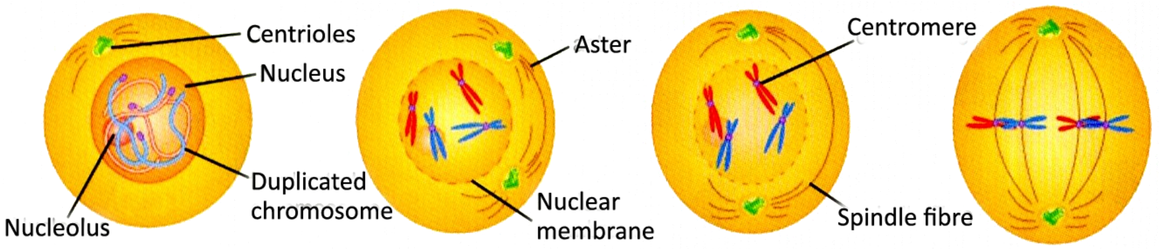
II. Cytokinesis: 'cytos' means 'cell' and kinesis means 'movement'. Cytokinesis is the division of cytoplasm. This phase marks the end of cell division. Mitosis is not only concerned with the division of the nucleus but is also concerned with the division of the cytoplasm. The division of cytoplasm occurs during Cytokinesis. After nuclear division, i.e., karyokinesis, the cytoplasm of the parent cell divides into two daughter cells, so that two daughter cells have their own nucleus and cytoplasm. The cell organelles present in the cytoplasm also distribute in two daughter cells.

In some organisms, karyokinesis is not followed by Cytokinesis. In these organisms, division of nucleus occurs but division of cytoplasm does not occur. As a result, large number of nuclei are present or embedded in the cytoplasm. This leads to the formation of syncytium i.e. a single cell containing large number of nuclei.

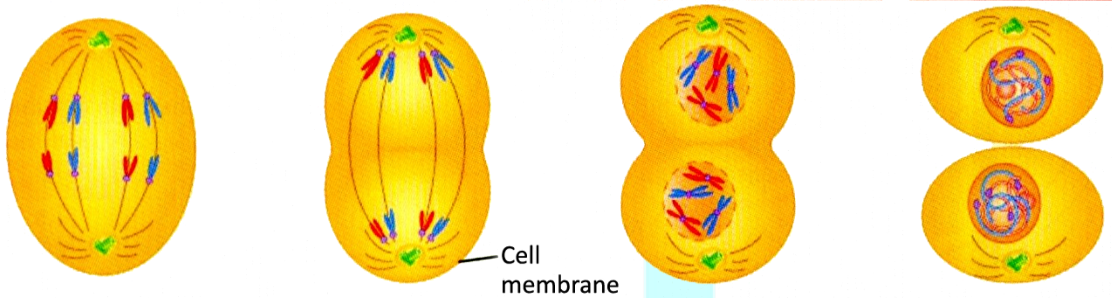
The cytokinesis occurs differently in animal cell and plant cell.

In animal cells, cytokinesis is achieved by the formation of a furrow. The furrow in the plasma membrane of the cell deepens gradually. It moves centripetally and ultimately joins in the centre dividing the cell cytoplasm into two. The constriction of the plasma membrane deepens further and finally joins and divides the animal cell into two daughter cells.

In plant cells, the cytokinesis is achieved by the formation of a cell plate. Phragmoplast is formed by Golgi complex and grows centrifugally to form cell plate. A plant cell is surrounded by an inextensible cell wall, hence it undergoes cytokinesis by a different mechanism. The cell plate starts from the centre of the cell and moves or grows centrifugally outwards to meet the lateral cell wall. It, therefore, divides the cell into two halves.



Prior to mitosis, each chromsome makes an exact duplicate of itself. The chromosomes then thicken and coil.	In early prophase, the centrioles, which have divided, form asters and move apart. The nuclear membrane begins to disintegate.	In late prophase, the centrioles and asters are at copposite poles. The nucleolus and nuclear membrane have almost disappeared.	The doubled chromosomes their centromeres attached to the spindle fibres - line up at mid-cell in the metaphase.



In early anaphase, the centromeres split. Half the chromosomes move to one pole, half to the other pole.	In late anaphase, the chromosomes have almost reached their respective poles. The cell membrane begins to pinch at the centre.	The cell membrane completes constriction in telophase. Nuclear membranes form around the separated chromosomes.	Mitosis completed, there are two cells with the same structures and number of chromosomes at the parent cell.

Table : Difference between cytokinesis in plant cell and animal cells.

	Cytokinesis in Plant Cell	Cytokinesis in Animal Cell
1.	The division of the cytoplasm (cytokinesis) occurs by formation of cell plate.	The division of the cytoplasm occurs by formation of furrow.
2.	Cell plate formation starts at the centre of the cell and grows outward, towards the lateral walls, dividing the cell into two halves.	Furrow starts at the periphery and then moves inward, dividing the cell into two halves.

SIGNIFICANCE OF MITOSIS

1. **Growth :** Mitosis is essential for the growth and development of multicellular organisms. A fertilized egg develops into an embryo which finally forms an adult by repeated mitotic divisions. Somatic cells of an organism are formed by mitosis.
2. **Maintenance of cell size :** Mitosis maintains the size of the cell. An overgrown somatic cell is induced to divide, so that it maintains a proper surface area to volume ratio, which is essential for proper functioning of the cell. If a cell becomes large, then it enters into mitosis.
3. **Maintenance of chromosome number (genetic stability) :** Mitosis maintains the same type and number of chromosomes in two daughter cells.
4. **Repair:** Mitosis is a mechanism for replacing old dead and worn out cells by the new cells.
5. **Reproduction :** Mitosis brings about reproduction (multiplication) in unicellular organisms.
6. **Healing and regeneration :** Mitosis produces new cells for healing the wounds and for regeneration.

MEIOSIS

The term meiosis was coined by **Farmer and Moore** in 1905. The division was studied by **Van Benedin Winiwarter and Strassburger.** Meiosis or meio is "to lessen", hence meiosis is a double division in which a diploid cell form four haploid cells, each having half the number of chromosomes. In this division, a single parent cell (diploid) forms four daughter cells (haploid). Meiosis involves two sequential cycles of nuclear division but only one cycle of DNA replication due to which four haploid daughter cells are formed.

Occurrence : Only the cells of sexually reproducing organisms undergo meiosis, and only special cells in the multicellular organism switch from mitosis to meiosis at a specific time in the life cycle.

An offspring produced by sexual reproduction involves fusion of two haploid gametes. These haploid gametes are formed by meiosis. Meiosis ensures the production of haploid phase in the life cycle of sexually reproducing organisms whereas fertilization restores the diploid phase.

Meiosis consists of two divisions, i.e., Meiosis I and Meiosis II, which occur in a sequential manner. **Meiosis I is called reductional division** because during this division, the chromosome number is reduced to half. Meiosis II is called equational division because during this division, the number of chromosome remains the same as produced at the end of Meiosis I. Meiotic events can be grouped under following phases .

	Meiosis I	Meiosis II
1.	Prophase I	Prophase II
2.	Metaphase I	Metaphase II
3.	Anaphase I	Anaphase II
4.	Telophase I	Telophase II

A. Meiosis I

It is the reductional division in which the number of chromosomes is reduced to half. It is studied in four stages:

1. Prophase I : Prophase I is more elaborate, prolonged, complex than prophase of mitosis. The events occurring during prophase I are also slightly different than prophase of mitosis. The long and complicated prophase I is further subdivided into five stages, viz., Leptotene, Zygotene, Pachytene, Diplotene and Diakinesis. We would study the details of these subdivisions.

(i) Leptotene : Condensation and coiling of chromatin fibres begins during leptotene. The chromatin material condenses to form distinct chromosomes which gradually become visible under the light microscope.

(ii) Zygotene : Zygotene is the second stage of prophase I. It occurs after leptotene. A diploid cell contains two sets of chromosomes. The two chromosomes which are similar in form, size, structure are called **homologous chromosomes**. One of the homologous chromosomes is paternal chromosome and the other is maternal chromosome.

During zygotene, these homologous chromosomes start pairing together. These homologous chromosomes come to lie side by side in pairs and this pairing is known as **synapsis**. The complex formed by a pair of synapsed chromosome is called bivalent. Bivalent because two homologous chromosomes form a pair.

Electron microscopic studies of this stage shows that chromosomal synapsis is accompanied by a structure called synaptonemal complex which is thought to stabilise the two homologous chromosomes till the crossing over is completed.

(iii) Pachytene : It is the third stage of prophase I. It occurs after zygotene and the following events occur during pachytene :

(a) The synapsed chromosomes continue to become thick and short. The chromatids of the homologous chromosomes now become clearly visible as tetrad. The two chromatids of the same chromosome are called **sister chromatids** and two chromatids of the two different homologous chromosomes are called **non-sister chromatids.**

(b) During pachytene, **crossing over occurs between the non-sister chromatids of the homologous** chromosomes. The exchange of genetic material (DNA) between the non-sister chromatids of the homologous chromosomes is known as crossing over.

(c) Crossing over leads to recombination of genetic material which involves a mutual exchange of the corresponding segments of non-sister chromatids of homologous chromosomes. It takes place by breakage and reunion of Chromatid segments.

(d) The site where crossing over occurs forms a recombination nodule. The recombination is an enzyme-mediated process. An enzyme called recombinase is involved during this process.

(e) By the end of pachytene, the recombination between the homologous chromosome is complete and the two chromatids are linked at the site of crossing over.

(iv) Diplotene : Diplotene is the fourth stage of prophase I. During this stage, the crossing over is completed and the two homologous chromosomes begin to separate from each-other.

The following events occur during this phase :

(a) The synaptonemal complex formed during the zygotene dissolves during diplotene. Therefore, the homologous chromosomes separate **except** in the region of crossing over.

(b) The point of attachment between the homologous chromosomes after **dissolution of the synaptonemal complex** is called **chiasmata**. It becomes visible during diplotene stage. The two homologous chromosomes begin to separate from each other but remain attached at the chiasmata. Chiasmata marks the sites where crossing over occurred during pachytene. The homologous chromosomes do not separate at chiasmata, and hence, they are seen as X-shaped structure.

(c) In oocytes of some vertebrates, diplotene lasts for month or years. It is called diplotene stage.

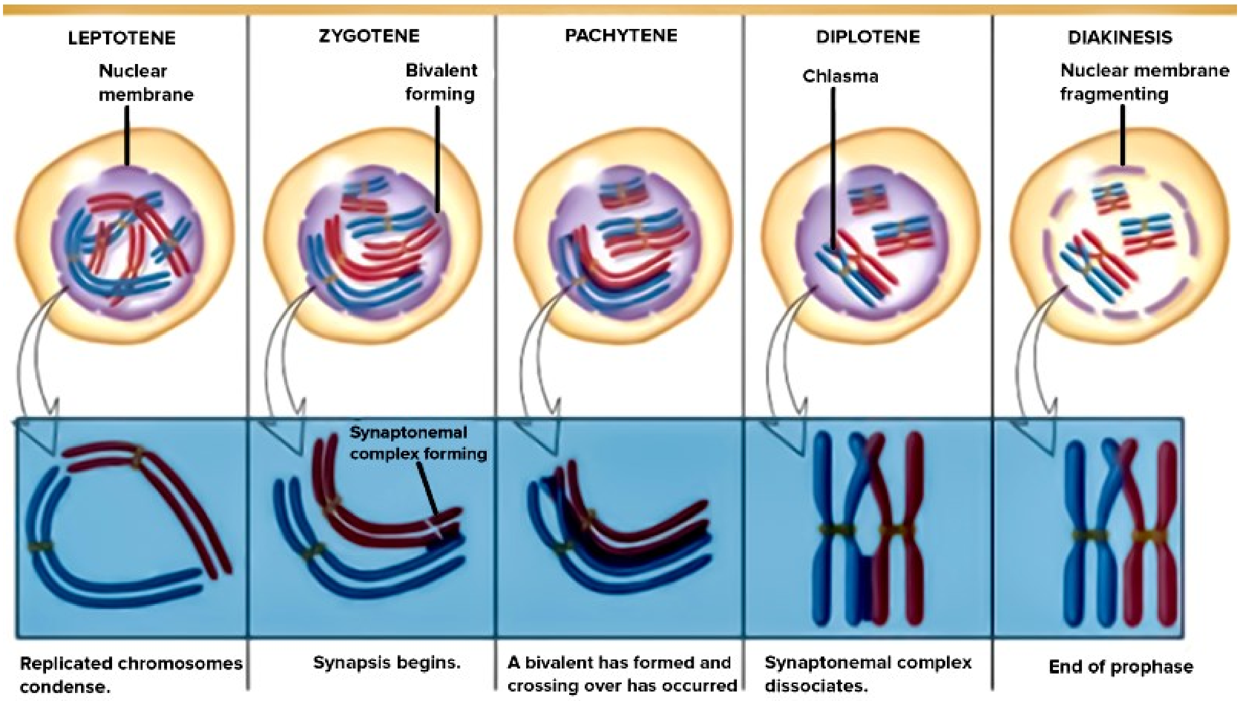
(v) Diakinesis : It is the final stage of prophase 1. It represents transition to metaphase I. The following events occur during diakinesis :

(a) Spindle assembles to prepare homologous chromosomes for separation. It assembles at the poles, so that it separates the homologous chromosomes into two cells.

(b) Terminalisation of chiasmata ; Due to tight condensation of chromosomes, the chiasmata disappear from the chromosomes by slipping off or sliding from the tip of the chromosomes. The chiasmata move or shift to the tip of the chromosome and from there it either slips off or remains at the tip.

(c) Nucleolus disappears and the nuclear envelope disintegrates.

STAGES OF PROPHASE OF MEIOSIS I



2. Metaphase I : After completing prophase I, chromosomes enter metaphase I. The nuclear envelope disintegrates, hence the chromosomes move into the cytoplasm. Following events occur during metaphase :

(i) The bivalent chromosomes align themselves on the equatorial plate. The centromeres of the two chromosomes are arranged in two rows at the equator. So double metaphasic plate is formed.

(ii) The distribution of the bivalent chromosomes are at random. The two chromosomes can face either of the poles. There is no fixed direction in which paternal or maternal chromosomes would face.

(iii) The microtubules of the spindle fibres from opposite poles attach to the centromere of the chromosome facing towards it.

3. Anaphase I: Following events occur during anaphase I

(i) The two homologous chromosomes separate from each other. They start moving towards the poles.

(ii) The intact chromosome or univalent containing two chromatids held together by a centromere separate and move towards the opposite poles due to spindle fibre attached to it. In this phase division at centromere does not occur.

(iii) Since only one chromosome out of a pair reaches the pole, the number of chromosome becomes half in the daughter cells. **The reduction in the number of chromosomes occurs during anaphase I.**

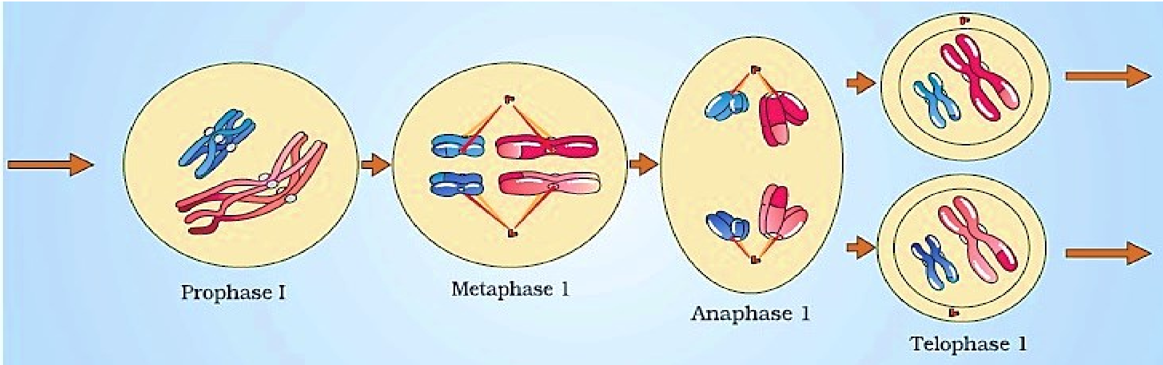
4. Telophase I: It is the final stage of reductional division, i.e. meiosis I. It is characterised by following events:

(i) The chromosomes reach the poles. The spindle fibres completely disappear.

(ii) The nucleolus and nuclear membrane reappear.

(iii) The chromosomes uncoil and elongate but remain straight in this phase. They do not reach the extremely extended state of the interphase nucleus.

(iv) It produces two daughter cells each containing a single nucleus. The nucleus of the daughter cell receives only one chromosome from each homologous pair and thus, it has half the number of chromosome but double the amount of nuclear DNA as both the chromatids move together to a single pole. The separation of these two chromatids occurs during meiosis II.



Cytokinesis : It generally follows the first nuclear division, so two daughter cells are formed which are haploid,

Interkinesis or Intrameiotic Interphase

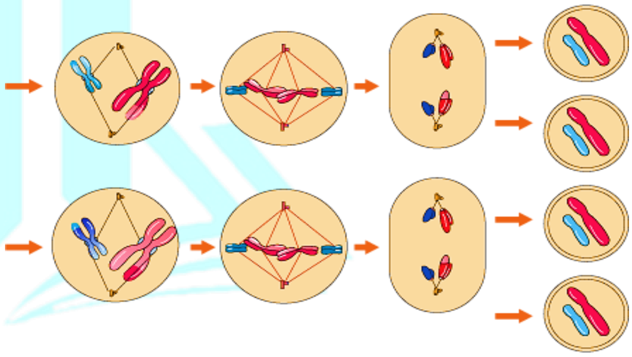
Interkinesis or intrameiotic interphase is a metabolic stage between telophase I and prophase II. It is a gap which exists between meiosis I and meiosis II. During this phase, the chromosomes are elongated but do not form chromatin fibres. There is no replication of DNA during this phase, but centrioles pairs replicate in animal cell. The RNA and protein required during meiosis II are synthesized during this phase.

B. Meiosis II

Meiosis II is similar to mitosis, i.e., equational division, but not an exact copy of mitosis because mitosis occurs in diploid somatic cell but meiosis II always occurs in haploid germ cells. Mitosis is always followed by DNA replication, but meiosis II is not followed by DNA replication. The daughter cell formed after meiosis II are neither similar to each other nor similar to the parent cell.

The main event which occurs during meiosis II is the separation of the Chromatid of the univalent chromosomes present in the daughter cell formed after meiosis I. The chromatids present in the univalent chromosome differ from each other due to crossing over. Meiosis II is divided into four phases, namely - Prophase II, Metaphase II, Anaphase II, Telophase II.

1. **Prophase II :** Prophase II is not long and complicated as prophase I. It is a short phase where the chromatids of the univalent condenses. The chromatin material again becomes compact. The nucleolus and the nuclear envelope disintegrate and disappear.
2. **Metaphase II :** The univalent, i.e., chromosomes align themselves at the equator, (on the equatorial plane) in the metaphase II. The microtubules from the opposite poles extend towards the equator and attaches at the kinetochore of the chromatids.
3. **Anaphase II :** It is the third phase of meiosis II. During this phase, the centromere holding the two chromatids splits and allow the separation and movement of the two chromatids. Chromatids move to the opposite poles.
4. **Telophase II :** This is the last stage of meiosis II. During this phase, the chromatids reach the poles and start uncoiling. They decondense and become thin. The spindle fibres degenerate. The nuclear membrane and nucleolus reappear and four haploid nuclei are formed. The telophase II is now followed by cytokinesis which divides the cytoplasm and forms four individual haploid cells.



Cytokinesis

The cytoplasm divides by forming a furrow in the animal cell and cell plate in the plant cell. After cytokinesis, a single cell divides into two daughter cells. The daughter cells contain a single nucleus and their own cytoplasm. Each daughter cells of meiosis I divides to form two daughter cells and hence at the end of meiosis, i.e., after meiosis I and meiosis II, a diploid cell gives rise to four haploid daughter cells.

SIGNIFICANCE OF MEIOSIS

1. **Formation of gametes :** Meiosis produces gametes for sexual reproduction. Gametes are essential for sexual reproduction because in sexual reproduction an organism is formed by the fusion of two gametes.
2. **Maintenance of chromosome number :** Meiosis reduces the chromosome number to half in the gametes, so that fertilization restores the original diploid number in the zygote.
3. **Introduction of variations** : Meiosis provides a chance for the formation of new combinations of chromosomes. This brings out variations.

Table : Some Major Differences between Mitosis and Meiosis

Mitosis	Meiosis
1. Karyokinesis and DNA replication occur once.	**1.** Karyokinesis occurs twice, but DNA replicates once only.
Prophase :	
2. Prophase is short and in **without sub-stages.**	**2.** Prophase I is prolonged **with 5 different sub-stages.**
3. There is **no pairing** of homologous chromosomes (synapsis) using synaptonemal complex and hence, **no chance of crossing over and chiasmata formation.**	**3.** Homologous chromosomes pair using synaptonemal complex during **zygotene sub-over during pachytene stage,** hence **forming chiasmata.**
4. Prophase chromosomes appear double from the very beginning.	**4.** The chromosomes appear as single thread initially.
Metaphase :	
5. All chromosomes form a single plate in metaphase.	**5.** Chromosomes form two parallel plates in metaphase I and one plate in metaphase II.
6. On equatorial plate, chromosomes appear two threaded.	**6.** On equatorial plate chromosomes appear four threaded in metaphase I, while metaphase II is similar to metaphase of mitosis.
Anaphase :	
7. Splitting of centromere of chromosomes and hence, separation of two chromatids of each chromosome occurs at anaphase.	**7.** There is no splitting of centromeres in anaphase I and there is **separation of homologous chromosomes in anaphase I. In anaphase II, splitting of centromeres and hence, separation of chromatids occurs.**
Telophase :	
8. Telophase occurs in all cases.	**8.** In some cases, telophase I is omitted.
9. Daughter cells have same number of chromosomes as parent cell.	**9.** At the end of telophase I, chromosome number is reduced to half.
Cytokinesis :	
10. Karyokinesis (division of nucleus) is usually followed by **cytokinesis** (wall formation).	**10.** Sometimes cytokinesis does not occur after telophase I, or meiosis I, but it **always occurs** after meiosis II or telophase II, thus forming cells simultaneously.
Significance :	
11. Mitosis is responsible for growth, repair and healing.	**11.** Meiosis is responsible for maintaining chromosome number constant from generation to generation, forms gametes or spores and also produces variations due to crossing over.

AMITOSIS OR DIRECT CELL DIVISION

It is the method of asexual reproduction, which occurs in acellular organisms like bacteria, protozoans, diseased cells, old cells, mammalian cartilage cells and in foetal membranes. It was first discovered by **Remak.** It is also called **direct cell division.**

During amitosis, the nucleus of the cell elongates. Then, a constriction appears in the nucleus which gradually deepens and divides the nucleus into two daughter nuclei. Finally, a constriction appears in the cytoplasm which divides the cytoplasm and the nuclei into two daughter cells, each with a nucleus. In this division, no **spindle**

formation and no distinct chromosome formation occurs. Nuclear envelope remains intact. The daughter cells are approximately the two equal halves of a parental cell.

ADDITIONAL INFORMATION

- The alkaloid **colchicine** inhibits the formation of mitotic spindle (inhibits polymerisation of microtubules) and holds the cells in metaphase. The chromosomes and DNA undergo replication but remain within the same cell. The nucleus does not divide. This increases the number of chromosome sets per cell. This process leads to **endopolyploidy** or **endomitosis** in which nucleus contains multiple sets of chromosomes instead of the normal two sets as found in a diploid cell. Such cells are called **polyploid cells**.
- **Anastral -** Division in which aster formation is absent e.g. plants.
- **Amphiastral-** Division which involves formation of two asters e.g. animals.

Chapter 11
Photosynthesis in Higher Plants

IMPORTANCE OF PHOTOSYNTHESIS

(i) It is the primary source of food on earth-

(ii) It is also responsible for the release of oxygen into the atmosphere by the green plants which is needed by mostly all life forms.

WHAT DO WE KNOW?

Study on photosynthesis started around 300 years ago. On the basis of what we have studied in our earlier classes, simple experiments have shown that chlorophyll (green pigment of the leaf), light and CO_2 are required for photosynthesis to occur. Experiment to demonstrate light & chlorophyll is necessary for photosynthesis; Take a destarched potted plant having variegated leaves and cover 2-3 leaves with the black paper. Expose the potted plant to sunlight for 1-2 hours. Pluck one covered leaf and one exposed leaf and test them for starch. The covered leaf does not show positive starch test showing that photosynthesis cannot occur in the absence of light. The exposed leaf shows blue and yellow parts where the blue color or positive starch test occurs in the chlorophyll-containing parts.

Experiment to demonstrate CO_2 is necessary for photosynthesis (Moll's Half leaf experiment): A part was of leaf was enclosed in a test tube containing some KOH-soaked cotton (which absorbs CO_2), while the other half of leaf was exposed to air. When the two halves of leaf were tested for starch, it was found that only the exposed part of leaf tested positive for starch. This showed us that CO_2 is required for photosynthesis.

HISTORICAL ACCOUNT - EARLY EXPERIMENTS

There have been several simple experiments done which led to a gradual development in our understanding of photosynthesis.

(i) **Joseph Priestley (1733-1804)** in 1770 revealed the essential role of air in the growth of green plants through several experiments, He discovered oxygen in 1774. In an experiment done, Priestley observed that a candle burning in a closed space i.e., a bell jar, soon gets extinguished. Similarly, a mouse would die of suffocation in a closed space (as shown in figure (a)&(b)). Through his experiment, he concluded that both, the burning, candle and the mouse damage the air they use. But, when a mint plant was placed in the same bell jar, the mouse stayed alive and the candle continued to burn (as shown in figure (c) &(d)). Thus, Priestley concluded that the plants restore to the air whatever the breathing mouse and the burning candle removed

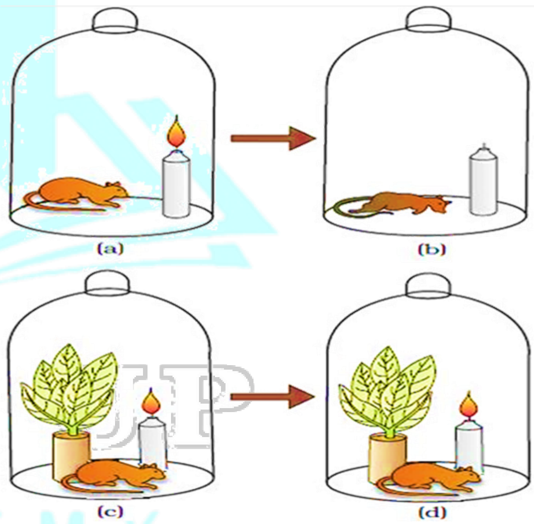


Fig. : Priestley's experiment

(ii) **Jan Ingenhousz (1730-1799)** through his experiments showed that sunlight is essential for the plant process that helps to somehow purify the air fouled by the breathing mouse and the burning candle. In another experiment, with an aquatic plant (Hydrilla) he showed that in bright sunlight, small bubbles were formed around the green parts of plant while in the dark, no bubbles were formed. He identified those bubbles to be of oxygen. Therefore, he showed that in the presence of sunlight it is only the green parts of the plants that could release oxygen.

(iii) **Julius von Sachs (1854)** found that the green parts in plants is where glucose is made and glucose is usually stored as starch. Later, he showed that the green substance in plants (now called chlorophyll) is located in special bodies (now called chloroplasts) within the plant cells.

(iv) T.W. Engelmann (1843-1909) experimented on Cladophora. Using a prism he split light into its spectral components and then he illuminated a green alga, Cladophora, placed in a suspension of aerobic bacteria. The bacteria were used to detect the sites of oxygen evolution. He found that the bacteria accumulated mainly in the region of blue and red light of the split spectrum. And thus, the first action spectrum of photosynthesis was described.

The empirical equation representing the total process of photosynthesis for organisms evolving oxygen was understood as:

$$CO_2 + H_2O \xrightarrow{\underline{Light}} [CH2O] + O_2$$

where $[CH_2O]$ represented a carbohydrate.

(v) Cornelius van Niel (1897-1985) a microbiologist, based on his studies of purple and green sulphur bacteria demonstrated that during photosynthesis, hydrogen released from a suitable oxidisable compound reduces carbon dioxide to carbohydrates and he inferred that oxygen evolved by the green plants comes from H_2O (water) and not from carbon dioxide. This hypothesis was later proved by using radio isotopic techniques.

$$2H_2A + CO_2 \xrightarrow{\underline{Light}} 2A + CH_2O + H_2O$$

where H_2A is the oxidisable compound (H_2O or H_2S).

The correct equation to represent the overall process of photosynthesis could thus be summed as:

$$6CC_2 + 12H_2O \xrightarrow{\underline{Light}} C_6H_{12}O_6 + 6H_6O + 6O_2\uparrow$$

where is $C_6H_{12}O_6$ glucose and O_2 is released from water.

Ruben, Kamen etal. used heavy but non-radioactive, stable isotope of oxygen ^O to prove that evolve during light reaction comes from and not from CC_2.

Light: Sunlight is like a rain of photons of different frequencies. Visible light consists of radiations having a wavelength between 390-760 nm. Part of spectrum used in photosynthesis has a wavelength between 400-700 nm. It is called **photosynthetically active radiation (PAR).**

WHERE DOES PHOTOSYNTHESIS TAKE PLACE?

Photosynthesis takes place in the green leaves of plants and other green parts of plants like stem etc. The most active photosynthetic tissue in higher plants is the mesophyll of leaves. Mesophyll cells have many chloroplasts, which contain the specialised light-absorbing green pigments, the chlorophylls.

Chloroplasts

In photosynthetic eukaryotes, photosynthesis occurs in the subcellular organelle known as the chloroplast. This double membrane-enclosed organelle possess a **third system** of membranes called **thylakoids**.

A stack of thylakoids forms a **granum**. Adjacent grana are connected by unstacked membranes called **stroma lamellae**. The fluid compartment surrounding the thylakoids, called the **stroma**.

There is a clear division of labor within the chloroplast.

(i) Proteins and pigments (chlorophylls and carotenoids) that function in the photochemical events of photosynthesis, i.e., trapping the light energy and synthesis of ATP and NADPH, are embedded in the thylakoid membrane.

(ii) In stroma, enzymatic reactions incorporate CO;, into the plant leading to the synthesis of sugar which in turn forms starch.

The former set of reactions, since they are directly light-driven are called light reactions. The latter are not directly light-driven but are dependent on the products of light reactions (ATP and NADPH). Hence, to distinguish the latter they are called by convention, as dark reactions. However, this should not be construed to mean that they occur in darkness or that they are not light-driven

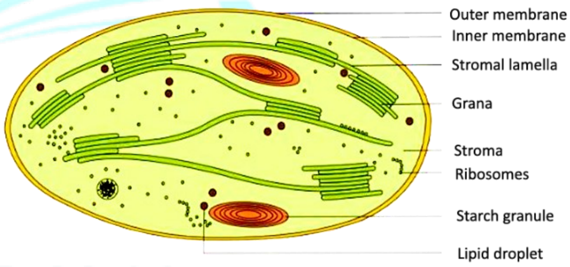


Fig. : Diagrammatic representation of an electron micrograph of a section of chloroplast

PHOTOSYNTHETIC PIGMENTS

Pigments are substances that have an ability to absorb light, at specific wavelengths.

A chromatographic separation of the leaf pigments shows that the colour of leaves is due to four pigments.

- **(i) Chlorophyll a** - Bright or blue green in the chromatogram.
- **(ii) Chlorophyll b** - Yellow-green
- **(iii) Xanthophyllls** - Yellow
- **(iv) Carotene** - Yellow to yellow-orange

Of these, chlorophyll-a is the primary photosynthetic pigment.

Accessory Pigments

All pigments other than chlorophyll a are called accessory pigments.

These have two major roles in photosynthesis;

(i) They absorb light of different wavelengths and transfer the energy to chlorophyll molecules; thus they are also called **antenna molecules**. This enables a wider range of wavelength of incoming light to be utilized for photosynthesis. Chlorophyll b accounts for about one-fourth of total chlorophyll' content.

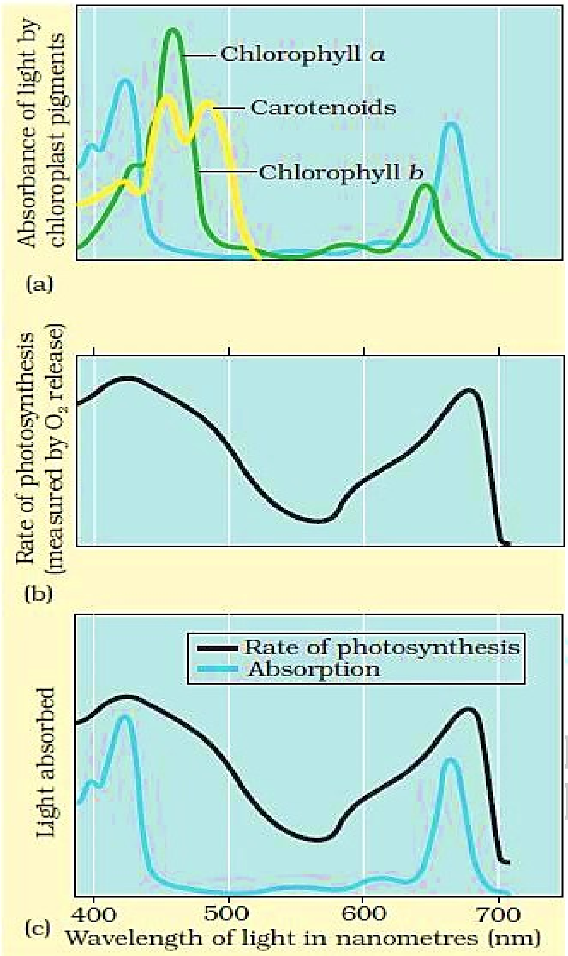


Fig. : (a) Graph showing the absorption spectrum of chlorophyll a, b and the carotenoids (b) Graph showing action spectrum of photosynthesis
(c) Graph showing action spectrum of photosynthesis superimposed on absorption spectrum of chlorophyl α.

(ii) Carotenoids protect plant from excessive heat and prevent photo-oxidation (oxidative destruction by light) of chlorophyll pigments. Thus, they are also called "**Shield Pigments**".

Let us study the graph showing ability of pigments to absorb lights of different wavelengths.

Absorption spectrum: The graphic curve showing the amount of energy of different wavelengths of light absorbed by a substance/pigments.

Action spectrum of photosynthesis corresponds closely to absorption spectra of chlorophyll a showing that chlorophyll a is the chief pigment associated with photosynthesis.

These graphs, together, show that most of the photosynthesis takes place in the blue and red regions of the spectrum, some photosynthesis does take place at the other wavelengths of the visible spectrum. These graphs depict that maximum photosynthesis occurs at the wavelength at which there is maximum absorption by chlorophyll a i.e., in the blue and red regions.

WHAT IS LIGHT REACTION?

Light reactions or the 'Photochemical' phase is thought to be responsible for the formation of high- energy chemical intermediates, ATP and NADPH, and it includes light absorption, water splitting and release of oxygen Several complexes are involved in this process which are discussed below :

THE PHOTOSYNTHETIC UNITS/ PIGMENT SYSTEMS

These are group of pigments molecules which take part in the conversion of light energy into the chemical energy. The photosynthetic units are called Photosystem I (PS-1) and Photosystem II (PS-11). Each unit has a **reaction centre** of a specific chlorophyll a molecule which absorbs light energy of long wavelength. There center can release electron upon absorption of energy. In PS-1, the reaction centre chlorophyll a has absorption peak at 700 nm, hence is called **P_{700}**, while in PS-II, reaction centre has an absorption maxima at 680 nm and is called **P_{680}**.

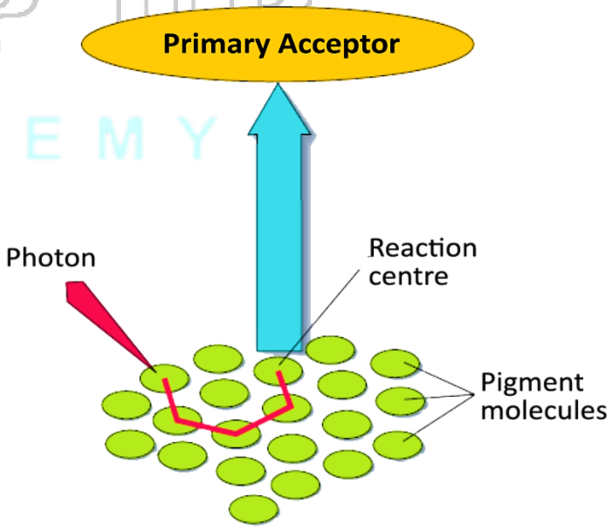
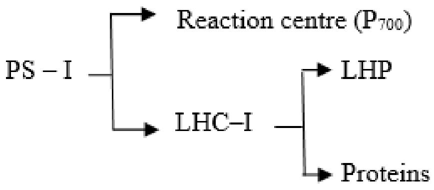
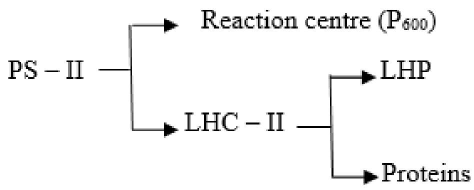


Fig. : The light harvesting complex

Reaction centre is surrounded by number of light harvesting pigment (LHP) molecules. These are also called antenna molecules. These absorb photons of different wavelength and transfer this energy to reaction centre.

Harvesting molecules occur in form of specific complexes called light-harvesting complexes (LHC) called LHC-1 and LHC-11. The pigment molecules of these complexes are bound to proteins. These help to make photosynthesis more efficient.





Photosystem I /Pigment system I	Photosystem II/ Pigment II
1. The reaction centre is P_{700}.	1. The reaction centre is P_{880}
2. PS I lies on the outer surface of the thylakoids.	2. PS II occurs on the inner surface of the thylakoids.
3. Found in both grana and stroma lamellae.	3. Found in grana lamellae only.
4. Participates in both cyclic as well as non-cyclic flow of electrons.	4. It is involved only in non-cyclic flow of electrons.
5. Not associated with splitting of water.	5. Associated with splitting of water and release of O_2.

Production of Assimilatory Powers in Photosynthesis

Arnon used the term assimilatory powers to refer ATP and NADPH.

The process of reduction of NADP into NADPH + H" may be denoted as electron transport system (ETS) in, photosynthesis while the process of formation of ATP from ADP and inorganic phosphate (JP) utilising light energy is called **photophosphorylation**.

The flow of electrons through ETS is linked to photophosphorylation,

THE ELECTRON' TRANSPORT

Electron transport chain is a series of electron carriers Over which electrons pass io a downhill' journal releasing energy at every step that is used in generating an electrochemical proton gradient which helps synthesizing ATP.

Non-Cyclic Photophosphorylation

It involves both Photosystem I and Photosystem H. These two photosystems work in series, first PS II1 are then PS 1. The two photosystems are connected through an electron transport chain. Both ATP and NADPH + H^+ are synthesised by this kind of electron flow.

First in PS II, the P_{680} molecule absorbs 680 nm wavelength of red light causing, electrons to become excited and jump into an orbit which is farther from the atomic nucleus.

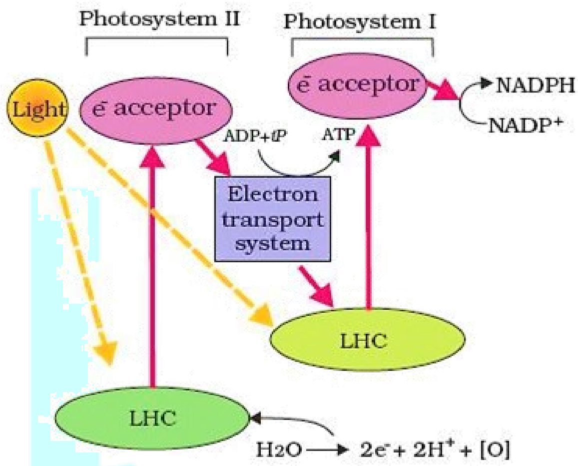


Fig-: Z scheme of light reaction

These electrons are picked up by an electron. acceptor which passes them to an electron transport system of cytochromes. This movement of electrons is downhill on redox potential scale. The electrons and then passed onto the pigments of PS I, without being used as they pass through the electron transport chain Simultaneously, electrons in the reaction center of PS I (P_{700}) are excited when they receive light of wavelengths 700 nm and -these electrons .are transferred to another acceptor molecule that has a greater redox potentials. These electrons are then moved downhill, again to a molecule of NADF$^+$. The addition of these electronic reduces .the NADP$^+$ to NADPH + H^+.

The whole scheme of transfer of electrons, starting from the PS 11. uphill to the acceptor, down the electrons transport chain to PS I, excitation of electrons, transfer to another acceptor and finally downhill to NADF causing it to be reduced to NADPH + H^+ is called Z-scheme. This shape is formed when all the carriers a placed in a sequence on a .redox potential scale.

Splitting of Water

The electrons that were removed from PS II must be replaced. This is achieved by electrons available did to splitting of water. The water splitting complex is associated with the PS li, which itself is physically locates on the inner side of the membrane of the thylakoid. Water is split into

H'1", 1(0] and electrons. The produce and oxygen formed .by splitting of water is released within the lumen of the thylakoids. The oxygen produce is released as one of the net products of photosynthesis,

$$2H_2O \rightarrow 4H^+ + O_2 + 4e^-$$

Cyclic Photophosphorylation

The process of cyclic photophosphorylation involves only PS I and this process takes place ill the stroma lamellae membrane. When only PS I is functional, the electron is circulated within the photosystem and the phosphorylation occurs, due to cyclic flow of electrons.

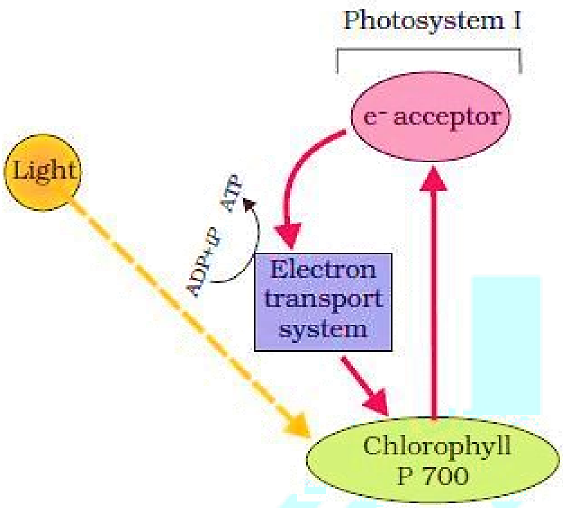


Figure 13.6 Cyclic photophosphorylation

Fig.: Cyclic photophosphorylation

The membrane or lamella of the grana have both PS I and PS II, the stroma lamella membranes lack PS II as well as NADP reductase enzyme. The excited electron does not pass on to NADP'1" and is cycled back to the PS 1 complex through the electron transport chain. Cyclic photophosphorylation also occurs when only light of wavelength beyond 680 nm are available for excitation.

Some important differences between Cyclic and Non-cyclic photophosphorylation are as follows :

Cyclic Photophosphorylation	Non-Cyclic Photophosphorylation
1. It is performed by photosystem I independently.	1. It is performed by collaboration of both photosystems II and I.
2. An external source of electrons is not required.	2. The process requires an external electron donor.
3. It is not connected with photolysis of water. Therefore, no oxygen is evolved.	3. It is connected with photolysis of water and liberation of oxygen occurs.
4. It synthesizes ATP only.	4. It is not only connected with ATP synthesis, but also with production of NADPH.
5. It operates under low light intensity, anaerobic conditions or when CO; availability is poor.	5. Non-cyclic photophosphorylation takes place under optimum light, aerobic conditions and in the presence of carbon dioxide.
6. The system does not take part in photosynthesis except in certain bacteria.	6. The system is connected with CO; fixation in green plants.
7. It occurs mostly in stroma lamellae membrane.	7. It occurs in the granal thylakoids.

Chemiosmotic Hypothesis

Chemiosmotic hypothesis was explained by **P. Mitchell.** Tins mechanism explains how ATP synthesized in the chloroplast. ATP synthesis is linked to the development of a proton gradient across the membrane of the thylakoid and the proton accumulation is towards the inside of the membrane i.e., the. lumen.

There are several processes that take place during activation of electrons and their transport which lead the development of a proton gradient:

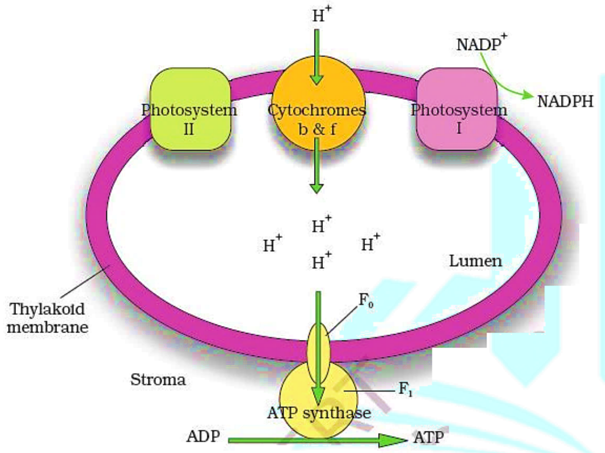
(a) Photolysis of water towards thylakoid lumen: The splitting of the water molecules takes, place in the inner side of the membrane and so the hydrogen ions (protons) that are produced, they accumulate within the lumen of the thylakoids.

(b) Transfer of H^+ from stroma to lumen as electrons move through photosystems : The primary acceptor of electron located towards the outer side of the membrane transfers its electron to a H^+ carrier and this molecule then removes a proton from the stroma while transporting an electron. When this carrier molecule passes its electron, to an electron carrier present on the inner side of the membrane the H^+ is released into the lumen of the membrane.

(c) NADPH reductase occur towards stroma : The NADP reductase enzyme is located on I stroma side of the membrane. Protons are necessary for the reduction of NADP + H^+ and these protons are removed from the stroma.

So, within the chloroplast. Protons in the stroma decrease in number, while in the lumen there accumulation of protons. This causes a decrease in pH in the lumen and creates a proton gradient across the thylakoid membrane.

This gradient is important because the breakdown of this gradient leads to release of energy; The gradual is broken, down due to the movement of protons across the membrane to the stroma through the transmembrane channel of the F_0 of the. ATPase. The **ATPase enzyme** consists of two parts, one call the F_O is embedded in the membrane and forms a transmembrane channel that carries out facilities diffusion of protons across the membrane. The other portion is called F_1 and protrudes on the outer surface of the thylakoid membrane on the side that faces the stroma. The breakdown of this gradient provided enough energy to cause a conformational change in the F_1 part of the ATPase, which makes the enzyme synthesise several molecules of ATP.



ATP synthesis through chemiosmosis

Chemiosmosis process requires a membrane, a proton pump, a proton gradient and ATPase enzyme. Energy is used to pump protons across the membrane into the lumen, which creates a proton gradient across the membrane. ATPase enzyme has transmembrane channel that allows diffusion of protons back across the membrane, this releases energy to activate ATPase enzyme which catalyses the formation of ATP.

Along with the NADPH produced, the ATP is used in the biosynthetic reaction taking place in the stroma, responsible for the fixation of carbon dioxide and synthesis of sugars.

WHERE ARE ATP AND NADPH USED?

The products of light reaction i.e., ATP and NADPH are essential for assimilation of CO_2 to carbohydrates. **This is the biosynthesis phase of photosynthesis**. These reactions take place in the stroma of chloroplast where all the enzymes required are present. This process does not depend directly on the presence of light but is dependent on the products of light reaction i.e., ATP and NADPH. This could also be verified as immediately after light becomes unavailable, this biosynthetic process continues for some time and then stops. But, if then, light is made available again, the synthesis starts again. Hence, calling the biosynthetic phase as the dark reaction is a misnomer. The dark reaction occurs through Calvin cycle. Calvin cycle may be supported by C_4 cycle or Crassulacean Acid Metabolism (CAM) in certain plants.

Calvin Cycle or C_3 Cycle

Melvin Calvin used radioactive ^{14}C in algal photosynthesis studies. This led to the discovery that the first CO_2 fixation product was a three-carbon organic acid. He also helped to mark out the complete biosynthetic pathway, hence it is called Cam Cycle. The first stable product identified was 3-phosphoglyceric acid (PGA), hence it is named C_3 pathway. Calvin cycle occurs in all **photosynthetic plants** whether they have C_3, or C_4 pathway.

Primary Acceptor of CO_2

The primary acceptor molecule during the C_3 cycle is a five-carbon ketose sugar-Ribulose bisphosphate (RuBP).The enzyme for CO_2 fixation is RuBisCO (Ribulose Bisphosphate Carboxylase Oxygenase). It is the most abundant enzyme on earth. It is characterised by the fact that its active site can bind to both CO_2 and O_2 hence the name. RuBisCO has a much greater affinity for CCL, than for CX, and the binding is competitive. It is the relative concentration of O_2 and CO_2 that determines which of the two will bind to the enzyme. Before the scientists discovered the 5-carbon ketose sugar as primary acceptor it was believed that since the first product was a C_3acid, the primary acceptor would be a 2-carbon compound.

Stages of Calvin Cycle

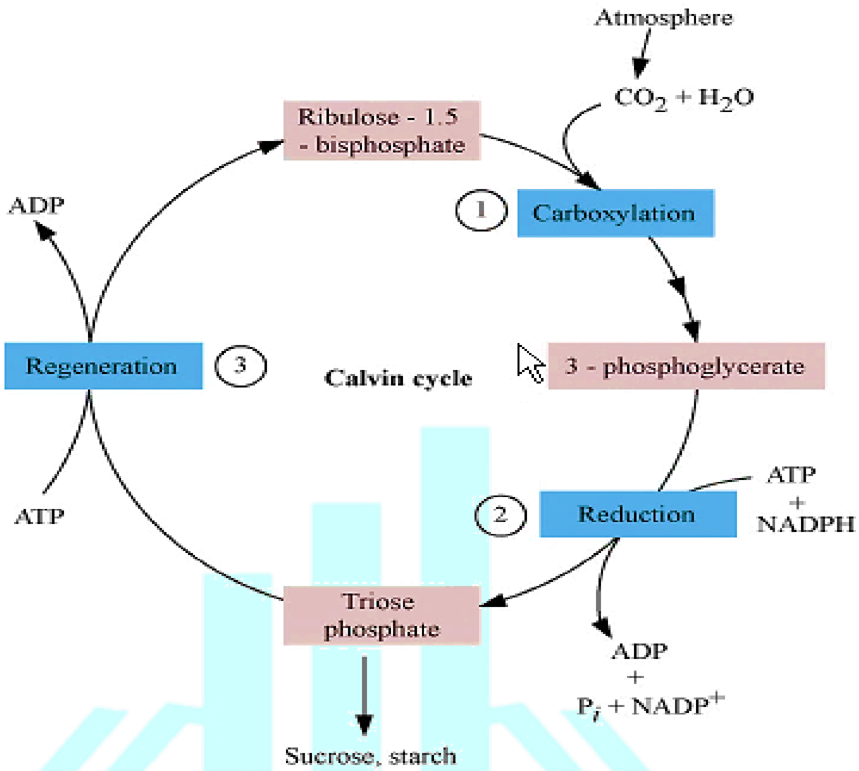
Calvin cycle can be described under three stages:

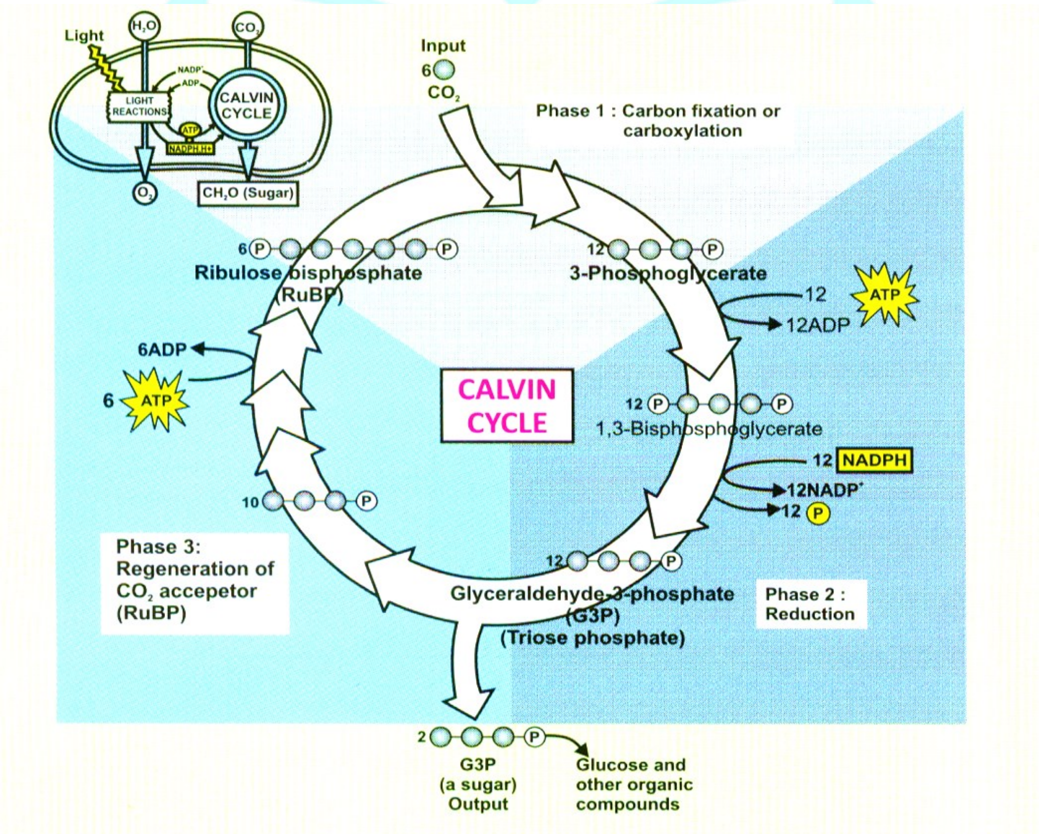
(i) Carboxylation: it is the fixation of CO_2 into a stable organic intermediate. In this, CO_2 is utilised for the carboxylation of RuBP. This reaction is catalysed by the enzyme RuBisCO and it results in the formation of two molecules of 3-PGA (3-P.hosphoglyceric acid).

(ii) Reduction: These reactions lead to the formation of glucose. The steps involve utilisation of two molecules of ATP for phosphorylation and two of NADPH for reduction, per molecule of CO_2 , fixed. The fixation of six molecules of CO_2 and six turns of the cycle are required for the removal of one molecule of glucose from the pathway.

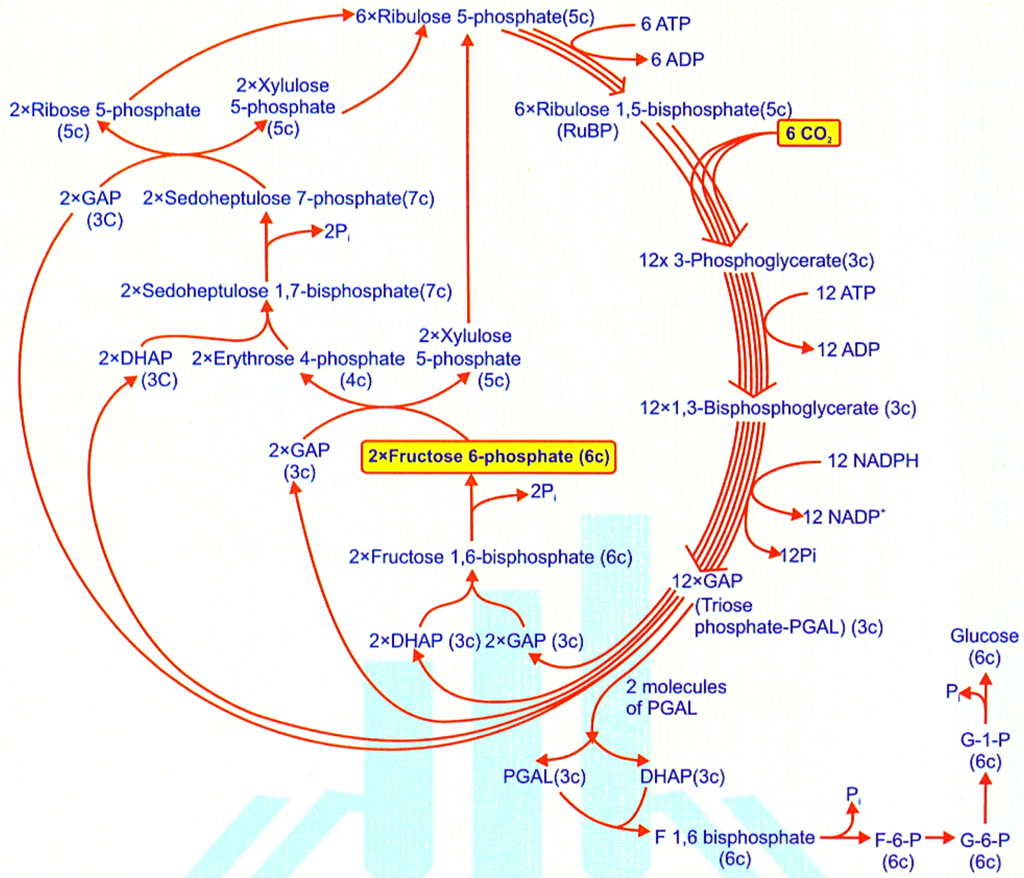
(iii) Regeneration: For the cycle to continue uninterrupted, regeneration of the CO_2, acceptor molecule is crucial. This step requires one ATP for phosphorylation to form RuBP. To make one molecule of glucose six turns of the cycle are required. 18 ATP and 12 NADPH molecules are used to make a molecule of glucose. Hence, for every CO_2 molecule entering the Calvin cycle, three molecules of ATP and two molecules of NADPH are required.

For every CO_2 molecule entering Calvin cycle, three molecules of ATP and two molecules of NADPH are required. It is to meet this difference in number of ATP and NADPH that the cyclic phosphorylation takes place.





CALVIN CYCLE : DETAIL DIAGRAM



Summary of Calvin cycle →

6 CO_2	1 Glucose
18 ATP	18 ADP
12 NADPH	12 NADP

THE C_4 PATHWAY (HATCH AND SLACK PATHWAY)

Most of the plants that are adapted to dry tropical regions have the C_4 pathway, e.g., Sugarcane, Maize Sorghum, Amaranthus etc. In these plants, double fixation of carbon dioxide occurs. The initial or the from product of this pathway is a four-carbon compound-Oxaloacetic acid (OAA) and hence the name. The Australian botanists Hatch and Slack discovered that tropical plants are much more efficient in CO_2 utilization Hence, Hatch-Slack cycle was named.

C_4plants are special as they have a special type of leaf anatomy, they can tolerate higher temperatures, the show a response to high intensities of light, they lack a wasteful process called photorespiration, thus there show greater productivity and higher yield as compared to the C_2 plants.

The C_4 pathway requires the presence of two types of cells i.e., **mesophyll cells** and **bundle sheath cell** The particularly large cells around the vascular bundles of C_4 plants are called bundle sheath cells, these car may form several layers around the vascular bundles, they are characterized by having large number chloroplasts, grana are absent, thick walls impervious to gaseous exchange and no intercellular spaces. The special anatomy of leaves of the C_4 plants is called **'Kranz' anatomy**. 'Kranz' means wreath and is reflection of the arrangement of cells.

Process of Hatch-Slack Pathway

It is a cyclic process. The primary CO_2 acceptor is a three-carbon molecule **phosphoenol pyruvate (PEP)** and it is present in mesophyll cells. The enzyme that catalyses this CO_2 fixation is. **PEP carboxylases or PEPcase,** the mesophyll cells of C_4 plants lack the enzyme RuBisCO. The 4-carbon oxaloacetic acid (OAA) is formed in the .mesophyll ceils- It is then converted of other four-carbon compounds like malic acid or aspartic acid in the mesophyll cells itself, these are then transported of the bundle sheath cell these C_4 acids are broken down to release CO_2 and a three-carbon molecule. The CO_2 released in the bundle sheath cells enters the C_3 or the Calvin pathway.

The bundle sheath cells are rich. in an enzyme RuBisCO, but lacks PEPcase. The three-carbon molecules is transported back to the mesophyll cell where it is converted to PEP again with the help of a cold sensitive enzyme, called PEP synthetase, thus completing the cycle.

Thus, the baste pathway that results in the formation of the sugars, the Calvin pathway is common to the C_3 and C_4 plants.

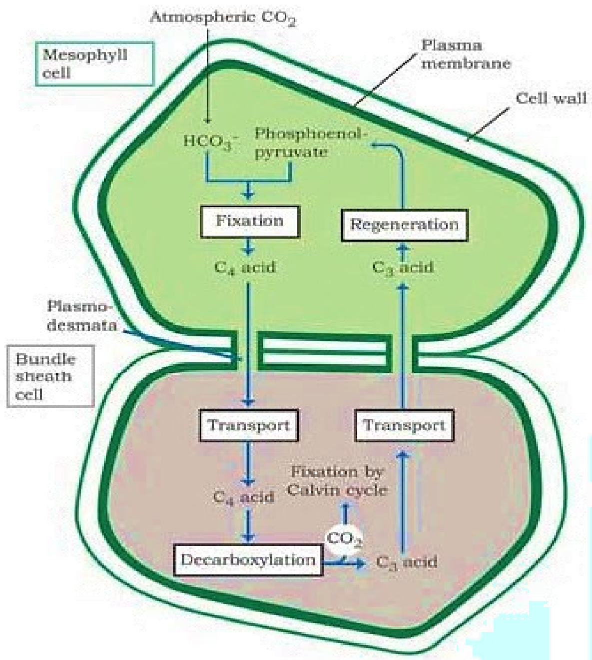


Fig. : Diagrammatic representation &f the Hatch and Slack Pathway

Regeneration of PEP from C_3 acid requires 2 ATP equivalent. However, there is no net gain or loss of NADPH in C_4 cycle.

ATP consumed in C_4 plants:

C_4 cycle - 2 ATP per CO_2 fixed

C_3 cycle - 3 ATP per CO_2 fixed

Total - 5 ATP per CO_2, fixed

Thus, to form a hexose or to fix 6 CO_2, 6 x 5 ATP = 30 ATP are consumed

Some major differences between C_3 pathway and C_4 pathway are :

C_3 pathway	C_4 Pathway
1. The primary acceptor of CO_2 is RuBP – a five carbon compound.	1. The primary acceptor of CO_2 is PEP – a three carbon compound.
2. The first stable product is 3-phosphoglycerate (3C-compound).	2. The first stable product is oxaloacetic acid (4C-compound).
3. It occurs in the mesophyll cells of the leaves.	3. It occurs in the mesophyll and bundle-sheath cells of the leaves.
4. It is a slower process of carbon fixation.	4. It is a faster process of carbon fixation.
5. 3 ATP are consumed to fix one CO_2.	5. 2 ATP are consumed to fix one CO_2.

Importance of C_4 Plants

(i) They can tolerate saline conditions due to abundant occurrence of organic acids (malic and oxaloacetic acid) in them which lowers their water potential than that of soil.

(ii) Can perform photosynthesis even when their stomata are closed due to the presence of strong CO_2 fixing enzyme i.e. PEPcase.

(iii) Concentric arrangement of cells in leaf produces smaller area in relation to volume for better water utilisation.

CRASSULACEAN ACID METABOLISM (CAM) (Diurnal acid cycle) :

(i) Certain plants called CAM plants: (with Crassulacean Acid Metabolism - CAM) have scotoactive stomata. These plants fix CO2 during night but form sugars only during day (when RuBisCO is active) e.g., Sedum, Kalanchoe, Pineapple, Opuntia.

(ii) CO_2 is fixed during night (dark) to OAA using PEP carboxylase. This CO2 comes from respiration (breakdown of starch) and also from the atmosphere. Malic acid gets stored in vacuoles.

(iii) The CAM plants also contain the enzymes of Calvin cycle. During day time, malic add breaks into pyruvate and CO2. While CO2 enters the Calvin cycle, pyruvate is used up to regenerate PEP.

(iv) The succulents, therefore synthesize plenty of organic acids from CO2 during night (when stomata are open) and plenty of carbohydrates during the day (when stomata are closed).

(v) Like Calvin cycle, CAM cycle also operates in the mesophyll cell. None of these have shown chloroplast dimorphism as is found in C4 plants.

(vi) It should be remembered that the slow growing desert succulents exhibiting CAM cycle have the slowest photosynthetic rate, while the species possessing C4 pathway possess the highest rates.

(vii) Thus, CAM plants are although not as efficient as C4 plants, they are definitely better suited to the adverse conditions (i.e., conditions of extreme desiccation).

FACTORS AFFECTING PHOTOSYNTHESIS

The rate of photosynthesis is very important in determining the yield of the plants including crop plants. An understanding of the factors that affects photosynthesis is very necessary. Photosynthesis is under the influence of both external and internal (plant) factors.

The **external factors** Include the availability of -sunlight, temperature, CO_2 concentration and water. Though several factors interact and simultaneously affect photosynthesis rate, at any point the rate is determined by the factors available at sub-optimal levels.

The **plantfactors** include the number, size, age and orientation of leaves, mesopnyll cells and chloroplasts, internal CO_2 concentration and amount of chlorophyll. The plant factors are dependent on the genetic predisposition and the growth of the plant.

In 1905, Blackman gave the Law of Limitting factors. When several factors affect any biochemical process, then this law comes into effect. This states that:

If a chemical process is affected by more than one factor, then its rate will be determined .by the factor which is nearest to its minimal value. R is the factors which directly affects the process if its quantity is changed.

To illustrate the law, suppose light intensity supplied to a leaf is just sufficient to utilize 5 mg of CO_2 per hour in photosynthesis. As the CO_2 supply is increased, the rate also increases till 5 mg of CO_2 enters the leaf per hour. After that, any further increase in the supply of CO_2 does not have any affect upon the rate. Light has now become the limiting factor and further increase in rate of photosynthesis will occur only by Increasing the intensity of light.

External factors affecting photosynthesis

Light: It is an essential factor for photosynthesis. It affects the rate of photosynthesis as :

(i) **Light intensity :** There is a linear relationship between incident light and CO;, fixation at low light intensities. At higher light intensities, gradually the rate does not show further increase as other factors become limiting. The light saturation occurs at 10 percent of the total sunlight available to plants. Increase in incident light beyond a point causes the breakdown of chlorophyll and thus resulting in decrease in photosynthesis. Hence, except for plants in shade or in dense forests, light rarely becomes a limiting factor.

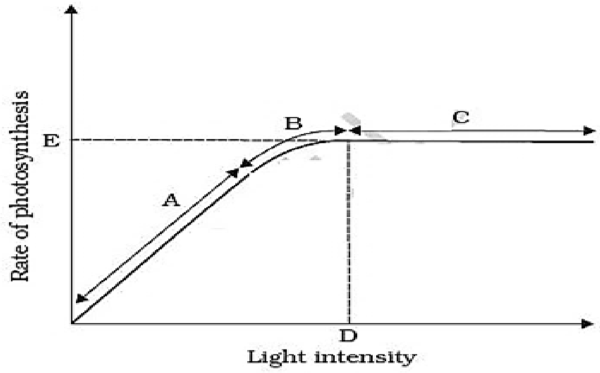


Fig: Graph of light intensity on the rate of photosynthesis

(ii) **Light quality:** Light between 400-700 nm wavelength constitute the photosynthetically active radiation (PAR). Maximum photosynthesis takes place in red and blue light of the visible spectrum and minimum photosynthesis takes place in green light.

(iii) **Duration of light:** Light duration does not affect the rate of photosynthesis, but it affects the overall photosynthesis.

Carbon Dioxide Concentration

It is a major limiting factor influencing the rate of photosynthesis. The concentration of CO_2 is very low in the atmosphere (between 0.03 percent and 0.04 percent). This level of carbon dioxide is far below the requirement for optimum photosynthesis. Increase in concentration up to 0.05 percent can cause an increase in the rate of photosynthesis but beyond this level, it becomes damaging over longer periods.

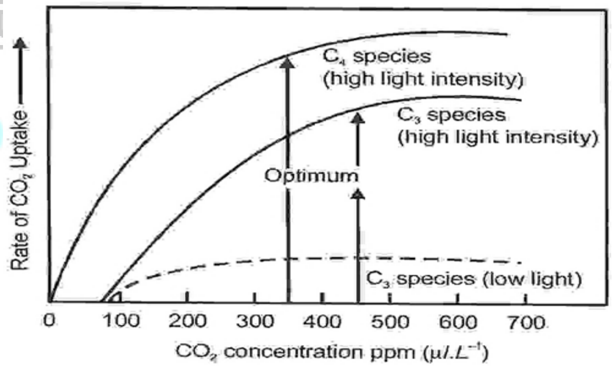


Fig: Photosynthetic response of C_3 and C_4 plants to CO_2 concentration

The C_3 and C_4 plants respond differently to CO_2 concentration. At low light Intensities neither type responds to high CO_2 concentration. At high light intensities, both C_3 and C_4 plants show increase in the rate of photosynthesis. The C_4 plants show saturation at about 360 μL^{-1} (ppm), while C_3 plants show saturation only beyond 450 μL^{-1} (ppm), thus, the current concentration of CO_2 is limiting for C_3 plants.

As C_3 plants respond to higher CO_2 concentration by showing increased rate of photosynthesis, leading to higher productivity, this has been used for the production of greenhouse crops like tomatoes and bell pepper. These crops are allowed to grow in CO_2 enriched atmosphere that leads to higher yields (CO_2 fertilization effect).

Temperature: Photosynthesis can fate place over a wide range of temperatures. The light reactions are temperature sensitive but they are affected to a much lesser extent. The dark reactions being enzymatic are temperature .controlled. Again, the temperature optimum for photosynthesis of different plants also depends on the habitat that they are adapted to. Tropical plants have a higher temperature optimum than the plants adapted to temperate climates.

The C_4 plants respond to higher temperatures and they show higher rate of photosynthesis, while C_3plants have much lower temperature optimum. Optimum temperature in C_3 plant is 20-25^{O}C and for C_4 plant is 30-45^{o}C.

Water : Water is one of the raw materials utilized for the process of photosynthesis. Photosynthetic process utilizes less than 1 of the water absorbed by a plant, hence it is rarely a limiting factor in photosynthesis. Water stress causes the stomata to close, hence reducing the CO_2 availability as gaseous exchange could not occur. Also, water stress makes leaves wilt, thus reducing the surface area of the leaves and the metabolic activity reduces as well. Thus, the effect of water as a factor is more through its effect on the plant, rather than directly on photosynthesis.

Chapter 12
Respiration in Plants

DO PLANTS BREATHE?

Plants require oxygen for respiration and release carbon dioxide. Animals have special organs for breathing like lungs, gills, trachea etc. Plants unlike animals, have no specialized organs for gaseous exchange but they have stomata and lenticels for this purpose. These are several reasons why plants can get along without respiratory organs.

Reasons for absence of respiratory organs in plants :

(i) Each plant part takes care of its own gas-exchange needs. There is very little transport of gases from one plant part to another.

(ii) Plants do not present great demands for gas exchange. Roots, stems and leaves respire at rates far lower than animals. Only during photosynthesis large volumes of gases are exchanged and each leaf is well adapted to take care of its own needs during these periods. Moreover, leaves also utilize O_2 released during photosynthesis.

(iii) In plants cells are closely packed and located quite close to the surface of the plant. Thus, the distance that gases must diffuse is not large. Each living cell in a plant is located quite close (like in leaves) to the surface of the plant. While in stems, the living cells are organized in the layers inside and beneath the bark and they have lenticels for gas exchange. Loose packing of parenchyma cells in leaves, stems and roots, which provide an interconnected network of air spaces also aids in easy exchange of gases. Thus, most cells of a plant organ have at least one part of the surface in contact with air. The complete combustion of glucose, which produces CO_2 and H_2O as end products, yields energy most of which is given out as heat.

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{Energy}$$

It this energy is to be useful to the cell, it should be able to utilize it to synthesise other molecules that the cell requires. The strategy that the plant cell uses is to catabolise the glucose molecule in such a way that not all the liberated energy goes out as heat. The key is to oxidize glucose not in one step but in several small steps enabling some steps to be just large enough such that the energy released can be coupled to ATP synthesis. This is done by the process of cellular respiration.

During the process of respiration, oxygen is utilized, and carbon dioxide, water and energy are released as products. But some cells or organism live where oxygen may or may not be available.

Type of Respiration :

1. On the basis of respiration substrate, **Blackman** classified two types of respiration:

   (i) **Floating Respiration:** When respiratory substrate is fat or carbohydrate.

   (ii) **Protoplasmic Respiration:** When respiratory substrate is protein.

2. On the basis of whether oxygen is present for oxidation of food or not, respiration is divided into two types :

   (i) **Aerobic respiration:** It is the process complete oxidation of organic molecules in the presence of molecular oxygen into carbon dioxide and water.

   (ii) **Anaerobic respiration:** It is the process of incomplete oxidation of organic molecules in the absence of molecular oxygen. All reactions occur in the cytoplasm and mitochondria is not needed in this process. There are sufficient reasons to believe that the first cells on the first cells on the planet lived in an atmosphere that lacked O_2. Even among present day living organisms, we know of several that are adapted to anaerobic conditions. Some of these organisms' anaerobes, while in others the requirement for anaerobic condition is obligate.

(a) **Facultative anaerobes :** The aerobic organisms which can respire even in the absence of O_2.

(b) **Obligate anaerobes :** Organisms which respire anaerobically only They lack enzymes necessary for carrying out aerobic respiration.

In any case, all living organisms retain the enzymatic machinery to partially oxidize glucose without the help of O_2. This breakdown of glucose to pyruvic acid is called glycolysis.

GLYCOLYSIS

It is a common step of both types of respiration. Glycolysis (Greek glycon – for sugar and lysis – for splitting) means splitting up of sugar. This scheme of glycolysis was given by **Gustav Embden, Otto Meyerhof, and J. Parnas,** and is often referred to as the EMP pathway. In anaerobic organisms, it is the only process in respiration. Glycolysis occurs in the cytoplasm of the cell and is present in all living organisms. Glycolysis is defined as the process of partial oxidation of glucose to form two molecules of pyruvic acid. Glycolysis does not require oxygen.

In plants, the glucose is derived from sucrose, which is end product of photosynthesis, or from storage carbohydrates. Sucrose is converted into glucose and fructose by the enzyme, invertase, and these two monosaccharides readily enter the glycolytic pathway. In animals, starch is digested into glucose and that is used in the glycolysis.

The first half of this pathway activates glucose (glucose activation phase). The second half extracts the energy (energy extraction phase).

Glycolysis proceeds in following steps:

(i) Glucose is phosphorylated to glucose-6-phosphate by ATP in the presence of enzyme **hexokinase.**

(ii) Glucose-6-phosphase, the phosphorylated form of glucose, isomerizes to fructose-6-phosphate by the action of the enzyme phosphohexoisomerase.

(iii) Fructose-6-phospate is phosphorylated to form 1, 6-bisphosphate. The enzyme which helps in the transfer of phosphate from ATP to fructose-6-phophate is **phosphofructokinase** (Pacemaker enzyme of EMP pathway). During phosphorylation, ATP is converted to ADP thus this pathway of conversion of glucose to fructose-1, 6-biosphosphate uses two ATP molecules. This step is also called **rate limiting step.**

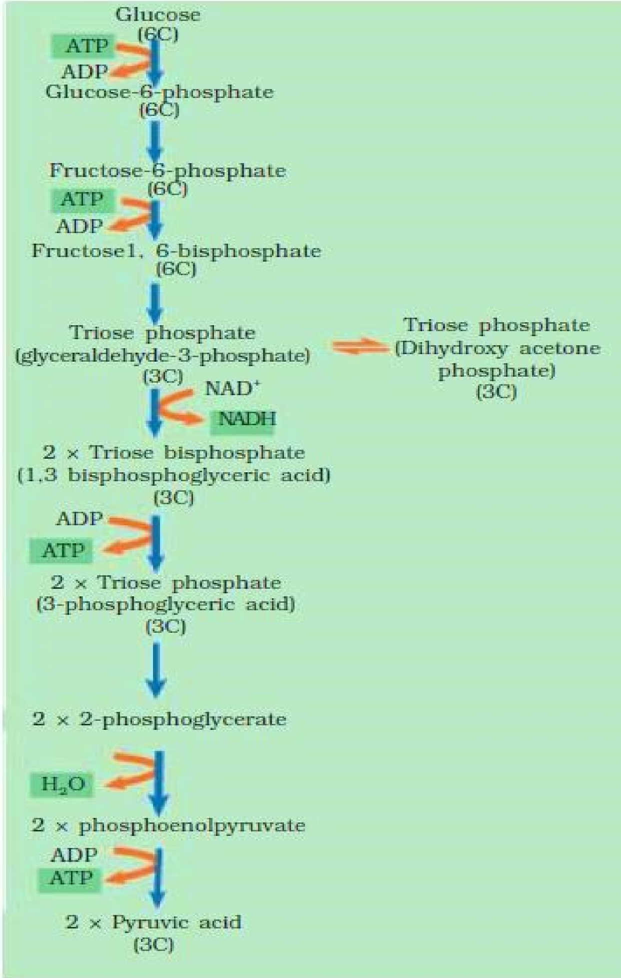


Fig. : Step of Glycolysis

Special features of glycolysis can be summarized as following :

(1) Each molecule of glucose produces 2 molecules of pyruvic acid after partial oxidation, at the end of the glycolysis.

(2) The net gain of ATP in this process is 2ATP molecules (four ATPs are formed but two are already used in reaction)

(3) During the conversion of glyceraldehydes-3-phosphate into 1, 3-bisphosphoglyceric acid, one molecules of NADH + H^+ is formed. As each molecule of glucose yield two molecules of 1, 3-bisphosphoglyceric acid, hence, each molecule of glucose forms 2 molecules of $NADH_2$.

(4) During aerobic respiration (when oxygen is available) each $NHDH_2$ forms 3ATP and a H_2O molecule through transport of mitochondria. In this process ½ O_2 molecule is utilized for the synthesis of each water molecule.

Fat of Pyruvic Acid

Pyruvic acid is the key product of glycolysis. The fate of pyruvic acid depends upon the cellular needs. There are three major ways in which different cells handle pyruvic acid. These are lactic acid fermentation, alcoholic fermentation and aerobic respiration.

Fermentation takes place under anaerobic conditions in many prokaryotes and unicellular eukaryotes. For the complete oxidation of glucose to CO_2 and H_2O, however, organisms adopt Krebs cycle, which is also called aerobic respiration. This requires O_2 supply.

Pfeffer-Kostychev scheme represents interrelationship between aerobic and anaerobic respiration.

FERMENTATION

Fermentation is a kind of anaerobic respiration, carried out primarily by fungi and bacteria. Although people had been using this process in the preparation of wines prehistoric times but failed in their attempts to understand the alcoholic fermentation. Gay Lussac was the first to discover fermentation.

Types of fermentation

1. Alcoholic fermentation

In fermentation, say by yeast, incomplete oxidation of glucose is achieved under anaerobic conditions by sets of reaction, where pyruvic acid is converted to CO_2 and ethanol.

Pyruvic acid formed at the end of glycolysis is concerted to alcohol by using two enzyme, pyruvic acid decarboxylase and alcohol dehydrogenase.

(i) In the step, pyruvic acid is decarboxylated resulting in the formation ofacetaldehyde and CO_2.

$$\underset{\text{(Pyruvic acid)}}{2CH_3COCOOH} \xrightarrow[MG^{++}]{\text{Pyruvic acid decarboxytase}} \underset{\text{(Acetaldehyde)}}{2CH_3CHO} + 2CO_2$$

(ii) In the second step, acetaldehyde is reduced to alcohol by $2NADH + H^+$.

$$\underset{\text{(Acetaldehyde)}}{2CH_3CHO} + 2NADH + 2H^+ \xrightarrow[\text{dehydrogenase}]{\text{Alcohol}} \underset{\text{(Ethanol)}}{2NADH} + 2NAD^+$$

Example: This is commonly seen in yeast and certain bacteria.

Ethyle alcohol does not stay inside micro-organisms but is excreted. Accumulation of alcohol a certain limit can, however, kill the microorganisms. Yeasts poison themselves to death when the concentration of alcohol reaches about 13%. Therefore, maximum concentration of alcohol in beverage that are naturally fermented is 13%. A higher concentration of alcohol is a beverage is achieved through distillation.

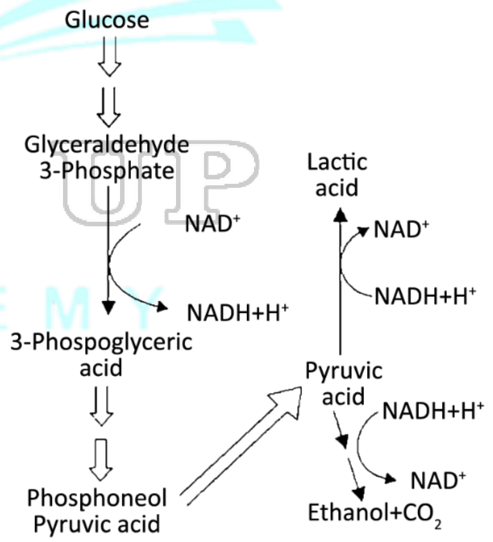


Fig. : Major pathway of anaerobic respiration

2. Lactic acid fermentation

Pyruvic acid formed at the end of glycolysis is reduced to lactic acid by homofermentative lactic acid bacteria (Lactobacillus lacti).

$$\underset{\text{(Pyruvic acid)}}{CH_3COCOOH} \xrightarrow[FMN,Zn^{+2}]{\text{Lactic acid dehyderogenase}} \underset{\text{(Lactic acid)}}{2CH_3CHOHCOOH}$$

During vigorous, when oxygen is inadequate for cellular respiration pyruvic acid is reduced to lactic acid by using the enzyme lactate dehydrogenase.

Special features of alcohol and lactic acid fermentation:

(i) In both lactic and alcohol fermentation not much energy is released, less than seven percent of the energy in glucose is released and not all of it is trapped as high energy bonds of ATP.

(ii) Both the processes are hazardous – either acid or alcohol is produced.

(iii) Net gain in both the types of fermentation is 2ATP.

(iv) Alcohol fermentation results in the release of CO_2 along with ethanol while lactic acid fermentation releases lactic acid only.

(v) The reducing agent is NADH + H^+ which is reoxidised to NAD^+ in both the processes.

AEROBIC RESPIRATION

It is the process by which organisms can carry out complete oxidation of glucose and extract the energy stored to synthesis a larger number of ATP molecules needed for cellular metabolism. In eukaryotes these steps take place within the mitochondria and this requires O_2. Aerobic respiration process leads to a complete oxidation of organic in the presence of oxygen, and releases CO_2, water and a large amount of energy present in the substrate. This type of respiration is most common in higher organisms.

For aerobic respiration take place within the mitochondria the pyruvic acid formed during glycolysis is transported from the cytoplasm into the mitochondria. The crucial events in aerobic respiration are :-

(i) The complete oxidation of pyruvic by the stepwise removal of all the hydrogen atoms, leaving three molecules of CO_2. It occurs in steps :

(a) Formation of Acetyl coenzyme A.

(b) TCA cycle (Tricarboxylic acid cycle) or Krebs cycle or Citric acid cycle.

This process takes place in the matrix of mitochondria.

(ii) The passing on of the electrons removed as part of the hydrogen atoms to molecule O_2 with simultaneous synthesis of ATP through ETS.

This process takes place on the inner membrane of the mitochondria.

(a) Formation of Acetyl coenzyme A or Oxidative decarboxylation :

Pyruvate, which is formed by the glycolytic catabolism of carbohydrates in the cytosol, after it enters mitochondrial matrix undergoes oxidative decarboxylation by a complex set of reactions catalysed by pyruvate dehydrogenase. It requires several coenzymes like NAD^+ and Coenzyme A.

$$\underset{(3C)}{\text{Pyruvic acid}} + \text{CoA} + \text{NAD}^+ \xrightarrow[\textit{Pyruvate dehydrogenase}]{Mg^{2+}} \underset{(2C)}{\text{Acetyl CoA}} + 2CO_2 + 2\text{NADH} + 2H^+$$

Two molecules of pyruvic acid formed one glucose molecule during glycolysis undergo the formation of two molecules of Acetyl CoA, $2CO_2$ and 2NADH + $2H^+$. This reaction is called link reaction or transition reaction or gateway reaction of aerobic respiration. The $NADH_2$ molecule formed in this process enters the electron transport system of the mitochondria to release energy.

(b) TCA cycle (Tricarboxylic Acid Cycle) or Krebs Cycle or Citric Acid Cycle :

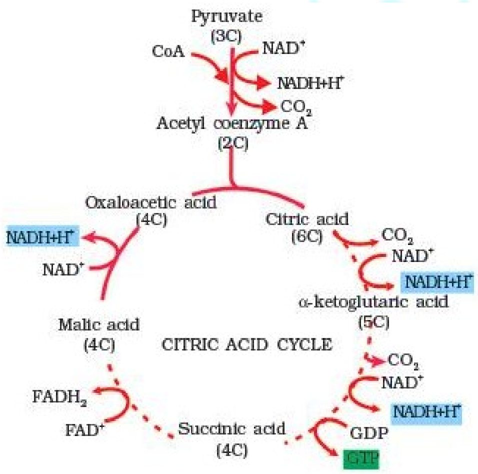


Fig. The citric and cycle

One molecule of ATP (via direct GTP), three $NADH_2$, one $FADH_2$ are released per molecule of acetyl CoA oxidized.

However, as two molecules of pyruvic acid formed one glucose molecule. TCA cycle must occur twice for each molecule of glucose respired. Therefore, 2ATP, 6 $NADH_2$ and 2$FADH_2$ are formed from 2 molecules of acetyl CoA (coming from one molecule of glucose).

The continued oxidation of acetyl CoA cycle requires the continued replenishment of oxaloacetic acid, the first member of the cycle. In addition, it also requires regeneration of NAD^+ and FAD^+ from NADH and $FADH_2$ respectively.

The summary equation for this phase of respiration (Oxidative decarboxylation + Kreb cycle) may be written as follows :

$$\text{Pyruvic acid} + 4NAD^+ + FAD^+ + 4H_2O + ADP + Pi \xrightarrow{\text{Mitochondrial matrix}} 3CO_2 + 4NADH + 4H^+ + FADH_2 + ATP + H_2O$$

Electron Transport System (ETS) and Oxidative Phosphorylation

Till Now, we have seen that glucose has been broken down completely but neither O_2 has been directly involved nor the large number of ATP molecules have been produced. The following steps in the respiratory process are to release and utilize the energy stored in FADH + H^+ and $FADH_2$. This is accomplished when they are oxidized through the electron transport system and the electron are passed on to

O_2 resulting in the formation of H_2O. The metabolic pathway through which the electron passes from one carrier to another, is called the electron transport system (ETS). This process occurs in inner mitochondrial membrane. This process proceeds in following steps :

(i) Electron from NADH produced in the mitochondrial matrix during citric acid cycle are oxidized by an NADH dehydrogenase (Complex I).

(ii) Electrons are then transferred to ubiquinone located within the inner membrane.

(iii) Ubiquinone also receives reducing equivalents via $FADH_2$ (complex II) that is generated during oxidation of succinate in the citric acid cycle.

(iv) The reduced ubiquinone (ubiquinol) is then oxidized with the transfer of electron to cytochrome c via cytochrome bc_1 complex (Complex III).

(v) Cytochrome is a small protein attached to the outer surface of the inner membrane and acts as a mobile carrier for transfer of electrons between complex III and IV. Cytochrome c oxidase complex containing cytochromes a and a_3 and two copper centres is referred as complex IV.

(vi) Oxygen acts as terminal electron accepter. It becomes reactive and combines with protons to forms metabolic water.

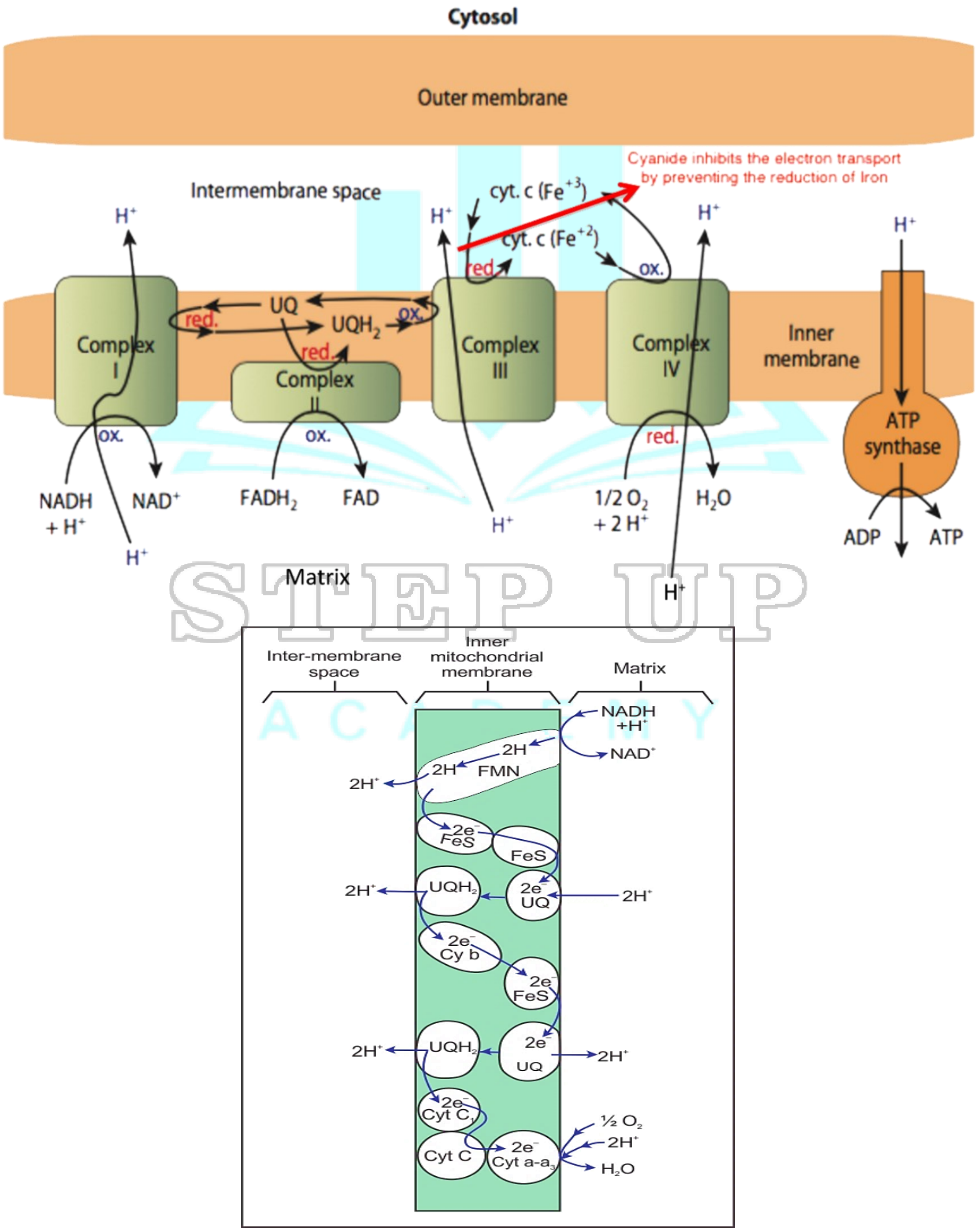


Fig. : Electron Transport System (ETS)

Oxidative phosphorylation

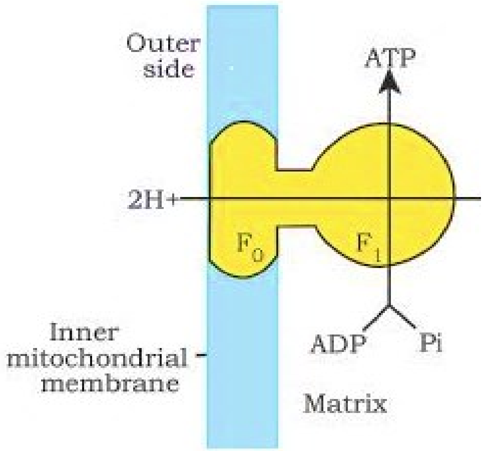


Fig. : Diagrammatic presentation of ATP synthesis in mitochondria

(i) When the electrons pass from one carries to another via complex I to IV in the electron transport chain, they are coupled to ATP synthase (complex V) for the production of ATP from ADP and inorganic phosphate.

(ii) Proton gradient or proton motive force (PMF) required for phosphorylation is obtained with the use of energy of oxidation-reduction. Therefore, it is called oxidative phosphorylation. Mechanism of membrane linked ATP synthesis is explained by chemiosmotic hypothesis, given by Petel Mitchell.

(iii) Inner mitochondrial membrane is permeable to protons only in the region of F_o – F_1 or elementary particles of ATP synthase.

(iv) The energy released during the electron transport system is utilized in synthesizing ATP with the help of ATP synthase (complex V). This complex consists of two major components F_1 and F_o.

(v) The F_1 headpiece is a peripheral membrane protein complex and contains the site for synthesis of ATP from ADP and inorganic phosphate. F_o in an integral membrane protein complex that forms the channel through which protons cross the inner membrane.

(vi) The passage of protons through the channel is coupled to the catalytic site of the F_1 component for the production of ATP. For each ATP produced, $2H^+$ pass through F_o from the inter membrane space to the matrix down the electrochemical proton gradient.

(vii) Three pairs of protons are pushed during oxidation of each NADH + H^+ and two pairs of protons during oxidation of each $FADH_2$.

(viii) Complete oxidation of NADH forms 3ATP molecules, while one $FADH_2$ forms 2ATP molecules.

THE RESPIRATORY BALANCE SHEET

It is possible to make calculations of the gain of ATP for every glucose molecule oxidized; but in reality, this can remain only a theoretical exercise. These calculations can be made only on certain assumptions that :

(i) There is sequential, orderly pathway functioning, with one substrate forming the next and with glycolysis, TCA cycle and ETS pathway one after another.

(ii) The NADH, synthesized in glycolysis is transferred into the mitochondria and undergoes oxidative phosphorylation.

(iii) None of the intermediates in the pathway are utilized to synthesise any other compound.

(iv) Only glucose is being respired – no other alternative substrates are entering in the pathway at any of the intermediary stages.

ATP molecules produced during respiration

Stage of Respiration	Source	Number of ATP Molecules Produced
Glycolysis	Direct 2-molecules of $NADH_2$ (one molecule of $NADH_2$ yields 3 molecules of ATP)	2 6
Pyruvic acid to acetyl-CoA	2 molecules of $NADH_2$	6
Citric acid cycle	6 $NADH_2$ 2$FADH_2$ ($FADH_2$ produces only 2 molecules of ATP) Direct	18 4 2

Total net gain of ATP = 36 or 38 depending upon type of shuttle system used in aerobic respiration. In most eukaryotic cells the net gain of ATP is 36 molecules.

But, these kind of assumptions are not really valid in a living system; all pathway work simultaneously and do not take place one after another; substrates enter the pathway and are withdraw from it as and when necessary, ATP is utilized as and when needed; enzymatic rates are controlled by multiple means.

Yet, it is useful to do this exercise to appreciate the beauty and efficiency of the living system in extraction and storing energy. Hence, there can be a net gain of 36 ATP molecules during aerobic respiration of one molecule of glucose.

Knowledge Cloud

Shuttles : The $NADH_2$ molecules produced during glycolysis cannot enter the mitochondria directly. They hand over their energy to other molecules. This entry of glycolytic inside mitochondria is performed using specific shuttles. Shuttles do not occur in prokaryotes. Two types of shuttles are described below :

(a) Glycerol-3Phosphate Shuttle : This explains that there is a loss of one ATP for each cytosolic NADH + H^+. Net ATP produced in respiration in 36 instead of 38 ATP. This shuttle occurs in flight muscle cells and brain.

(b) Malate Aspartate Shuttle : Occurs in heart, kidney and other organs. 38 ATP are produced as net in aerobic respiration.

Now let us compare and aerobic respiration

Fermentation	Aerobic respiration
1. In fermentation partial degradation (breakdown) of glucose occurs.	1. In this respiration complete degradation of glucose occurs.
2. There is a net gain of 2ATP molecules for each molecule of glucose degraded.	2. 36-38 ATP molecules are released.
3. Oxygen is not required.	3. Oxygen is required.
4. End products are lactic acid or alcohol.	4. End products are CO_2 and H_2O.
5. NADH is oxidase to NAD^+ slowly in fermentation.	5. Here the conversion is very vigorous.

AMPHIBOLIC PATHWAY

Glucose is the favored substrate for respiration. All carbohydrates are usually first converted into glucose before they are used for respiration. Other substrates can also respire, but then they do not enter the respiratory pathway at the first step. Fats are first broken down into glycerol and fatty acids. Fatty acids are degraded into acetyl CoA and enter the pathway. Glycerol would enter the pathway after being converted to PGAL (phosphoglyceraldehyde). Proteins are degraded by proteases into amino acids and depending on their structure would enter the pathway at some stage within the Krebs cycle or even as pyruvate or acetyl CoA. Breaking down processes within the living organism is catabolism and synthesis of molecules within the living organism is anabolism. Respiratory pathway is mainly a catabolic process which serves to run the living system by providing energy. The pathway produces a number of intermediates. These intermediates of the pathway are precursors of various compounds e.g.,

(i) Acetyl CoA → raw material for carotenoids, terpenes, gibberellins etc.

(ii) Succinyl CoA → raw material for chlorophyll, cytochrome.

(iii) Oxaloacetic acid → raw material for alkaloids, pyrimidines.

(iv) α-ketoglutaric acid → raw material for amino acid synthesis.

Thus, the respiratory pathway is involved in both anabolism and catabolism, it would hence be better to consider the respiratory pathway as an **Amphibolic Pathway** rather than as a catabolic one.

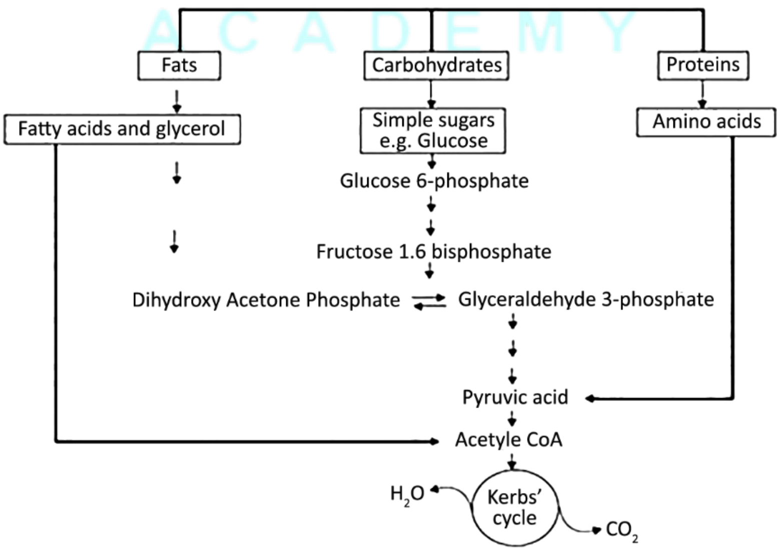


Fig. : Interrelationship among metabolic pathways showing respiration mediated breakdown of different organic molecules to CO_2 and H_2O

RESPIRATORY QUOTIENT

During aerobic respiration, O_2 is consumed and CO_2 is released. The ratio of the volume of CO_2 evolved to the volume of O_2 consumed in respiration is called the **respiratory quotient** (RQ) or respiratory ratio.

The respiratory quotient depends upon the type of respiratory substrate used during respiration.

1. When carbohydrates are used as substrate and are completely oxidized, he RQ will be 1, because equal amounts of CO_2 and O_2 are evolved and consumed, respectively, as shown in the equation below.

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{Energy}$$

$$RQ = \frac{6CO2}{6O2} = 1.0$$

2. When fats are used in respiration, the RQ is less than 1. Calculations for a fatty, acid, tripalmitin, if used as a substate is shown :

$$\underset{\text{Tripalmitin}}{2\,(C_{51}H_{98}O_6)} + 145O_2 \rightarrow 102\,CO_2 + 98H_2O + \text{Energy}$$

$$RQ = \frac{102CO2}{145O2} = 0.7$$

3. When proteins are respiratory substrates, the ratio would be about 0.9.
4. RQ value is 4 for oxalic acid and 1.33 for malic acid. RQ value of organic acid is more than unity as organic acids contain high proportion of oxygen as compared to carbon and hydrogen, therefore, less oxygen is absorbed than CO_2 liberated.
5. In case of anaerobic condition

$$\underset{\text{(Glucose)}}{C_6H_{12}O_6} \xrightarrow{Zymase} \underset{\text{(Alcohol)}}{2C_2H_5OH} + 2CO_2$$

$$RQ = \frac{2CO2}{0O2} = \infty \text{ (infinite)}$$

Chapter 13
Plant Growth and Development

GROWTH

Growth is a fundamental characteristic of all living organisms. It is defined as an irreversible permanent increase in size, volume and weight of an organ or its parts or even of an individual cell. The growth of a part or whole of an organism is caused by synthesis of new materials intracellular *i.e.,* within the cell and extracellular *i.e.,* outside the cell, cell division and cell enlargement. For example, expansion of leaves and increase in height of a stem of a plant.

Plant Growth Generally is Indeterminate

Plants have the capacity for indeterminate or unlimited growth which continues throughout their life. Due to which, **the growth of a plant is known as unique**. The growth of the plants is due to the presence of different types of meristems at specific locations in their body. Meristems are the cells which are capable of self-perpetuation *i.e.,* have the power of continue indefinitely through division. The continued growth due to which new cells are always being added to the plant body by the activity of the meristem is called the **open form of growth**. *What would happen if the meristem ceases to divide? Does this ever happen?*

Yes, this happen. If meristems cease to divide then they take a permanent shape and size to form various structures of the plant body which are specific to a particular function, *e.g.,* parenchyma, collenchyma, sclerenchyma, xylem etc. Parenchyma stores food, collenchyma provides elasticity and flexibility to the plant body, sclerenchyma provides mechanical support and xylem helps in the conduction of water. These are amongst the various examples of permanent tissues which are formed after the differentiation of meristematic tissues.

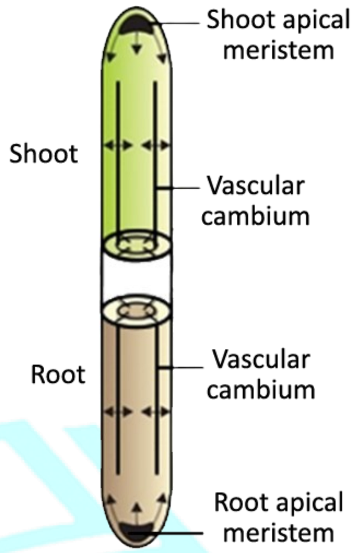


Fig.: Diagrammatic representation of locations of root apical meristem, shoot apical meristem and vascular cambium. Arrows exhibit the direction of growth of cells and organ.

The meristems such as root apical are responsible for the elongation or increase of length of the plants along their axis. When this type of growth or increase occurs in plants it is known as **primary growth**. Primary growth is the characteristic of all types of plants. In plants like dicotyledonous and gymnosperms, some meristems appear later in their life which are responsible for another type of growth known as **secondary growth**. It means the increase the girth or diameter of plants. The meristems which appear in their later life are lateral meristems such as vascular cambium and cork cambium.

Growth in Measurable

The growth which occurs at the cellular level is due to the increase in protoplasm content. This increase in protoplasm is difficult to measure directly. Therefore, growth can be measured by various parameters which are more or less proportional to it. These parameters are:

(i) **Increase in fresh weight and dry weight:** The increase in fresh weight of fruits, vegetables and storage organ is used as an indicator of growth. However, the actual growth is found out by increase in dry weight.

(ii) **Increase in cell size:** The increase in cell size is a parameter for measuring the growth. For example, in watermelon cell may increase in size by up to 3,50,000 times.

(iii) **Increase in surface area:** It is used for measuring growth in flat organs like leaves. The increase in surface area is measured by placing the leaf on a standard graph paper and drawing its outline at fixed intervals.

(iv) **Increase in volume:** The growth of fruits and storage can be measured by finding out the increase in volume. The fruit is dipped in water and increase in level of water will indicate the volume of fruit which can be observed/measured at regular intervals.

(v) **Increase in cell number:** It gives an estimate about the rate of growth. For example, single maize root apical meristem can give rise to more than 17,500 new cells per hour. The rate of growth in bacteria, algae and yeast is measured by increase in number of cells.

Phases of Growth

Plant growth takes place in three phases:

(1) **Meristematic phase or phase of cell division:** It is the first phase of growth in plants which occurs in the areas where meristematic cells are present. For example, at shoot and root tip of the plants where meristems are constantly dividing. As a result this phase is also known as cell division.

The cells at this phase of growth show following features:

(i) Have dense protoplasm.

(ii) Contain large nucleus.

(iii) Have high respiration rate.

(iv) Cell wall is primary in nature. It means that the cell wall is made up of cellulose, thin walls with abundant plasmodesmata connections so that cells can communicate with each other.

(2) **Elongation phase or phase of enlargement:** The cells present just next to the cells of meristematic zone represent the elongation phase. The cells found in this zone show the following features:

(i) **Increased vacuolation:** The number and size of vacuoles increase as growth occurs.

(ii) **New cell wall deposition:** The cell wall of the cells starts depositing new materials resulting in cell enlargement.

(iii) **Cell size:** The size of the cells of this phase increase mainly due to vacuolation.

(3) **Maturation phase or phase of differentiation:** The cells present just next to the cells of elongation phase represent the phase of differentiation. The enlarged cells develop into special or particular type of cells by undergoing structural and physiological differentiation.

(i) **Structural differentiation:** A cell attains a particular shape, size and internal constitution.

(ii) **Physiological differentiation:** A cell attains a particular function. For example, absorption of water and minerals by root hair, photosynthesis by mesophyll cells etc.

So, cells of this zone, attain their maximal size in terms of wall thickening and protoplasmic modifications.

After differentiation, the mature cells do not grow further and remain unchanged till death.

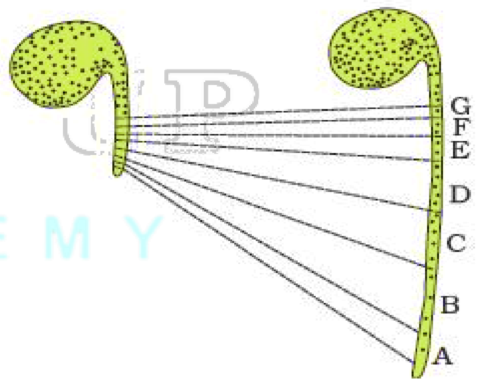


Fig.: Detection of zones of elongation by the parallel line technique. Zones A, B, C, D, immediately behind the apex have elongated most.

Growth Rates

An organism or a part of the organism can produce more cells in a variety of ways. The increase in growth per unit time is defined as growth rate. Thus, it can be expressed mathematically, being either arithmetical or geometrical.

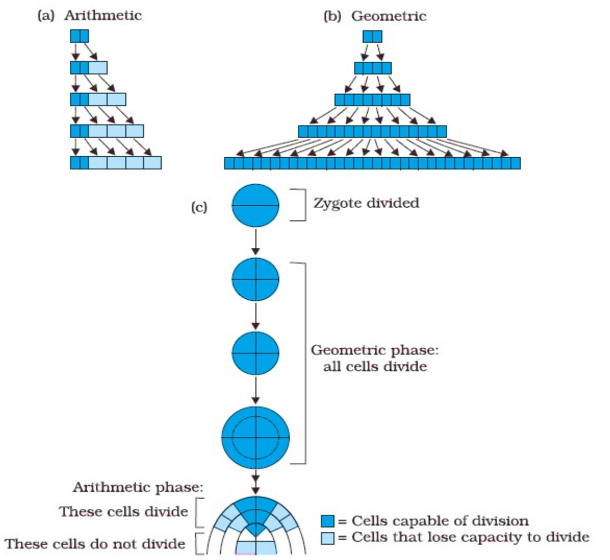


Fig.: Diagrammatic representation of: (a) Arithmetic (b) Geometric growth and (c) Stages during embryo development showing geometric and arithmetic phases.

(i) Arithmetic growth: It is the growth rate in which growth occurs at a constant rate from the very beginning and progress arithmetically. Here, following mitotic cell division only one daughter cell divides continuously whereas other cells undergo differentiation and become mature. For example, we can study the arithmetic growth pattern in root elongation where elongation occurs at a constant rate. If a graph is plotted by taking length of the organ of plant Y-axis against the time at X-axis, a linear curve is obtained. Mathematically, it can be expressed by following equation:

$$L_t = L_0 + rt$$

where L_t = Length of the organ at time 't'

L_0 = Length of the organ at time 'zero'

r = Growth rate or elongation per unit time.

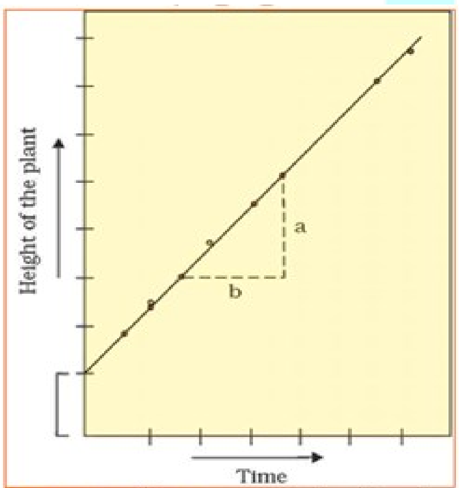


Fig: Constant linear growth, a plot of length L against time t

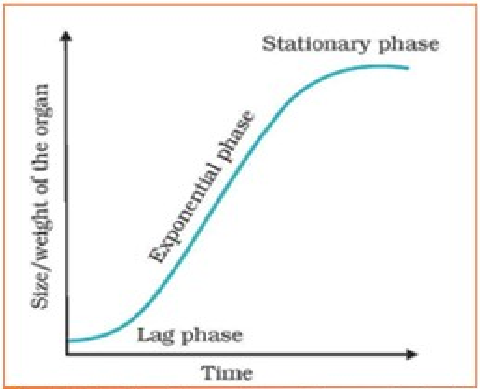


Fig: An idealised sigmoid growth curve typical of cells in culture, and many higher plants and plant organs.

(ii) Geometrical growth: It is a growth rate where every cell divides with all the daughters growing and dividing again. We can take the example of microorganisms to study the pattern of geometrical growth. In microorganisms, growth occurs when they are provided with enough food and space. During their growth, three phases can be observed.

(1) Lag phase: This is the initial phase of growth when the rate of growth is very slow. It represents the beginning of growth of microorganisms where their cell number is small.

(2) Log phase or exponential phase: In this phase, growth progresses rapidly or exponentially *i.e.,* reaches to its maximum. Here, both the progeny or daughter cells obtained after mitotic cell division have ability to divided continuously. However, such a growth cannot be sustained for long and growth reaches to next phase.

(3) Stationary phase: Due to the shortage of space, food and accumulation of toxins, growth slows down leading to a phase known as stationary phase.

If we plot all these phases graphically then we will obtain S-shaped or sigmoid curve.

Similarly, we can study the growth of cells, tissues and organs of a plant. For example, if we plot the parameters of growth such as size, weight of the organ at Y-axis against the time at X-axis, we get a typical sigmoid or S-shaped curve which explains the geometrical growth.

But a tree showing seasonal activities does not show a typical S-shaped curve. Here, the curve will show small steps indicating stoppage and resumption of growth ever year.

$$W_1 = W_0 e^{rt}$$

where, W_1 = Final size (weight, height, number etc.);

W_0 = Initial size at the beginning of the growth;

e = Base of natural logarithms;

r = Growth rate;

t = Time of growth

The 'r' expressed in the above equation is actually the relative growth rate which measures the ability of the plant to produce or synthesize new plant material. This ability of plant is referred as **efficiency index**. The overall size of any organ of the plant depends on its initial size *i.e.,* W_0.

There are two ways by which quantitative comparisons between the growth of living system can be made:

(i) Absolute growth rate

(ii) Relative growth rate

Absolute growth rate: It is the measurement and comparison of total growth per unit time.

Relative growth rate: The growth of the given system per unit time expressed on a common basis, example, per unit initial parameter is called the relative growth rate.

For example, two leaves, A and B of different size show an absolute increase in area at the given time to give leaves A^1 and B^1.

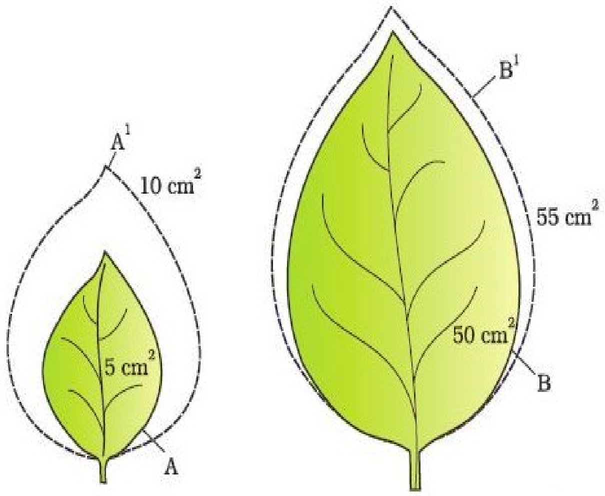


Fig. : Diagrammatic comparison of absolute and relative growth rates. Both leaves A and B have increased their area by 5 cm² in a given time to produce A¹, B² leaves.

The absolute growth rate of both the leaves A^1 and B^1 is same but if we calculate the relative growth rate, it is found that A^1 leaf has higher relative growth rate than B^1 leaf which can be proved by the following calculations.

A^1 leaf has 100% relative growth rate whereas B^1 leaf has 10% relative growth rate.

Relative growth rate (RGR) of A^1 leaf $\frac{5}{5}$ x 100 = 100% ∵ Growth per unit time = 5 cm^2

Initial size = 5 cm^2

Relative growth rate (RGR) of B^1 leaf $\frac{5}{50}$ x 100 = 10% ∵ Growth per unit time = 5 cm^2

Initial size = 50 cm^2

Condition for Growth

The growth of a plant involves synthesis of more protoplasm, cell division, cell enlargement and cell differentiation. It is influenced by various factors which are discussed below:

(i) **Water:** It is an essential factor required for the proper growth of a plant. It is responsible for cell elongation and maintenance of turgidity of growing cells *i.e.,* cells full with water. It also provides the medium for enzymatic activities which are needed for growth.

(ii) **Oxygen:** All higher plants respire aerobically for which they need oxygen. The amount of oxygen available to the plants determines the amount of respiratory energy that can be utilized for biosynthetic activity i.e., anabolic activity required for growth. For example, in water-logging condition, the growth of root is inhibited due to the reduced availability of oxygen to roots.

(iii) **Nutrients:** Macronutrients like C, O and micronutrients like Zn, Fe are the raw material for the synthesis of protoplasm. The initial rate of growth of a seed, tuber, bulb etc. depends upon the amount of nutrition contained in it.

(iv) **Temperature:** A temperature of 28° - 30°C is optimum for the proper growth of most of the plants. If there is any deviation from this range, there could be detrimental or adverse consequences on the growth of the plant. For example, higher temperature above 45°C hinders growth due to excessive transpiration, denaturation of enzymes and coagulation of protoplasm.

(v) **Light:** It is not essential for early growth of the plant but growth is sustained only in its presence. It is required by the plant for tissue differentiation, synthesis of photosynthetic pigments and photosynthesis.

(vi) **Gravity:** It determines the direction of orientation or movement of many root, stem and the branches borne over them.

DIFFERENTIATION, DEDIFFERENTIATION AND REDIFFERENTIATION

Differentiation

The phenomenon by which the cells derived from root apical meristem, shoot apical meristem undergo permanent changes in their structure, biochemistry, size, physiology of cell wall and protoplasm content. Thus, enabling the cells to perform a specific function.

Some examples of the differentiation are:

(i) Tracheary element: The tracheary element is formed by the process of differentiation where the cells elongate and lose their protoplasm to form tracheid's. A strong, elastic lignocellulosic secondary cell wall develops which does not allow tracheids to collapse under extreme tension and allow it to carry water to long distances.

(ii) Chlorenchyma: It is specialised to perform photosynthesis which is developed due to formation of chloroplasts in the living thin-walled cells.

Other structures found in plants such as aerenchyma, stomata, collenchyma, trichomes, root cap etc. are formed after the differentiation.

Dedifferentiation

During differentiation cells lose their ability to divide and form permanent cells. But some cells regain their capacity to divided under certain conditions. This phenomenon where certain living differentiated cells regain or attain their ability to divide and form new cells is known as dedifferentiation.

A dedifferentiated tissue can act as a meristem *e.g.,* interfascicular vascular cambium, cork cambium, wound cambium. These are formed from fully differentiated parenchyma cells.

Redifferentiation

The dedifferentiated cells can again lose their ability to divide to form permanent cells specialised for a particular function. The process where the dedifferentiated cells again lose their ability to divide to form permanent cells is called redifferentiation. It is similar to differentiation of cells and tissues formed by primary meristem. (For examples - Secondary phloem, secondary xylem, cork, secondary cortex are some tissues formed through redifferentiation).

Like growth, differentiation is also open in plants. The same apical meristem produces parenchyma, fibers, xylem, phloem, collenchyma and epidermis. The final structure of a cell, formed at maturity is also determined by the neighboring cells present in the tissue. For example, cells positioned away from root apical meristem differentiate as root cap cells, while those pushed to the periphery mature as epidermis.

DEVELOPMENT

Development is the sequence of changes that occurs in the structure and functioning of an organism, organ, tissue or cell involving its formation, growth, differentiation, maturation, reproduction, senescence and death. Plant during its life cycle passes through development stages of seed germination, seedling, juvenile phase, maturation, flowering, seed formation and senescence. The conversion of one phase into next is also development *e.g.,* leaf initiation to leaf expansion, vegetative or juvenile phase to reproductive phase *i.e.,* flowering. Appearance of chloroplasts in cells when exposed to sunlight is also a type of development. Development leads ultimately to senescence and then death.

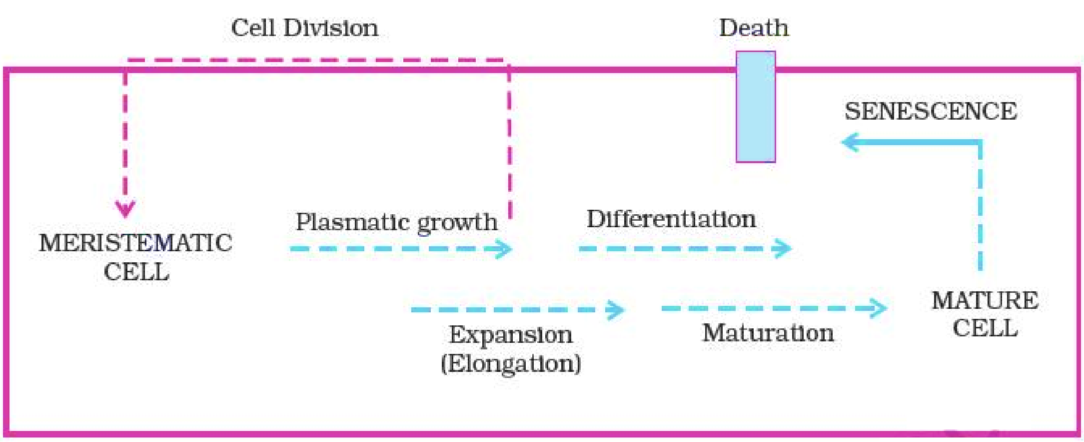


Fig.: Sequence of the developmental processes in a plant cell

The development process is not always straight. Plants show **plasticity** which means the ability of plant to follow different pathways and produce different structures in response to environment. Example of plasticity is **heterophylly**. Heterophylly is the phenomenon of appearance of different forms of leaves on the same plant. It can be seen or observed in plants like cotton, coriander and larkspur. In such plants, the leaves of the juvenile plants are different in shape from those of mature plants. On the other hand, difference in shapes of leaves can be observed in buttercup present in air and water. It means this plant shows different shapes of leaves according to its habitat.

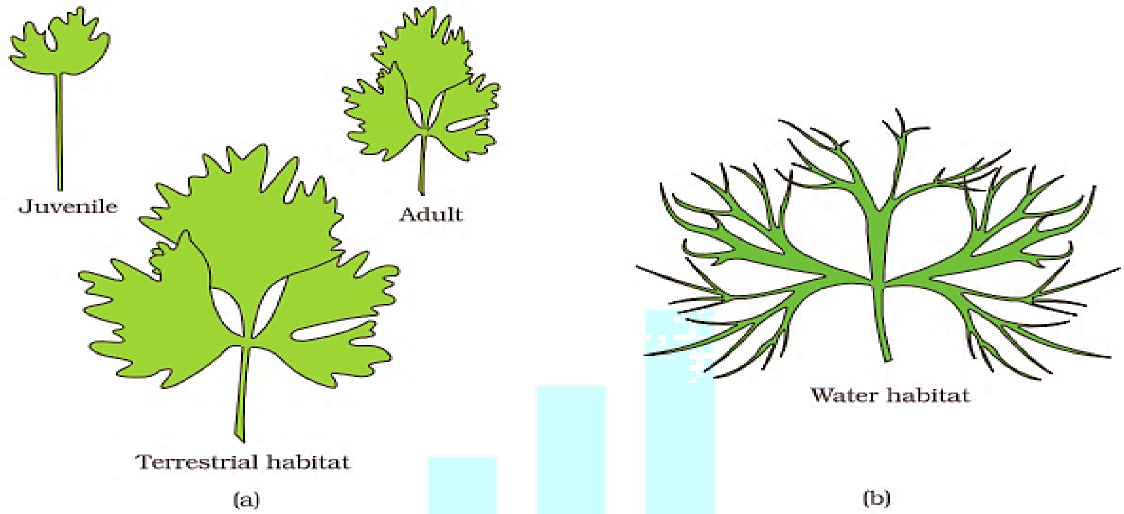


Fig.: Heterophylly in (a) larkspur and (b) buttercup

It is clear, therefore, that development includes both growth and differentiation. There are various intrinsic and extrinsic factors which influence the development stages of a plant. The intrinsic factors include genetic which are intracellular and chemical substances like PGRs which are intercellular. The extrinsic or external factors are light, temperature, oxygen, CO_2, water, nutrition etc. These factors influence various events such as dormancy, seed germination, flowering, plant movements etc. occurring in plants during their development.

PLANT GROWTH REGULATION

Plant growth regulators (PGRs) are small, simple organic substances of diverse or different chemical composition which are required in low concentration like hormones in animals. The PGRs influence physiological activities of plants leading to promotion, inhibition and modification of growth. Therefore, they are also called as **plant growth substances, plant hormones or phytohormones**.

A plant hormone can be best defined as a chemical substance other than nutrients which regulate one or more physiological activities at the same site where it gets synthesised or away from that. These phytohormones are composed of different types of chemical compounds which are as follows:

S. No.	Composition	Phytohormones
1.	Indole compounds	IAA - Indole-3-acetic acid, IBA - Indole butyric acid
2.	Terpenes	Gibberellic acid or Gibberellins (GAs)
3.	Adenine derivatives	N6 Furfurylamino purine, kinetin
4.	Gases	Ethylene (CH2 = CH2)
5.	Derivatives of carotenoids	Abscisic acid (ABA)

Classification of PGRs/Phytohormones

On the basis of their functions performed in a living plant body, these can be broadly classified into two groups *i.e.,*

(i) **Plant growth promoters:** These are the chemical substances involved in growth-promoting activities such as cell division, cell enlargement, tropic growth, flowering, fruiting and seed formation. *e.g.* **Auxin, gibberellins and cytokinin**.

(ii) **Plant growth inhibitors:** These are the chemical substances such as **ABA**, involved in growth-inhibiting activities like dormancy and abscission.

(a) **Dormancy:** It is a period when growth and development are temporarily stopped. For example, failure of seeds to germinate due to the lack of favorable conditions in the environment.

(b) **Abscission:** It is the falling or shedding of leaves, fruits and flowers.

One other type of phytohormone *i.e.,* **ethylene** could fit either of the two above mentioned groups, but it is largely an inhibitor of growth activities and is a gaseous hormone.

Now we will study different types of phytohormones in detail.

1. Auxin: The word auxin is derived from Greek word '*auxein*' which means 'to grow'.

Discovery: Auxin was the first hormone to be discovered. **Charles Darwin** and his son **Francis Darwin** observed that the stimulus of light was perceived by coleoptile tip of canary grass but the bending response to unilateral light was produced at a distance in growth zone *i.e.,* subapical part.

After a series of experiments conducted by other scientists, it was concluded that the sensation picked up by the coleoptile tip is transmitted to the subapical part which bends towards the direction of light. As it was found that:

(a) In an experiment if the coleoptile tip was removed then there was no bending of shoot towards light because the stimulus of light was not perceived.

(b) When coleoptile tip was covered by an opaque tin foil cap, it could not perceive the stimulus of light and hence, no bending was observed.

(c) When coleoptile tip was covered with a translucent cap, it could perceive the stimulus of light and hence, bending was observed.

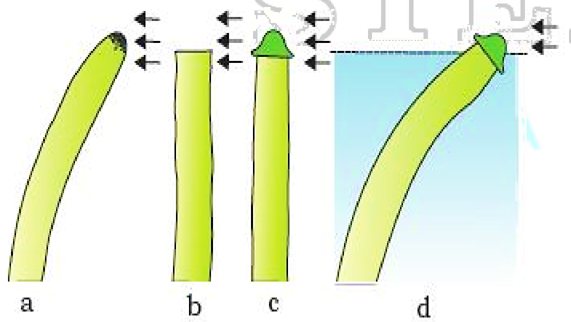


Fig.: Experiment used to demonstrate that tip of the coleoptile is the source of auxin. Arrows indicate direction of light.

Isolation:

(a) Auxin was first isolated from human urine samples because auxins do not have metabolic role so excreted out of the body.

(b) It was also isolated from the tips of coleoptiles of oat seedings by **F. W. Went**.

(c) **Precursor:** Tryptophan (amino acid).

Occurrence: They occur in the growing apices of the stems and roots from where they migrate to their site of action.

Types: Auxins are of two types:

(a) Natural auxins: These are produced by plants and can be isolated from them.

For example, IAA - Indole-3-acetic acid

IBA - Indole-3-butyric acid

(b) Synthetic auxins: These are produced artificially.

For example, 2, 4-D –

2, 4-Dichlorophenoxyacetic acid

2, 4, 5-T - 2, 4,

5-Trichlorophenoxy acid.

NAA - Naphthalene acetic acid.

All these auxins have been used extensively in agricultural and horticultural practices.

Bioassay: The functions of auxins can be tested with the help of bioassays. **Bioassay** means the testing of substance for its activity in causing a growth response in a living plant or its part. The test measures the concentration required to produce the effect, and thus, it is quantitative. The ***Avena* curvature test** and **root growth inhibition test** are some of the bioassays for examining auxin activity.

F. W. Went cut off tips of oat coleoptiles and placed them on small agar blocks and let them for a few hours to allow all the 'chemical influence' to diffuse into the agar. By this, he isolated auxins in agar block. He then placed these agar blocks on one side of freshly decapitated coleoptiles. He observed that the coleoptiles grew and bent directly proportional to the concentration of the chemical influence in the agar block. Went named this 'chemical influence' responsible for the phototropic response as **auxin**. Hence, Went is credited with the discovery of auxins.

Physiological effects/Function of auxin:

(i) Abscission: In the presence of normal level of auxin, plant organs such as fruits, leave cannot abscise. Thus, auxin inhibits the abscission, it can occur only when auxin content or level decreases and a layer called abscission layer is formed between the organs like fruits, flowers etc. and the stem. Thus, auxin inhibits abscission of young leaves, fruits and flowers whereas it promotes the abscission of older mature leaves, fruits and flowers.

(ii) Apical dominance: It is the phenomenon by which the presence of apical bud does not allow the nearby lateral or axillary buds to grow. Apical bud secretes auxin which inhibits the growth of lateral buds. If the apical bud is removed (***Decapitation***), the lateral buds sprout *i.e.,* start growing. However, if a paste containing auxin is applied on the cut portion of the decapitated shoot, the lateral buds remain in the similar way when apical bud is present.

The removal of apical bud is done for the preparation of hedges and bushy growth in certain plants. For example, when the apical bud of tea plants is removed, the lateral buds start developing into branches. It is done to produce more number of leaves so that yield can be increased.

(iii) Cell division and Xylem differentiation: Auxin is responsible for initiation and promotion of cell division in cambium. It also controls the xylem differentiation.

Uses/Applications

(1) Rooting: Auxin stimulates root formation on stem cuttings, particularly the woody ones. The common auxins used for inducing the rooting are NAA and IBA.

(2) Flowering: The dilute solutions of NAA and 2, 4-D, are sprayed on litchi and pineapple which induce flowering in them. However, flowering in most plants can be inhibited by spraying high concentration of auxins. This effect is used advantageously to prevent flowering in lettuce, where only leaves are edible.

(3) Parthenocarpy: Auxins such as IAA and IBA in diluted form are used to produce parthenocarpy or seedless fruits *e.g.,* tomatoes. It has been observed that the carpels (female part) producing parthenocarpy or seedless fruits like banana, grapes etc. have a higher internal production of auxins.

(4) Weedicides: Some synthetic auxins are used as weedicides. Weedicides are the chemicals used to kill weeds (unwanted plants) growing with the crops. 2, 4-D is widely used to remove broad leaved weeds or dicotyledonous weeds in cereal crops or monocotyledonous plants.

The auxins are also used by gardeners to prepare weed-free lawns. Thus, auxins are widely used in agricultural and horticultural practices.

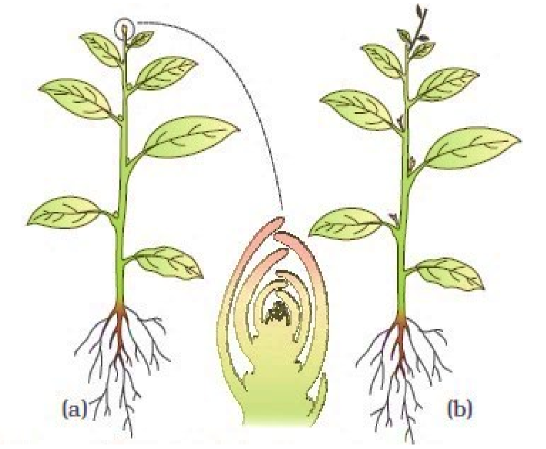


Fig. : Apical dominance in plants : (a) A plant with apical bud intact, (b) A plant with apical bud removed

Note the growth of lateral buds into branches after decapitation.

(2) Gibberellins

Discovery: The effect of gibberellins had been known in Japan for over a century ago. Japanese farmers observed that certain rice seedings in their fields grow excessively tall and become weak and sterile. It was found that it is a type of disease from which the seedings suffered known as 'bakane' or 'foolish seedling' disease.

Japanese plant pathologist. **E. Kurosawa** (1926) found that the disease was caused by a fungus, *Gibberella fujikuroi*. With the extract of this fungus, he could produce symptoms of foolish seeding in healthy plants.

Yabuta extracted the active substances *i.e.,* growth-promoting substances and termed them as gibberellin.

Presently, more than 100 gibberellin have been identified from widely different organisms such as fungi and higher plants. They are acidic in nature and denoted as GA_1, GA_2, GA_3, and so on. Among all gibberellins or gibberellic acid, GA_3, is one of the first to be discovered and thoroughly the most intensively studied form.

Precursor: Acetyl-CoA

Physiological effects/Functions:

(i) **Stem and leaf growth:** Gibberellins stimulate stem elongation and other aerial parts. Therefore, these increase the size of stem and fruits. However, gibberellins have no effect on roots.

(ii) **Bolting:** Gibberellins induce stem elongation in 'rosette plants' *e.g.,* cabbage, beet; in rosette plants, internodal growth is retarded and leaves are developed profusely. In these plants, just prior to the reproductive phase, the internodes elongate enormously causing a marked increase in stem height. This is known as bolting.

(i) **Seed germination:** Gibberellins stimulate the synthesis of various types of hydrolytic enzymes for mobilisation of reserve food, *e.g.,* amylases, proteases.

Uses/Application:

(1) **Fruit growth:** Gibberellins are used to increase the size of apple as well as improve its shape and increase bunch length in grapes.

(2) **Delayed ripening:** With the help of gibberellins, ripening of fruits can be delayed so that their plucking can be postponed. Thus, fruits can be left on the tree longer so as to extend the period for marketing.

(3) **Malt yield:** GA_3, is used to speed up the malting process in brewing industry. It increases the yield of malt from barley grains.

(4) **Sugarcane:** Carbohydrate in the form of sugar is stored in the stems of sugarcane. When gibberellin is sprayed on sugarcane crop, the length of the stem increases. As a result, the sugar content increases which finally increases the yield by as much as twenty tones per acre.

(5) **Quicker maturity:** In juvenile conifers, gibberellin has been found to cause quicker early growth so that maturity is reached early. It is useful for obtaining early and quickly yield of economically important seeds.

(3) Cytokinins

Discovery: F. Skoog and his co-workers found that tobacco callus *i.e.,* a mass of undifferentiated cells proliferated only when in addition with auxin, the culture medium is provided either with coconut milk or yeast extract DNA.

Miller *et al.* discovered the first cytokinin from degraded product of autoclaved herring sperm DNA which had a powerful cytokinesis (division of cytoplasm) promoting effect. It is called kinetin (N^6-furfurylamino purine). It is a synthetic product and does not occur naturally in plants.

Isolation: The first natural cytokinin was isolated from unripe maize grains or kernels known as zeatin. It can also be isolated from coconut milk. Since the discovery of zeatin, several naturally occurring cytokinins, and some synthetic compounds with cell division-promoting activity have been identified.

Occurrence: Cytokinin's occur in regions where rapid cell division occurs such as root apices, developing shoot buds, young fruits etc.

Chemically these are modified purines, **derived from tRNA**. *e.g.* zeatin (Benzyl amino purine; BAP), dehydrogenation, Isopenfenyl adenine (IPA).

Functions/Physiological effects

(i) **Growth of leaves and shoot:** It helps in the production of new leaves and chloroplasts in leaves. It also stimulates lateral shoot growth and adventitious shoot formation.

(ii) **Counteracting apical dominance:** Cytokinin initiates the growth of lateral buds despite the presence of apical bud. In the presence of cytokinins, supply of water and minerals increases to lateral buds. Therefore, the lateral buds grow even in the presence of apical bud.

(iii) **Delay in senescence:** Cytokinins delay the senescence (ageing) of leaves and other organs by controlling protein synthesis and mobilisation of nutrients as resources (**Richmond Lang effect**).

(iv) **Cell division:** Cytokinins are essential for cytokinins *i.e.,* division of cytoplasm. Along with auxin, cytokinin causes division even in permanent cells. These two hormones are also responsible for cell division in callus *i.e.,* a mass of undifferentiated cells.

(v) Shelf life of cut shoot, vegetables and flowers is increased by applying this hormone.

Uses/Applications

(1) **Overcoming senescence:** Cytokinins are used to delay the senescence of intact leaves and other plant parts.

(2) **Tissue culture:** Cytokinins along with auxins are essential in tissue culture as they are required for cell division and morphogenesis/organogenesis.

Auxin concentration = Cytokinin concentration Callus

Auxin concentration > Cytokinin concentration Root

Cytokinin concentration > Auxin concentration Shoot

(4) Ethylene

It is gaseous plant hormone

Discovery: Cousins discovered and confirmed that ripe organs emitted a volatile substance that brought about early ripening unripe bananas kept nearby. Later on, this volatile substance was identified as ethylene.

Synthesis: It synthesised in almost all plant parts like roots, leaves, flowers, fruits, seeds etc. The maximum synthesis occurs during ripening of fruits and in the tissues undergoing senescence *i.e.,* ageing.

Precursor: Methionine

Physiological effects/Functions

(i) Transverse or horizontal growth: Ethylene inhibits longitudinal growth but stimulates transverse growth of seedlings. It is also responsible for the formation of apical hook in dicot seeding and swelling of the axis due to which stem looks swollen.

(ii) Senescence: It promotes senescence of plant parts like leaves, flowers. It has been found that leaf senescence is largely caused by ethylene.

(iii) Abscission: Ethylene accelerates abscission *i.e.,* shedding of leaves, flowers and fruits.

(iv) Fruit ripening: Ethylene is a ripening agent. It is involved in ripening of **climacteric fruits**. The climacteric fruits are fleshy fruits which show sudden sharp rise in the rate of respiration at the time of ripening. This sudden sharp rise in the rate of respiration is called **respiratory climactic**.

(v) Breaking of dormancy: It breaks the dormancy of seeds, but and initiates the germination of seeds such as peanut seeds. It also causes the sprouting of potato tubers.

(vi) Elongation of stem in deep water rice plants: Both stem and petiole elongation in submerged and partially submerged aquatic plants is promoted by ethylene. For example, leaves of rice seedlings remains out of water due to ethylene where it induces rapid growth of internodes and leaf bases.

(vii) Roots and root hairs: Ethylene induces development of adventitious roots on various types of cuttings. It promotes the development of lateral roots and growth of root hairs so as it increase the absorption surface.

(viii)Flowering: Flowering and fruit set up are synchronised by ethylene in pineapples. It also initiates flowering in mango.

(ix) Sex expression: Ethylene increases the number of female flowers and fruits in certain plants like cucumber.

(x) Epinasty: Exposure to ethylene causes drooping of leaves and flowers.

(xi) Apogeotropism: Ethylene decreases sensitivity of roots to gravity.

Uses/Applications

Ethylene is one of the most widely used PGRs in agriculture as it regulates so many physiological processes which are discussed earlier. The most widely used compound as a source of ethylene is processes is **ethephon**. The uses of ethylene are as follows:

(1) Fruit ripening: Ethephon is used in artificial ripening. It is an aqueous solution, which is readily absorbed and transported within the plant and releases ethylene slowly. Ethephon has the capacity to increase or hasten fruit ripening.

(2) Abscission and thinning: It is used to accelerate or increase the abscission of flowers and fruits and also the thinning of fruits. *e.g.,* cotton, cherry, walnut.

(3) Increase in number of fruits: Application of ethylene in cucumber increases the number of female flower thereby increasing the yield.

(4) Sprouting of storage organs: The sprouting of storage organs such as rhizomes, tubers can be enhanced by exposing them to ethylene.

(5) ABA - Abscisic acid

Abscisic acid is mildly acidic growth hormones which functions as a general growth inhibitor.

Discovery: During mid-1960s, three independent researchers reported the purification and chemical characterisation of three different kinds of inhibitors - inhibitor , abscission and dormin. Later all the three were proved to be chemically identical. In order to avoid confusion the name abscisic acid was given.

Occurrence: Dormant buds, seeds.

Precursor: Violaxanthin

Physiological effects/Functions

(i) Abscission: ABA promotes abscission of flowers and fruits.

(ii) Dormancy of buds and seeds: ABA acts as a growth inhibitor and induces dormancy of buds and seeds. As ABA induces dormancy, it is also known as dormin. The buds as well as seeds sprout only when ABA is overcome by gibberellins.

(iii) Metabolism: ABA inhibits the protein and RNA synthesis and cause destruction of chlorophyll. As a result senescence of leaves is stimulated.

(iv) Inhibition of seed germination: abscisic acid inhibits gibberellin mediated amylase formation during germination of cereal grains and thus inhibits their sprouting.

(v) Closure of stomata: The concentration of ABA increases in the leaves of the plants during desiccation and other stressful condition. As a result, stomata present in the epidermis of leaves close to prevent the loss of water *i.e.,* transpiration. Therefore, it can also be known as anti-transpiration. Thus, synthesis of

ABA is stimulated by drought, water logging and other adverse environmental conditions. Therefore, it is known as **stress hormone**.

In most situation, ABA acts as an antagonist to GAs that's why it is known as **Anti GA**.

Uses/Applications

(1) **Anti transpiration:** Application of minute quantity of ABA to leaves reduces transpiration to a great extent through partial closure of stomata. It thus, conserves water and reduces the requirement of irrigation.

(2) **Dormancy:** ABA is used to induce the dormancy of buds, seeds and storage organs. By inducing dormancy ABA helps the seed to withstand desiccation and other unfavorable factors. Thus, ABA plays an important role in seed development and maturation.

Synergistic actions

(1) **Cell division:** Both auxin and cytokinin promote cell division which shows their synergistic effect on cell division.

(2) **Abscission:** Both ethylene and ABA are responsible for promoting the shedding of leaves, fruits and flowers

Antagonistic effects

(1) **Dormancy:** ABA induces dormancy of buds, seeds and storage organs whereas gibberellins inhibit it.

(2) **Apical dominance:** Auxin promotes the apical dominance whereas it is inhibited by cytokinin. Thus, these two hormones act antagonistically.

(3) **Senescence:** Senescence is prevented by auxins while it is stimulated by ABA.

The role of PGR is of only one kind of intrinsic control. Along with genomic control and extrinsic factors, they play an important role in the plant growth and development. Many of the extrinsic factors such as temperature and light, control plant growth and development via PGR. Some of such events could be dormancy, seed germination, flowering, plant movements etc. Let us try to understand some of these.

Seed Dormancy

The seed undergoes a period of suspended growth and does not germinate as soon as it is formed. The suspension of growth is referred to as **quiescence** when it is due to exogenous factors, such as the environmental conditions. The seeds may be in a state of **dormancy** or rest due to endogenous control during which metabolic activity of the seed is greatly reduced. Quiescence is the condition of a seed when it is unable to germinate because the conditions for germination are not available. Such seeds will germinate if they are supplied with water and suitable temperature. While dormancy is the condition of seed when it is unable to germinate in spite of the availability of all environment's conditions suitable for germination.

Factors: Dormancy in seed may be due to impermeable or mechanically resistant seed coats, rudimentary or physiologically immature embryos and even due to the presence of germination inhibitors such as abscisic acid, phenolic acid, short chain fatty acids and coumarin.

Breakage of dormancy: Dormancy of the seed can be broken, or its duration can be reduced to initiate germination, by mechanical or chemical scarification of the seed coat, stratification of seeds or changing environment conditions such as temperature, light and pressure.

Scarification of seed involves scratching of seed coat to break the seed dormancy caused by hard and impermeable seed coat. Stratification of seed is subjecting the most seeds oxygen for variable periods of low or high temperatures.

Germination of seed/Seed germination

The resumption of active growth of the embryo present in the seed after a period of dormancy is known as germination. For the germination of a seed, water, temperature and oxygen are essential requirements. When a seed is provided with these essential requirements, it starts to germinate. During this process, first structure developed within the seed is known as radicle. Radicle breaks the seed coat and passes downwardly in the soil to establish itself as the primary root. Later it gives rise to tap root system. Soon after the elongation of the radicle, either hypocotyl shows active growth which pushes plumule out of the soil which form shoot system. The growth of radicle and plumule is due to the cell extension, division and initiation of several biochemical processes. The seed also needs a suitable temperature (optimum between 25°C to 35°C).

In bean, hypocotyl grows actively and becomes curved. It brings the seed above the soil. After coming above the surface of the soil, the hypocotyl straightens. The loosened seed coats fall down. Now, epicotyl grows and the plumule gives rise to green leaves.

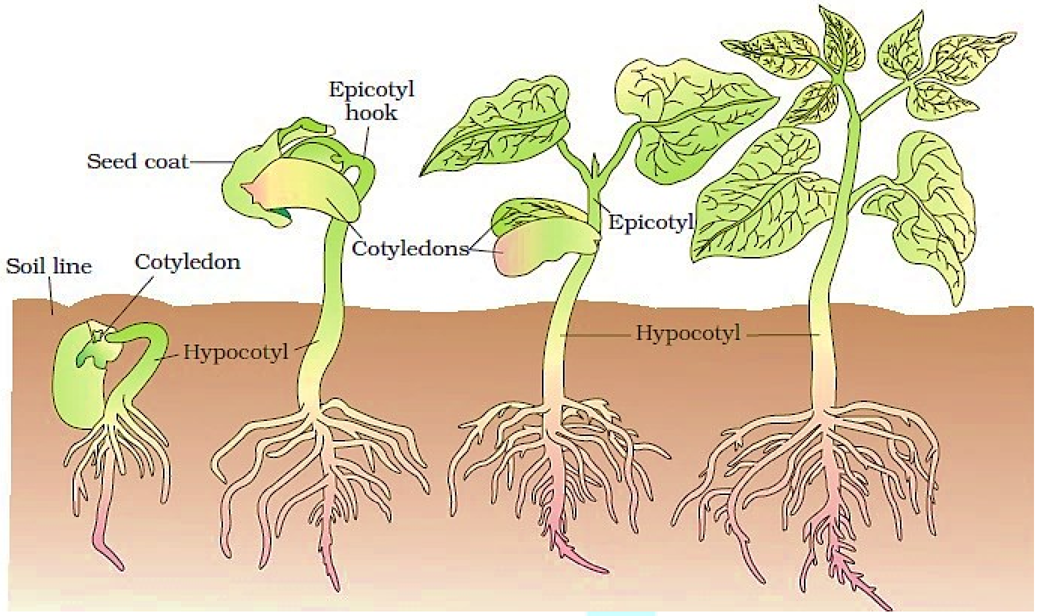


Fig: Germination and seedling development in bean.

Emergence of radicle by rupturing seed coat is called seed germination. It is of two types:

(a) Epigeal: Hypocotyl grows first, cotyledons comes out of soil, as in cucurbits, mustard, castor, onion, tamarind, bean etc.

(b) Hypogeal: Epicotyl grows first, cotyledons remains underground as in rice, maize, mango, gram, groundnut etc.

Vivipary

Vivipary is the germination of a seed while it is still attached to the parent plant and is nourished by it. It occurs in mangrove plans like *Rhizophora* and *Sonneratia*. These plants grow in saline marshy habitats along sea shores. Seeds cannot germinate in such habitats due to excessive salt and deficiency of oxygen. Mangroves plants have solved this problem through vivipary. The seed does not undergo dormancy, soon it germinates while present inside the fruit attached to parent plant. As the germinating seed forms a seedling, its weight increases and the seedling separates and falls down into the mud. The lateral roots then develop from radicle to help proper anchorage of the seedling.

Flowering

Plants flower when they reach the reproductive phase. These are various parameters which influence the process of flowering. Two main phenomena involved in the flowering process are photoperiodism and vernalisation.

PHOTOPERIODISM

The relative lengths of dark and light periods vary from place to place and from season to season which influence the flowering process to a great extent in different plants. The length of light period is called **photoperiod** and the responses shown by the plants to changes in the relative lengths of dark and light period is called **photoperiodism**. Thus, plants exhibiting such response are known as **photoperiodic plants**.

Garner and **Allard**, found that the tobacco plants could flower only if the plants were exposed to a number of short days. In autumn, this occurred naturally. But in summers the plants did not flower even after attaining much heights, until and unless these were provided a number of short days of 7 hours in a greenhouse. When they examined more plants for this behavior, they found that plants differ in their requirements for day length.

Most plants can flower only if they were exposed to light for less or more than a certain period, which is known as **critical period**. Accordingly, plants can be categorised as follows:

(1) Long day plants: These plants flower when they receive long photoperiods or light hours which are above than a critical period. *e.g.,* wheat, radish, sugar beet, henbane etc.

(2) Short day plants: These plants flower when they are exposed to a photoperiod shorter than a critical period. Most of winter-flowering plants belong to this category. *e.g.,* soyabean, tobacco etc.

(3) Day neutral plants: These plants do not show any correlation between exposure to light duration and induction of flowering response. They can blossom throughout the year *e.g.,* tomato, pepper, cucumber etc.

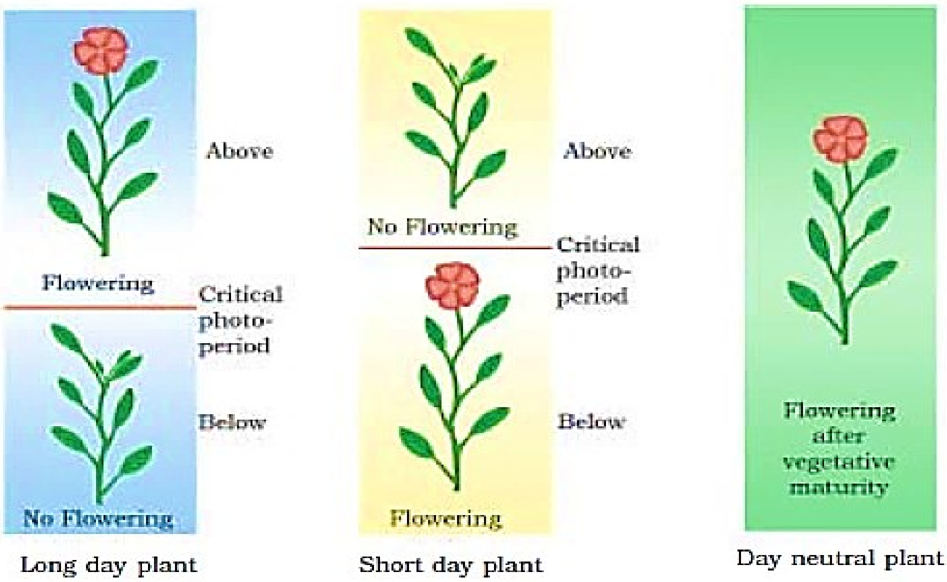


Fig. Photoperiodism: Long day, short day and neutral plants.

It is also interesting to note that before flowering, shoot apices modify themselves into flowering apices. Shoot apices of plants themselves cannot perceive photoperiods. **The site of perception of light/dark is the leaves of plants**. It has been hypothesised that there is a hormonal substance known as **florigen** which is responsible for flowering. When plants are exposed to the required inductive photoperiod, the hormonal substance *i.e.,* florigen migrates from leaves to shoot apices for inducing flowering.

Important of Photoperiodism

(1) The knowledge of photoperiodic effect is useful to the commercial flower growers. It enables them to induce or retard flowering by regulating the photoperiodic and temperature conditions in glass houses to meet the demands of the market.

(2) The knowledge of photoperiodism is also useful in laying out gardens, orchards and planning crop pattern in a particular area.

(3) The knowledge of photoperiodism can be utilized in keeping some plants in vegetative growth to obtain higher yield of tubers, rhizomes etc. or keep the plant in reproductive stage to yield more flowers and fruits.

VERNALISATION

There are various plants for which flowering is either quantitatively or qualitatively dependent on exposure to low temperature. This phenomenon is termed **vernalisation** or it refers to promotion of flowering by a period of low temperature. Here, the stimulate is perceived by the mature stem apex, or by the embryo of the seed, but not by the leaves as in photoperiodism.

Vernalisation is seen in many winter annuals and biennial plants.

(a) Winter annuals: Some important food plants, wheat, barley, rye have two kinds of varieties-winter and spring. The 'spring' variety is normally planted in the spring season. In this variety, flowering and production of grain occurs before the end of the growing season. However, if winter varieties are planted earlier to their sowing period *i.e.,* in spring season, this would result in no flowering and production of mature grains within a span of a flowering season. Hence, they are planted in autumn. They germinate and over winter come out as small seedlings, resume growth in the spring, and are harvested usually around mid-summer. Therefore, we can say that plants require a specific temperature.

(b) Biennial plans: Biennial plants such as sugar beet, cabbage, carrot are monocarpic that normally flower and die in the second season. When growing biennial plants are subjected to a cold treatment, it leads to the stimulation of a subsequent photoperiodic response which results in flowering. The main role of vernalisation is to prevent the precocious *i.e.,* early reproductive development so that the plants have enough time to reach maturity.

Importance of Vernalisation

(1) Vernalisation can help is shortening the period between germination and flowering. Thus, more than one crop can be obtained during a year.

(2) Sowing of winter crops (cereals) in spring season after vernalisation can avoid killing of cereals in severe winter.

Chapter 14
Breathing and Exchange of Gases

Introduction:

All activities of an animal require energy which is derived from the breakdown of nutrient molecules like glucose. During this catabolic reaction (the breakdown of a molecule into simpler components) glucose is broken down into CO_2 and water in the presence of O_2 and energy is released in the form of ATP. This energy is utilized by the animals to carry out their bodily function.

The CO_2 produced by the cells during catabolic reactions is a harmful and toxic to the body cells so it is eliminated out the body. This process of exchange of O_2 form the atmosphere with CO_2 produced by the cells is called breathing. Breathing is simply defined as intake of fresh air and removal of foul air, i.e., CO_2 whereas respiration is defined as oxidation of food (glucose) to form CO_2 .H_2O and energy.

Respiratory organs is different animals

S.No.	Animal	Respiratory Organ/System	
1	Lower invertebrates	No well-developed respiratory organ is present.	Sponges' coelenterates, flatworms
		Exchange of gases by simple diffusion.	Example
		Moist, thin and vascular cuticle.	Earthworm
		Tracheal system (network of tubes)	Insects like cockroach.
		Gills- plate-like or filamentous and vascularised structures.	Aquatic arthropods like cray fish, prawn and molluscs like Unio.
2.	Fishes	Gills	Cartilaginous and bony fishes.
	Amphibian	Gills	Tadpole larva of frog.
		Moist skin, lungs, Buccal cavity	Frogs, toads etc.
	Reptiles	Lungs	Snakes, lizards etc.
	Birds	Lungs	Pigeon, sparrow etc.
	Mammals	Lungs	Humans .

HUMAN RESPIRATORY SYSTEM

Respiratory passage : It is a passage that takes air form outside to the respiratory surface of lungs. It consists of a pair nostrils, nasal cavity, a pair of internal nares, pharynx, trachea, bronchi and their branches and the respiratory surface of lungs, i.e., alveoli.

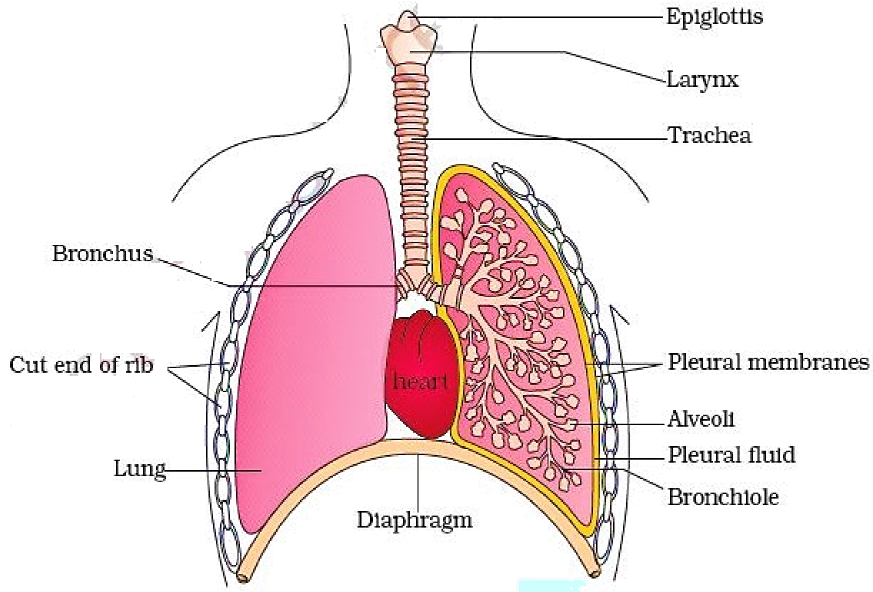


Fig. : Diagrammatic view of human respiratory system sectional view of the left lung is also shown

Structures involve in respiratory passage

External nostrils : A pair of external nostrils represent the first part of respiratory passage. These are the holes of our nose opening out above the upper lips. These lead into nasal chamber.

Nasal chambers: These are also two in number. The epithelial lining of cavities is known as respiratory epithelium. It has pseudostratified ciliated columnar, non-ciliated brush border epithelium and goblet cells, The epithelium also possess glands. It is richly supplied with blood vessels. Mucus is produced by goblet cells.

Functions :

- Mucus from goblet cells and glands makes the surface sticky for trapping dust particles present in the inspired air.
- Moisture from the epithelium also makes the air humid.
- It brings the temperature of the incoming air, up to body temperature.

Internal nares : These are the posterior openings of the nasal cavities that lead into the nasopharynx.

Nasopharynx : Internal nares open into a part of pharynx known as naso pharynx. It is a portion of pharynx. Only air passes through naso pharynx. It opens into the trachea through glottis of larynx region.

Glottis in the opening at the upper part of larynx.

Larynx : It is also known as sound/voice box because it helps in the production of sound. It is made up of cartilage present at the upper part of trachea. Its upper part has an opening i.e., glottis. During swallowing this glottis can be covered by epiglottis which is a leaf-shaped cartilaginous structure made up of elastic cartilage. Epiglottis is the covering or lid of glottis to prevent the entry of food into the larynx during swallowing.

Trachea : It is also known as wind pipe. It is a straight tube extending up to the mid-thoracic cavity commonly called chest cavity. This tube finally divides into right and left primary bronchi at the level of 5^{th} thoracic vertebra. It is lined by incomplete cartilaginous rings to prevent it from collapsing during inspiration.

Bronchi (Plural), bronchus (sing.) : Each bronchus undergoes repeated divisions to from its branches, these are secondary, tertiary bronchi and bronchioles are the terminal branching of bronchi. Finally, Bronchioles give rise to a number of very thin, well-supplied with blood vessels, irregular walled incomplete cartilaginous rings.

Alveoli : Bronchioles open into the alveolar ducts, i.e, a tube-like structure which lead into an expanded passages which open into the alveolar sacs of air sacs. There are about 300 millions of alveoli in two lungs.

Surfactant : A surface active agent-lecithin secreted by type II alveolar epithelial cells, reduces surface tension between the alveolar fluid and air. It prevents collapsing of lung alveoli.

LUNGS

A pair of lungs is present in humans, lie in an air-tight chamber known as thoracic cavity or chest cavity. This cavity is formed dorsally by the vertebral column, ventrally by the sternum, laterally by the ribs. It is closed below by the diaphragm which is a dome-shaped structure made up of muscles and separates thoracic cavity from abdominal cavity (containing most of the digestive organs).

Membranes enclose the lungs : Each lung is enclosed by two membranes known as pleura or pleural membranes.

The outer pleural membrane is in close contact with the thoracic cavity whereas inner pleural membrane is in close contact with lungs surface. In between these two membranes, a narrow space is present known as pleural cavity. This pleural cavity is filled with a fluid secreted by pleural membrane known as pleural fluid.

Internal structure of lungs

Left lung is divisible by an oblique fissure into two lobes left superior and left inferior. **Right lung has two fissures, horizontal and oblique.** They divide the right lung into 3 lobes- right superior, right middle and right inferior. The lobes are divided internally into segments and segments into lobules. There are 8 segments in the left lung and 10 segments in the right lung.

Flow chart showing structures involved in respiratory passage

External nostrils
↓
Nasal chamber
↓
Internal nares
↓
Nasopharynx
↓
Glottis (a part of larynx) — Conducting part
↓
Trachea
↓
Primary bronchi
↓
Secondary bronchi
↓
Tertiary bronchi
↓
Bronchioles
↓
Alveolar ducts
↓
Atria
↓
Alveolar sac
↓ — Exchange / Respiratory part
Alveoli

Steps involve in respiration

Respiration is a complex process which occurs in number of steps. These are

Breathing : it is simply the inhalation of atmospheric air and exhalation of CO_2 rich alveolar air. It is also known as pulmonary ventilation.

Diffusion of gases across alveolar membrane : Diffusion of gases 0_2 and CO_2 takes place across the alveolar membrane to the blood capillaries surrounding it. The membranes is very thin and richly supplied with blood capillaries.

Transport of gases : Blood is the medium for transport of gases O_2 and CO_2, which transports O_2 to the body cells from alveoli and CO_2 from the body cells to alveoli.

Diffusion of gases between blood and tissues : O_2 is Diffused from blood to tissues and CO_2 is Diffused form tissues to blood.

Utilization of O_2 : O_2 is used by the body cells for the release of energy. Breakdown of glucose occurs in presence of O_2 which produces CO_2, water and energy. This is also known as cellular respiration as it occurs inside the cells. It is a biochemical reaction. The CO_2 produced us eliminated out of the body.

MECHANISM OF BREATHING

It includes two stages :

Inspiration :

(i) It is defined as a process by which fresh air enters the lungs.

(ii) It is inflow or inhalation of fresh air.

Expiration :

(i) It is defined as a process by which the foul air (containing CO_2) is expelled out the lungs.

(ii) It is outflow or exhalation of air.

The movement of air into and out of the lungs is carried out by creating a pressure gradient between lung and the atmosphere. the flow of gases from their higher-pressure region to their lower pressure region. For example pressure of O_2 in atmospheric are higher than the alveoli so O_2 diffuses from atmospheric air to alveoli.

1. **Inspiration :** Diaphragm and external inter costal muscles play an important role. The pressure within the lungs is made less than the atmospheric pressure so that air can flow to lungs.

   Role of diaphragm in inspiration : The contraction of muscle fibers of diaphragm causes it to become flat and lowered down thereby increasing the volume of thoracic cavity in antero-posterior axis.

Increase in the volume of thoracic cavity
↓ Leads to
Similar increase in the volume of pulmonary cavity
↓ Causes
Decrease in pressure within the pulmonary cavity (as we know
That pressure and volume are inversely proportional
↓ Causes
Air enters from atmosphere to the lungs as it moves from Higher pressure to lower pressure

External intercostals muscles : These muscles are present between the ribs. The contraction of These muscles lift ribs and sternum up and outward causing an increase in the volume of the thoracic cavity in dorso-ventral axis.

Increase in the volume of thoracic cavity
↓ Leads to
Similar increase in the volume of pulmonary cavity
↓ Causes
Decrease in pressure within the pulmonary cavity which is
less than the atmospheric pressure
↓ Causes
atmosphere air enters into the lungs (inhalation)

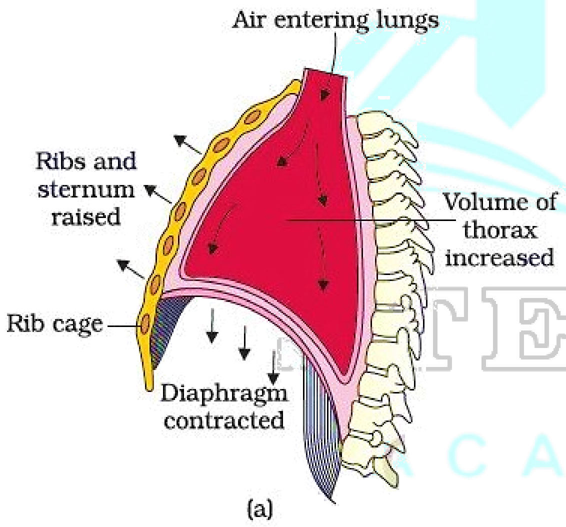


Fig. : Mechanism of breathing showing : (a) inspiration

Expiration : It is the moving of air out of lungs if the pressure within the lungs is more than the atmospheric pressure.

Diaphragm : The relaxation of muscle fibers of diaphragm causes it to come in normal position which reduce the volume of thoracic cavity.

decrease in the volume of thoracic cavity
↓ Leads to
Similar increase in the volume of pulmonary cavity
↓ Causes
Increase in pressure of pulmonary cavity
↓ Causes
Expulsion of air from higher pressure (lungs)
to lower pressure (atmosphere)

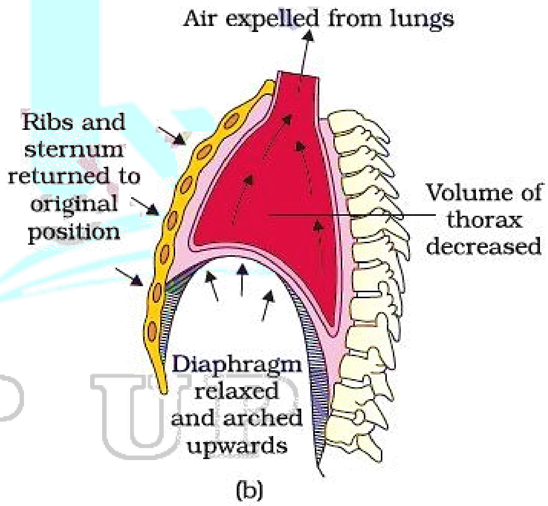


Fig. : Mechanism of breathing showing : (b) expiration

Table : Role of muscles in inspiration and expiration

No.	Stage of Breathing	Muscles involved	Contraction / Relaxation	Volume of thoracic cavity
1	(i) Normal inspiration	(a) Diaphragm	Contracts	Increases
		(b)External intercostals muscles	Contract	Increases
2	(i) Normal expiration	(a) Diaphragm	Relaxes	Decreases
		(b) External intercostals	Relaxes	Decreases
	(ii) Forceful expiration	(a)Internal intercostals muscles	Contract	Decreases
		(b) Abdominal muscles	Contract	Decreases

Pulmonary/ Respiratory Volumes and Capacities

Respiratory volume : It is defined as quantity of air which our lungs can hold or expel under different conditions.

1. **Tidal Volume (TV) :** During normal breathing, the volume of air inspired is known as tidal volume. its value is approximately 500 ml.
2. **Inspiratory Reserve Volume (IRV) :** It is defined as the additional or extra volume of air, a person can inspire by forceful inspiration. This volume averages 2500 ml to 3000 ml.
3. **Expiratory reserve volume (ERV) :** It is defined as the additional or extra volume of air, a person can by forceful expiration. This volume averages 1000 ml 1100ml.
4. **Residual volume (RV):** The **volume** of air which remains in the lungs even after the forceful expiration. It about 1100 ml 1200 ml.

Respiratory Capacities :

Sum of two or more respiratory volumes is called respiratory capacities.

(i) **Inspiratory Capacity (IC) :** It is the total volume of air a person can inspire after a normal expiration. This includes **tidal volume** and **inspiratory reserve volume**.

(ii) **Expiratory Capacity (EC) :** After a normal inspiration, the total volume of air a person can expire is known as expiratory capacity. This includes **tidal volume** and **expiratory reserve volume**.

(iii) **Functional Residual Capacity (FRC) :** It is defined as the volume of air that will remain in the lungs after a normal expiration. This includes **expiratory reserve volume** and **residual volume**.

(iv) **Vital Capacity (VC) :** It is defined as the maximum volume of air a person can breathe in after a forceful expiration or the maximum volume of air person can breathe out after a forceful inspiration. This includes **expiratory reserve volume**, **tidal volume** and **inspiratory reserve volume**.

(v) **Total lung capacity :** It is defined as the total volume of air present in the lungs and the respiratory passage after a maximum inspiration. It includes **residual volume**, **expiratory reserve volume**, **tidal volume** and **inspiratory reserve volume**. In other words, it is combination of vital capacity and residual volume.

S. No.	Respiratory volumes and capacities	Value
1	Tidal volume (TV)	500 ml
2	Inspiratory reserve **volume** (IRV)	2500-3000 ml
3	Expiratory reserve volume (ERV)	1000-1100 ml
4	Residual volume (RV)	1100-1200 ml
5	Inspiratory capacity (TV + IRV)	3500 ml
6	Expiratory capacity (TV + ERV)	1600 ml
7	Functional residual capacity (ERV + RV)	2300 ml
8	Vital capacity (TV + IRV + ERV)	4600 ml
9	Total lung capacity (TV + IRV + ERV + RV)	5800 ml

EXCHANGE OF GASES

Gases are exchanged by simple diffusion mainly based on pressure or concentration gradient. To explain the exchange of O_2 and CO_2, Partial pressure is studied. It is the pressure contributed or exerted by an individual gas in a mixture of gases. Partial pressure for oxygen is represented as pO_2 and for CO_2 it is pCO_2. The diffusion of gases. takes place from a region of their higher partial pressure to a region of their lower pressure.

Respiratory Gas	Atmospheric Air	Alveoli	Deoxygenated blood	Oxygenated blood	Tissues
O_2	159	104	40	95	40
CO_2	0.3	40	45	40	45

Factors that affect the rate of diffusion :

1. **Solubility of gases :** A gas having high solubility diffused at faster rate than the gas having low solubility. For example, solubility of CO_2 is 20-25 times higher than that of O_2, the amount of CO_2 that diffuses across diffusion membrane is much higher than that of O_2,

2. **Partial pressure :** As we know that are diffused according to their partial pressure. For example, O_2 is diffused form atmospheric air having partial pressure 159 mm Hg to the alveoli pO_2 is less, i.e., 104 mm hg.
3. **Thickness of membrane :** More the thickness of membrane, less will be the rate diffusion. More the membrane thin more will be the rate of diffusion. For efficient diffusion to occur membrane should be very thin.

Diffusion membrane : The wall of alveoli is very thin and has reach network of blood capillaries. Due to this network, alveolar wall looks like a sheet flowing blood and is called diffusion or respiratory or alveolar-capillary membrane. The membrane is made up of three layers.

(i) Thin squamous epithelium of alveoli that lines it.

(ii) Endothelial lining of alveolar capillaries that surround it.

(iii) **Basement substance :** in between thin squamous epithelium of alveoli and endothelium of alveolar capillaries, basement substance is present.

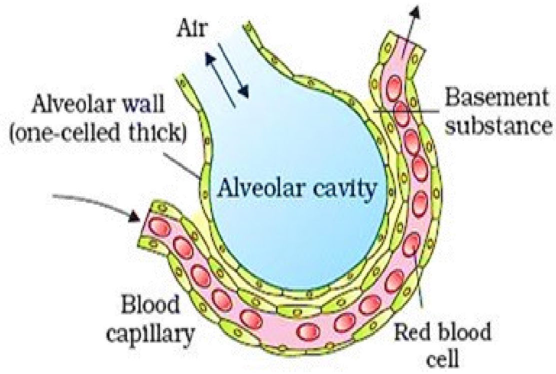


Fig. : A Diagram of a section of an alveolus with a pulmonary capillary

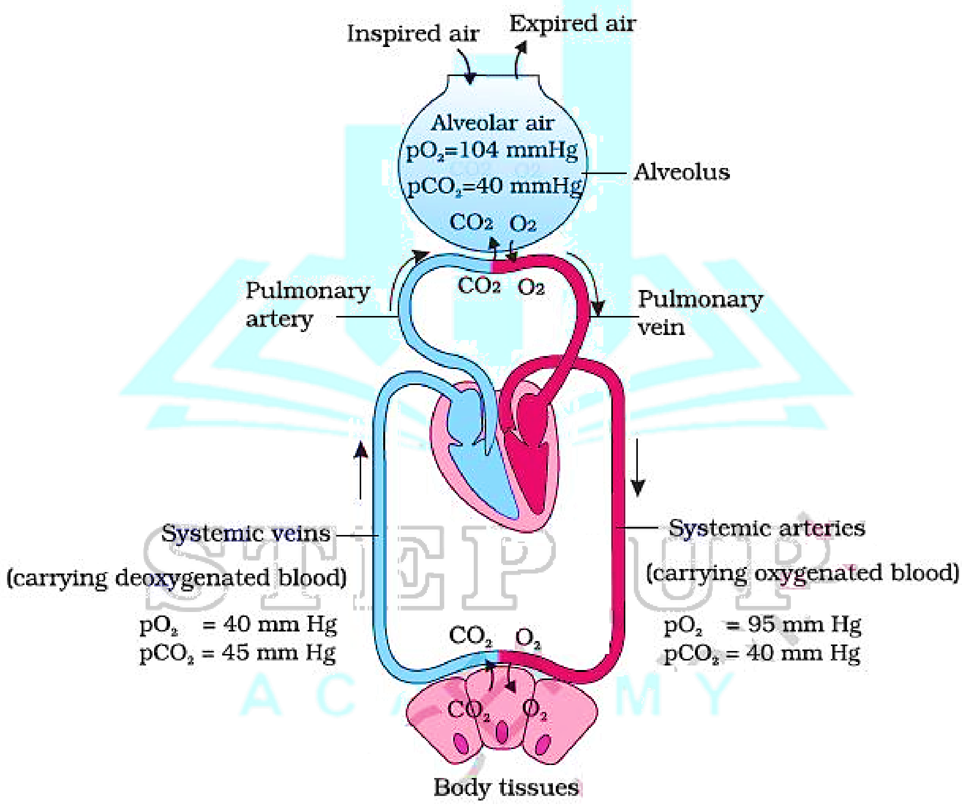


Fig. : Diagrammatic representation of exchange of gases at the alveolus and the body tissues with blood and transport of oxygen and carbon dioxide

TRANSPORT OF GASESS

Blood transports nutrients, vitamins, gases etc. within the body. Some amount of gases get dissolved in plasma and transported, whereas some amount is transported in bound state. O_2 and CO_2 bind with hemoglobin present in RBCs. Now, we discuss the transport of O_2 and CO_2 in detail.

Transport of O_2

Blood carries oxygen from the lungs to the heart and from there it reaches to various body cells. Oxygen is transported in the following manner :

1. **In dissolved from :** About 3% O2 is carried in dissolved state through plasma.
2. As oxyhaemoglobin : About 97% O_2 is transported by RBCs in the blood, Hemoglobin (Hb) is made up of two part-haem and globin. Haem is iron part and globulin is protein part.

   It is red coloured iron containing pigment present is RBCs. It binds with O_2 in a reversible manner to form oxyhaemoglobin (OxyHb) and transports it.

   Single molecule of Hb can carry a maximum of four molecules of oxygen. This is because it has four polypeptide chains and four haem groups each containing an iron atom to which an oxygen can attach.

Hb	+	O_2	$\longrightarrow$	HbO_2
Haemoglobin	+	Oxygen	$\longrightarrow$	Oxyhaemoglobin (OxyHb)

O_2 binds with Hb the lungs surface and gets dissociated at the tissues. Under the partial pressure oxygen easily binds with Hb in the pulmonary blood capillaries. When this oxygenated blood reaches to different tissues the pO_2 decreases and the bonds holding oxygen to Hb become unstable. As a result, oxygen is released from blood capillaries to tissues where it is utilized for oxidation of glucose.

Oxyhaemoglobin dissociates near tissues due to **increase in acidity** and decrease **in pH**. It can also be caused due to **high temperature**.

Oxygen-dissociation curve : A graphical representation of relationship between pO_2 and percentage saturation of Hb with O_2 known as O_2 dissociation curve or oxygen haemoglobin dissociation curve. It is sigmoid or 'S' shaped. The amount of O_2that can bind with Hb is determined by partial pressure of oxygen. The percentage of Hb that is bound with O_2 is called percentage saturation of Hb.

As shown in the graph, Hb gets saturated to about 50% when the PO_2 is 25 mm Hg. It means the blood contains about 50% oxygen. The partial pressure at which Hb saturation is 50% is called P_{50}.

Factors the affect the O_2-dissociation curve : This curve is very much useful in studying the effect of factors like PO_2, PCO_2 etc. on binding of O_2 with Hb. For example, if PO_2 decreases then dissociation of O_2 from Hb takes place which occurs in tissues. It shifts the curve towards right which indicates dissociation of O_2 from Hb. Various factors are responsible for shifting the curve either to left or right.

1. **Shift to right :** Shifting of curve towards right indicates the dissociation of oxygen from Hb and this dissociation occurs in tissues. Following are the conditions responsible for shifting oxygen haemoglobin curve towards right.

(1) Low partial pressure of oxygen.

(2) High partial pressure of CO_2.

Bohr's Effect : A rise in pCO_2 of fall in pH decreases oxygen affinity of haemoglobin, raising the P_{50} value and increase dissociation of oxyhaemoglobin. This is called Bohr's effect. Inversely a fall in pCO_2 and rise in pH increases oxygen affinity of haemoglobin.

(3) High H^+ ion concentration and decrease in pH means increase in acidity.

(4) High temperature.

All these factors are favorable for the dissociation of O_2 from Hb which occurs in the body tissues.

2. **Shift to left :** This shift indicates the association of O_2 and Hb. Following are the conditions responsible for shifting the curve (O_2 -dissociation curve) towards left.

(1) High partial pressure of oxygen.

(2) Low partial pressure of CO_2.

(3) Less H^+ ion concentration and high pH.

(4) Low temperature.

All these factors are favorable the association of O_2 and Hb which occurs in alveoli

Transport of CO_2

When O_2 reaches the body cells, oxidation of food (glucose) takes place during which CO_2, H_2O and energy are produced. CO_2 in gaseous form diffuses out the cells into the capillaries, where it transported in three different means.

1. **In dissolved form through plasma :** About 7% CO_2 gets transported in dissolved form.

2. **As bicarbonate ions :** About 70% of CO_2 is converted into $HCO_3^-$and transported in plasma. CO_2 diffuses in the RBCs where it binds with water, forming carbonic acid (H_2CO_3). Carbonic acid quickly dissociates into hydrogen and ions as it is unstable. The reaction is facilitated by an enzyme know as carbonic anhydrase which is present in very high concentration in RBCs and in small quantity in plasma.

$$CO_2 + H_2O \xrightleftharpoons{\text{Carbionic anhydrase}} \underset{\text{Carbonic acid}}{H_2CO_3} \xrightleftharpoons{\text{Carbionic anhydrase}} \underset{\text{Hydrogen ion}}{H^+} + HCO_3^-$$

At the alveolar site (lungs) the process is reversed means CO_2 and H_2O are formed form HCO_3^- and H^+. The reaction proceeds as

$$HCO_3^- + H^+ \xrightleftharpoons{\text{Carbionic anhydrase}} H_2CO_3 \xrightleftharpoons{\text{Carbionic anhydrase}} H_2O + CO_2$$

Bicarbonate ions re-enter the RBCs and bind H^+ to form carbonic acid which then quickly splits into H_2O and CO_2. Finally, CO_2 is diffused from blood to the lungs, where pCO_2 is low.

3. **By RBCs as carbaminohaemoglobin ($HbCO_2$) :** About 20-25% CO_2 is transported as carbaminohaemoglobin. CO_2 That enters in the RBCs forms a reversible compound, i.e., $HbCO_2$, CO_2 binds with amino group of globin protein which is a part of Hb. The reaction is similar to the oxygen but CO_2 binds not with haem part but with protein part of Hb

$$\underset{\text{Haemoglobin (RBCs)}}{\mathbf{Hb}} + \mathbf{CO_2} \rightleftharpoons \underset{\text{Carbamino Haemoglobin}}{\mathbf{HbCO_2}}$$

Hamburger' s phenomenon : HCO_3^- ions diffuse out plasma and CI^- ions enter into the RBCs at the level of tissues This is known as "chloride shift" or "Hamburger phenomenon" at the level of alveoli, CI^- move out as HCO_3^- move in this is called reverse of chloride shift.

Haldane's Effect : It is related to the transport of CO_2 in the blood. It is based on the simple fact that **oxyhaemoglobin** behaves as strong acid and releases an excess of H^+ ions which bind with bicarbonate HCO_2^- ions to form H_2CO_3 which dissociates into H_2O and CO_2. Secondly, Due to the increased acidity, CO_2 loses the power to combine with haemoglobin and form carbamino-heamoglobin. **Effect of oxyhaemoglobin formation** on CO_2 transport is called **Haldane's effect.**

1. **Asthma**

   Causes : It occurs due to an allergic reaction to foreign substances that affect the respiratory tract. The agents which cause allergy are known as **allergens.**

   Symptoms : It is characterized by spasm of smooth muscles present in walls of bronchiole. Coughing, wheezing (means producing sound during breathing), difficulty in breathing due to inflammation, i.e., swelling and redness of bronchi and bronchioles.

2. **Emphysema :** The word 'Emphysema' means 'full of air' or 'inflation. It is a chronic disorder.

   Causes : The major cause is excessive cigarette smoking. Others may include inhalation of smoke or toxic substances over a period of time.

   Symptoms : The walls of alveoli are damaged due to excessive smoking, loss of elasticity of walls of bronchioles and alveoli. Due to this, the surface area for exchange of gases is reduced.

3. **Occupational respiratory disorders**

   Causes : Continuous exposure to harmful substances, gases, fumes and dust in the environment, where a person works are main causes of these disorders.

   Silicosis and **asbestosis** are the common examples and caused due to continuous exposure to silica and asbestos dust at place of work.

1. **Symptoms** : serious lung damage due to fibrosis and caused due to fibrosis of upper part of lungs, i,e., proliferation of fibrous tissues, causing inflammation, i,e., swelling and redness of lungs.
2. **Anoxia :** Absence of oxygen in inspired gases, arterial blood tissues.
3. **Hypercapnia :** It is increase in carbon dioxide content of tissues.
4. **Asphyxia :** It is a combination of hypoxia and hypercapnia.
5. **Terms associated with breathing:**

   (i) Eupnea - Normal breathing

   (ii) Hypopnea - Slow breathing

   (iii) Hyperpnea - Rapid breathing

   (iv) Apnea - No breathing

   (v) Dyspnea - Painful breathing

   (vi) Orthoponea- Difficult breathing

Chapter 15
Body Fluids and Circulation

Blood:

Blood is a specialized connective tissue consisting of a fluid matrix, plasma and a cellular portion called formed elements. The plasma constitutes approximately 55 % of the blood and the formed elements account for the remaining 45%

Composition of Blood

- Plasma
- Formed elements
  - Blood cells
    - Erythrocytes
    - Leucocytes
      - Granulocytes
        - Neutrophils
        - Basophils
        - Eosinophils
      - A granulocytes
        - Monocytes
        - Lymphocytes
          - B-lymphocytes
          - T-lymphocytes
  - Blood platelets

PLASMA

Plasma is a straw-colored viscus fluid forming matrix of the blood (matrix is the ground substance of a tissue a non-living substance occupying the space between cells).

Composition of plasma

1. **Water :** 90-92% of plasma is water.
2. **Proteins :** They constitute about 6-8 percent. of it. **Fibrinogens, globulins** and **albumins** are the major plasma proteins.

(i) **Fibrinogen :** fibrinogen is an important. clotting factor produced by the liver.

(ii) **Globulins :** Globulins are primary involved in the defense mechanism of the body. They are grouped into three subtypes: alpha globulins, beta globulins, and gamma globulins. Gamma globulins are antibodies which function in immune response of the body.

(iii) **Albumins :** Albumins help in osmotic balance. They maintain the osmotic pressure (pressure generated by the osmotic flow of water through a semi permeable membrane into an aqueous tissue fluid into the capillaries. This action is needed to maintain **blood volume** and **pressure.**

3. **Minerals :** plasma contains small amounts of minerals like Na^+,Ca^{++},Mg^{++},$HCO_3^-$$Cl^-$ etc.
4. Glucose, amino acids, lipids etc. are also present in the plasma as they are always in transit in the body. They are being carried by the plasma form one place to another. These substance enter and leave the plasma at regular intervals.

Plasma without the clotting proteins is called **serum.**

Formed Element

The formed elements include : erythrocytes (red blood cells), leucocytes (white blood cells) and thrombocytes (platelets).

Erythrocytes (Red blood corpuscles or RBCs) : The erythrocytes are the most abundant of all cells in blood.

Number : A healthy about man on an average has 5 millions of RBCs mm^{-3} of blood.

Shape and structure : In most of the mammals, RBCs are biconcave in shape and are without nucleus. As the red blood cells lack nucleus and other organelles so it helps in providing more room for haemoglobin. Due to the absence of mitochondria they respire anaerobic ally and do not use up any of the oxygen they carry.

- Red blood cells also contain the enzyme carbonic anhydrase which plays a role in carbon dioxide transport.

Quantity of haemoglobin in RBCs : A healthy individual has 12-16 gms of haemoglobin in every 100 ml of blood. Iron is present in haemoglobin.

Formation : The formation of RBCs in known as erythropoiesis. It occurs in the red bone marrow in adults.

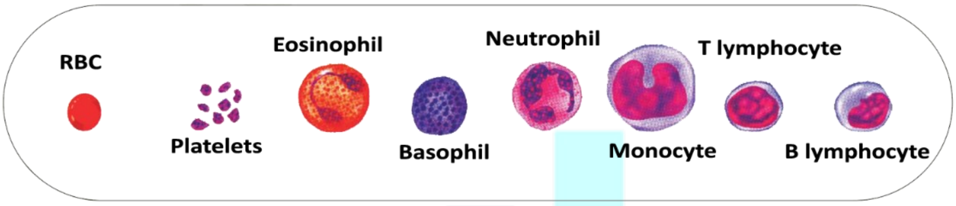


Fig. : Diagrammatic representation of formed elements in blood

Functions

(1) Haemoglobin of erythrocytes play a significant role in transport of respiratory gases. Haemoglobin combines readily with oxygen and form oxyhaemoglobin. Oxyhaemoglobin readily gives up its oxygen in the tissues where it is used for breakdown or oxidation of food.

(2) RBCs also transport carbon dioxide form tissues to lungs. CO_2 carried by hemoglobin as carbamino-haemoglobin.

Leucocytes (white blood colorless bloods)

Leucocytes white blood corpuscles due to the lack of haemoglobin.

Number : Leucocytes are much lesser in number as compared to erythrocytes which averages 6000-8000 mm^{-3} of blood

Shape and structure : Leucocytes possess nuclei and other cell organelles and can move in an amoeboid fashion. The movement of leucocyte capillary walls is referred to as diapedesis.

Types :

(i) Leucocytes : Leucocytes containing granules in their cytoplasm are called granular leucocytes/granulocytes and those without clearly visible granules are called **agranular leucocytes/agranulocytes.**

(ii) Agranulocytes : There are two types of agranulocytes: lymphocytes and monocytes.

(a) **lymphocytes :** lymphocytes (20-25 percent of the total WBCs) are usually the second most numerous type of leucocytes. They are small cells with round nuclei and little cytoplasm. They exist in two major forms namely B and T-lymphocytes and responsible for immune responses of the body.

(b) Monocytes : They are the largest leucocytes and are somewhat amoeboid in shape. They have kidney or horse-shoe shaped nuclei. Form blood, monocytes enter the tissues where they become macrophages. Macrophages are phagocyte in nature and engulf bacteria and other cellular debris.

(iii) Granulocytes : Granulocytes are of three types :

(a) Eosinophils : Eosinophils (2-3 percent) have nucleus with two lobes. They have coarse granules which contain hydrolytic enzymes and peroxides. The eosinophils have antihistaminic properties. They resist infections and are also associated with allergic reactions. The number of eosinophils increases during allergic conditions such as asthma and hay fever. Parasitic form a cause their destruction by liberating lysosomal enzymes on their surfaces.

(b) Basophiles : They are least abundant (0.5-1 percent) of the total WBCs. In these cells the nucleus is generally three-lobed. The cells secrete **serotonin, heparin**(an anti-coagulant) and **histamine** (a chemical involved in inflammation) etc.

(c) Neutrophils : They are the most abundant cells (60-65 percent) of the total WBCs. They are phagocytic in nature. They commonly squeeze between the cells of the capillary walls and sander through the intercellular spaces. Form here they move to infected areas of the body.

Thrombocytes (Blood platelets) : Thrombocytes are the smallest of the formed elements.

Number : Blood normally contains 150,000-3,50,000 platelets mm^{-3} of blood.

Shape and structure : Thrombocytes are cell fragments rather than true cells. They are rounded of oval disc-like bodies. They lack nuclei and contain a few cell organelles and secretory granules in them.

Formation : They are produced form special cells in the bone marrow called **megakaryocytes.**

Life span : Normal life span of blood platelets is about a week. They are destroyed in the spleen and liver.

- **Function :** They play an important role in blood clotting. platelets can release a variety of substances most of which are involved in coagulation of blood. They constitute most of the clot and activate the clotting factors in plasma that result in formation of threads of fibrin.
- A reduction in the number of platelets is called thrombocytopenia which leads to excessive loss of blood from the body. Purpura in a group of bleeding diseases due to thrombocytopenia.

Blood Group

The membranes of red blood cells (RBCs) also possess several antigens. Depending on the nature of antigens present on the membrane of RBCs, various types of blood grouping has been done. Two such groupings the ABO and Rh- are widely used all over the word.

ABO grouping

Karl Landsteiner (1901) along with his co-worker recognized four types of blood groups in human beings commonly known as ABO blood grouping. ABO grouping is based on the presence of absence of absence of two surface antigens of the RBCs namely A and B. Similarly, the plasma of different individuals also contain two natural antibodies called anti-A and anti-B.

According to Landsteiner law, if an antigen is present on the RBCs, the corresponding antibody must be absent from the plasma. It also state that if the antigen is absent on the RBCs, the corresponding antibody must be present in the plasma.

The immune system exhibits tolerance to its own red blood cell antigens. Persons with 'A' Group for example, do not produce anti-A antibodies. However they do make antibodies against the B antigen and persons with 'B' Group make antibodies against the A-antigen. Persons with 'AB' group develop tolerance to both of these antigens and turns do not produce either anti-A or anti-B antibodies. People with 'O' group, by contrast, do not develop tolerance to either antigens, they have both anti-A anti-B antibodies in their plasma.

Transfusion reactions

In many clinical conditions blood Transfusion in needed. In such cases the donor's blood and recipient's blood must be compatible to avoids problems of clumping (destruction of RBC).

A major cross-match is made by mixing serum form the recipient with blood cells from the donor. If the blood groups do not match for example, it the donor's blood group is 'A' and the recipient's blood group is 'B', the recipient's antibodies attach to the donor's red blood cells and cause clumping (agglutination). Transfusion errors that result in such agglutination can lead to blockage of small blood vessels and causes hemolysis (rupture of red blood cells). Therefore, the blood of a donor has to be carefully matched with the blood of recipient before and blood transfusion. The donor's compatibility is shown below:

Blood Group	Antigen of RBCs	Antibodies in plasma	Donor's Group
A	A	Anti-B	A, O
B	B	Anti-A	B, O
AB	A,B	Nil	AB,A,B,O
O	Nil	Anti-A,B	O

From the above-mentioned table it is evident that group 'O' can be donated to person with any other blood group and hence 'O' group individuals are called 'universal donor'. Group 'O' red blood cells lack A and B antigens, therefore the recipient's antibodies cannot cause agglutination of the donor's RBCs. Persons with 'AB' group can accept blood from persons with AB as well as the other groups of blood. This is because blood group AB lacks anti-A and anti-B antibodies and thus cannot agglutinate donor's red blood cells. Therefore, Such persons are called ' universal recipients.

Rh Grouping

Another group of antigens found on the red blood cells of most people is the Rh factor (Rh stands for rhesus monkey in which these antigens were first discovered). It was discovered by Landsteiner and Wiener. People who have these antigens are said to Rh+ve, whereas those who do not are called Rh-ve. An Rh-ve person, if exposed to Rh+ve blood, wall form specific antibodies against the Rh antigen. Therefore, Rh group should also be matched before transfusions.

A Special Case for Rh incompatibility (mismatching) has been observed between the Rh-ve blood a pregnant mother with Rh+ve blood to the foetus. The Rh-ve mother is not usually exposed to the antigen of the foetus during the first pregnancy as the foetal and maternal blood are normally keep well separated by the placental barriers. However, at the time of birth the first child, there is a possibility of exposure of the maternal blood to small amount of the Rh+ve blood from the foetus. In such cases the mother starts preparing antibodies against Rh antigen in her blood.

These antibodies could cross the placental barriers in subsequent pregnancies and cause hemolysis of the Rh+ve are blood cells of the foetus. This could be fatal to the foetus of could cause severe anaemia and jaundice to the body (HND- haemolytic disease of newly born). This condition is called erythroblastosisfoetalis.

Coagulation of blood

When you cut your finger or hurt yourself, the wound doses not continue to bleed for a long time. It usually stops bleeding after sometime as blood exhibits coagulation or clotting in response to an injury of trauma. This is a mechanism to prevent excessive loss of blood from the body. You must observed a dark reddish-brown scum formed at the site of a out or an injury over a period of time. It is a clot or coagulum formed mainly of a network of threads called fibrins in which dead and damaged formed elements of blood are trapped.

Mechanism of blood coagulation

An injury or trauma stimulates the platelets in blood to release coagulation promoting substances called thromboplastins which activate the mechanism of coagulation. Tissues at the site of injury also release tissue thromboplastins.

Thromboplastins help in the formation of the enzyme complex **thrombokinase.** This complex is formed by a series of linked enzymic reaction (cascade process) involving a number of factors present in the plasma (i.e., plasma clotting factors) in an inactive state.

Thrombokinase converts an inactive portein prothrombin present in the plasma into thrombin. Prothrombin $\xrightarrow[ca\ 2+]{thrombokinase}$ Thrombin

Thrombin is an enzyme which converts soluble fibrinogen of plasma into insoluble fibrin. Ca^{2+} ions are essential for both the activation and action of thrombin

$$\text{Fibrinogen} \xrightarrow[ca\ 2+]{thrombin} \text{Fibrin}$$

Fibrins form network of threads which traps dead and damaged formed elements of blood to form the **blood clot** or **coagulum.** The clot seals the wound in the vessel to stop bleeding. This is called blood clotting.

LYMPH (TISSUE FLUID)

- As the blood passes through the capillaries in tissues, some water along with many small water-soluble substances move out into the spaces between the cells of tissue leaving the larger proteins and most of the formed elements (erythrocytes and platelets) in the blood vessels. This fluid released out is called the interstitial fluid or tissue fluid. The mineral distribution of both plasma and tissue fluid are similar. Exchange of nutrients, gases, etc. between the blood and the cells always occurs through the tissue fluid acts as middle man.
- This fluid is collected and drained back to the major veins by an elaborate network of vessels called the **lymphatic** system. The fluid present in the lymphatic system is called the lymph.
- lymph is colourless fluid containing specialized lymphocytes which are responsible for the immune responses of the body.
- The lymphatic system comprises of lymphatic capillaries, lymphatic vessels, lymphatic nodes and lymphatic ducts.
- **lymphatic capillaries** are the smallest vessels of the lymphatic system. Lymphatic capillaries are microscopic, closed-ended tubes that form vast network in the intercellular spaces within most organs. interstitial fluid, proteins, microorganisms and absorbed fat (in the intestine) can easily enter the lymphatic capillaries as the walls of the lymphatic capillaries are composed of endothelial cells with porous junctions.
- Once the tissue fluid enters the lymphatic capillaries, it is known as **lymph.** lymphatic capillaries merger and form larger lymphatic vessels. the walls of larger lymphatic vessels are similar to veins. They have valves to prevent back flow. Eventually, the larger lymphatic duct (in the right). Further these ducts drain the lymph into the left and right subclavian veins, respectively. These veins connect with a number of smaller veins and drain into the superior vena cava (major vein) which connects to heart. Thus, tissue fluid, which is formed by filtration of plasma out of blood capillaries is ultimately returned to the major veins or cardiovascular system.
- There are lymph nodes located at regular intervals along the course of lymphatic vessels. Lymph is filtered through the lymph nodes. These are abundant in neck, groin and armpits. Lymph nodes contain phagocytic cells which help to remove pathogens and has sites for lymphatic production. The **tonsils, thymus** and **spleen** are also the lymph nodes. They are called lymphoid **organs.**

Function

1. Lymph transports oxygen, nutrients, hormones, etc., to the body cells and brings carbon dioxide and other metabolic wastes, form the body cell and finally pours the into the **venous system.**

CIRCULATORY PATHWAYS

The circulatory patterns are of two types-open or closed. In open circulatory system, blood pumped by the heart passes through large vessels into open spaces or body cavities called sinuses. This system is present in arthropods and molluscus. In closed circulatory system, the blood pumped by the heart is always circulated through a closed network of blood vessels. This system or pattern is considered to be more advantageous and chordates.

In all vertebrates, the consists of 1 or 2 atria and 1 or 2 vertebrates. The heart of lower vertebrates has additional chambers, namely, sinus venosus and **conus arteriosus** or **truncus arteriosus**.

- All vertebrates have a muscular heart. Fishes have a two-chambered heart with and atrium and a ventricle, Amphibians and the reptiles' (except crocodiles) process a three chambered heart with two atria and single ventricle, whereas crocodiles, birds and mammals possess a four-chambered heart with two atria and two ventricles.
- In fishes, the heart pumps out deoxygenated blood which undergoes oxygenation in the gills. The oxygenated blood is then supplied to the body parts from where deoxygenated blood is returned to the heart. This is known as single circulation.
- In amphibians and reptiles, the left atrium gets oxygenated blood from the gills/lungs/skin and the right atrium receives the oxygenated blood from other body parts. However, both oxygenated and oxygenated blood get mixed up in the single ventricle. The heart thus pumps out mixed blood. This is known as **incomplete double circulation.**
- In birds and mammals, the left and the right atria receive oxygenated blood, respectively which is passed into the ventricles of the same sides. Here, there is no mixing of oxygenated and deoxygenated blood. Thus, the ventricles pump it out without and mixing, i.e., two separate circulatory pathways are present in these organisms. hence, these animals have **double circulation.**

Human Circulatory System

Human circulatory system also known as the blood vascular system consists of a muscular chambered heart, a network of closed branching blood vessels and blood, the fluid which is circulated.

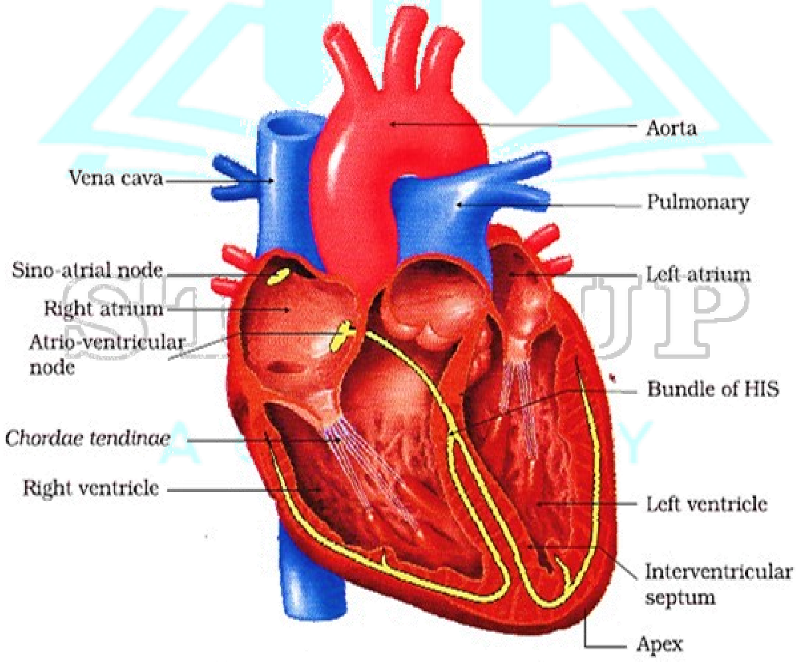


Fig. : Section of a human heart

Heart is located in the **thoracic** cavity in between the two lungs, slightly tilted to the left. It is derived from the mesoderm and the size of a clenched fist.

- Heart is protected by a double walled membranous bag called **pericardium.** The pericardium consists of two layers, an outer parietal pericardium and an inner **visceral** pericardium attached to the heart. A space called **pericardial cavity** is present between the two layers which is filled with a fluid called pericardial fluid. The pericardium protects the heart form shocks and mechanical injuries.
- Our heart is divided into four chamber, two relatively small upper chambers called atria (singular, atrium) and two larger lower chambers called ventricles. The walls of the ventricles are much thicker than that of the atria. The right and the left atria are separated by a thin,

muscular wall called the **interatrial septum** whereas the right and left ventricles are separated by thick-walled inter ventricular septum.

- A thick fibrous tissue called the atrio-ventricular septum separates the atrium and the ventricle of the same side. However, both of the atrio-ventricular septa are provided with and opening through which the two chambers of the same side are connected.
- The opening between the atria and the ventricles are guarded **atrioventricular(AV) Valves.** The AV valve between right atrium and right ventricle has three flaps or cusps and is therefore called the **tricuspid valve.** The AV valve between the left atrium and left ventricle has two flaps or cusps and is thus called the **bicuspid or mitral valve.**
- Special fibrous cords called the **chordae tendineae** are attached to the flaps of the bicuspid and tricuspid valves at one end and their other ends are attached to the ventricular wall with the special muscles, the **papillary muscles.** The chordae tendineae prevent the bicuspid and tricuspid valves form collapsing back into the atria during powerful ventricular contractions.
- Three semilunar valves (half-moon shaped pockets) are found at the points where the pulmonary (arising from the right ventricle and carrying oxygenated blood to the lungs) and aorta (large artery arising from left ventricle and carrying oxygenated blood to all parts of the body) leave the heart. These valves prevent blood from getting back into the ventricles.
- The right atrium receives deoxygenated blood through coronary sinus (discussed later) and two large veins called vena cava (one superior vena cava and one inferior vena cava). The left atrium receives oxygenated blood from the lungs through two pairs of pulmonary veins.

Conducting system in Human Heart

- distributed in the heart. A patch of this tissue called the **sino-atrial node** (SAN) is present in the upper right corner of the right atrium. Another mass of tissue called the **atrio-ventricular node** (AVN) is present in the lower left corner of the right atrium, close to the atrio-ventricular septum.
- A bundle of nodal fibres, i.e., atrio-ventricular bundle (AV bundle) continues from the AVN which passes through the atrio-ventricular septa to emerge on the top of the interventricular septum and immediately divides into a right and left bundle.
- These branches give rise to minute fibres called **Purkinje fibres** throughout the ventricular musculature of the respective sides. The Purkinje fibers along with right and left bundles are known as **Bundle of His.**
- The nodal musculature has the to generate action potentials without and external stimuli, i.e., it is auto excitable. Action potential is a short-lasting event in which the electrical membrane potential (difference in electrical potential between the interior and the exterior of a biological cell) of a cell rapidly rises and falls. Although all the heart muscle cells have the ability to generate the electrical impulses (or action potentials) that trigger cardiac contraction, the SAN initiates it, simply because it generates the maximum the rhythmic contractile activity of the heart. Therefore it is called the pacemaker of the heart. Our heart normally beats **70-75 times** in a minute (average 72 beats min-1). This is called **heart rate.**

Cardiac cycle

- The cardiac cycle refers to the repeating pattern of contraction and relaxation of the heart. The phase of contraction is called **systole** and the phase of relaxation **called diastole.**
- How does the heart function ? Let us take a look. To begin with all the four chambers of heart are in a relaxed state, i.e., they are in joint diastole. Blood from pulmonary veins and vena cava fills the left and right atria, respectively. The buildup of pressure that results, causes the AV valves to open and blood to flow form atria to the ventricles. At this stage the semilunar valves are closed. The SAN now generates.
- action potential which stimulates both the atria to undergo a simultaneous contraction known as **atrial systole**. It result in increase of blood flow into the ventricles by about 30 percent.
- The action potential generated by the SAN is conducted to the ventricular side by the AVN and AV bundle form where the bundle of His transmit it through the entire ventricular musculature. This causes contraction of the ventricular muscles known as ventricular systole. The atria now undergo relaxation called as atrial diastole which coincides with ventricular systole. As the ventricles begin now undergo relaxation the intraventricular pressure rises, causing the closure of tricuspid and bicuspid valves (AV valves) due to attempted backflow of blood into the atria.
- When the pressure in the left and right ventricles becomes greater than the pressure in aorta and pulmonary artery respectively the semilunar valves are forced open. Opening of semilunar valves, guarding the pulmonary artery (right side) and the aorta (left side) allow the blood in ventricles to flow through these vessels into the circulatory pathways. Now the ventricles relax, i.e., **ventricular diastole** occurs and the ventricular pressure falls causing the closure of semilunar valves. It prevents the backflow of blood into the ventricles.

- The ventricular pressure declines further and AV valves are pushed open due to the pressure in the atria exerted by the blood which was being emptied into them by the veins. Once again, the blood moves freely into the ventricles.
- The ventricles and atria are again in joint diastole (relaxed state) as earlier. Soon as now action potential is generated by SAN and the events described above are repeated in that sequence and the process constitute.
- This sequential event which is cyclically repeated in the heart constitute the **cardiac cycle** which consists of systole and diastole of both the atria and ventricles.
- Our heart beats 72 times per minute, i.e., 72 cardiac cycle are performed per minute. Now, if 72 cardiac cycles are performed in 60 seconds (1 min) then one cardiac cycles would occur in 0.8 second.
- During a cardiac cycle, each ventricle pumps out approximately 70 mL of blood. this is called the **stroke** volume. the stroke volume multiplied by the number of beats per minute (heart rate) gives the cardiac output. the cardiac output is 72 x 70 or **5040 mL** per minute i.e., about **5 liters per minute.** therefore, the volume of blood pumped out by each ventricle per minute is known as the cardiac output.

Heart Sounds

During each cardiac cycle two prominent sound are produced which can be easily heard through a stethoscope.

First heart sound (LUBB)	Second heart sound (DUBB)
1. It is produced by closing of AV valves (tricuspid and bicuspid) during ventricular systole.	1. It is produced by closing of semilunar valves at the beginning of ventricular diastole.
2. It is low pitched and of long duration.	2. It is higher pitched and of short duration.

These sounds are of clinical diagnostic significance.

Heart murmur : In case of defective or damaged heart valves, their improper closure leads to leakage of blood which produces an abnormal sound referred to as heart murmur.

Electrocardiogram (ECG)

The pacemaker region of the heart (SA node) exhibits a spontaneous depolarization that causes action potentials, resulting in the automatic beating of the heart. Impulses which travel through cardiac muscles during the cardiac cycle produce electrical currents. The electrical currents are conducted through the body fluids to the body surface, where the amplified currents can be detected by placing electrodes on the skin and recorded as an electrocardiogram (ECG.) It was discovered by Einthoven.

Electrocardiogram (ECG) is a graphical representation of the electrical activity of the heart during a cardiac cycle. The machine used to obtain an electrocardiogram is known as electrocardiograph and this technique is called electrocardiography.

To obtain a standard ECG, a patient is connected to the machine with three electrical leads one to each wrist and one to the left ankle.

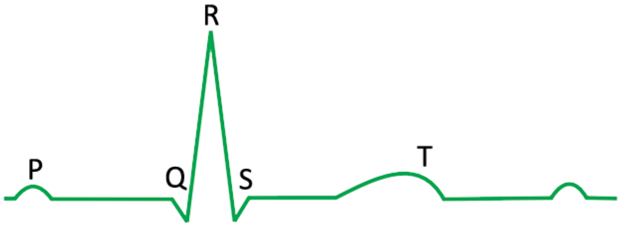


Fig. : Diagrammatic presentation of a standard ECG

- The **P wave** is a small upward wave that represents electrical excitation (or depolarization) of the atria leads to contraction of both the atria.
- The **QRS (wave) complex** represents the depolarization of the ventricles, which initiates the ventricular contraction (ventricular systole). The contraction of the ventricles starts shortly after Q and makes the beginning of the systole.
- The T-wave represents the return of the ventricles form excited (depolarized) to normal state (i.e., repolarization). they and of the T-wave marks the end of systole.
- Thus, by counting the number of QRS complexes that occur in given time period, the heart beat rate of individual can be determined. ECG obtained from different individuals have roughly the same shape for a **given lead configuration.** ECG is of great clinical significance as any deviation from this shape indicates a possible abnormality of disease.

DOUBLE CIRCULATION

Double circulation means that the blood passes through the heart twice for each circuit of the body. It includes pulmonary and systemic circulation.

(i) Pulmonary Circulation

The deoxygenated blood into the pulmonary artery is passed on to the lungs from where the oxygenated blood is carried by the pulmonary veins into the left atrium. This pathway is known as pulmonary circulation.

(ii) Systemic Circulation

The oxygenated blood entering the aorta is carried by a network of arteries, arterioles and capillaries to the tissues form where the deoxygenated blood is collected by a system of venules, veins and vena cava and emptied into the right atrium. This is the systemic circulation. Thus, the systemic circulation provides nutrients, oxygen and other essential substances to the tissues and takes CO_2 and harmful substances away for elimination.

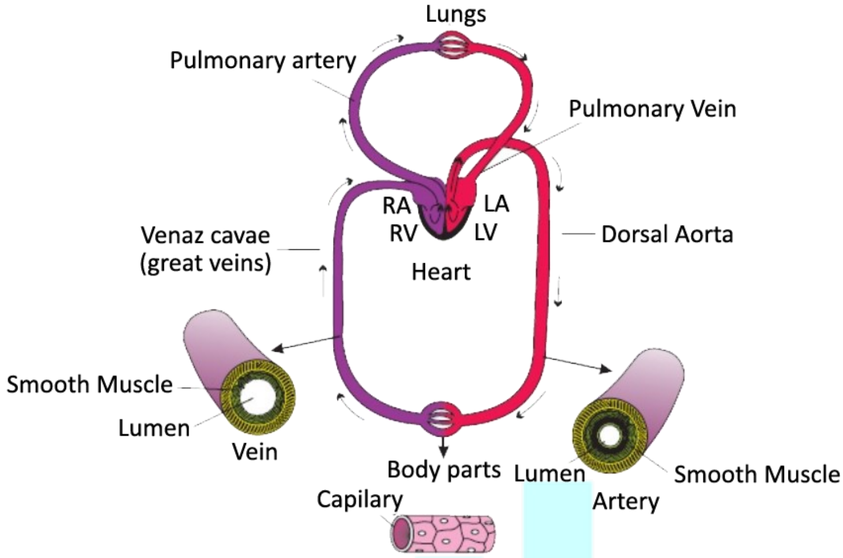


Fig. : Schematic plan of blood circulation in human

REGULATION OF CARDIAC ACTIVITY

Normal activity of the heart are regulated intrinsically, i.e., auto regulated by specialized-by-specialized muscles (nodal tissue), hence the heart is called **myogenic**. This automatic rhythm is produced by the spontaneous **depolarisation**, which leads to contraction of heart.

A special neural centre in the **medulla oblongata** (in the brain) can moderate the cardiac function through autonomic nervous system (ANS). **Sympathetic** and parasympathetic nerves (parts of ANS) are connected to the heart and can modify the rate of spontaneous depolarization of the SA node.

Sympathetic nerve endings release nor adrenaline which stimulates the SAN that accelerates the heartbeat, the strength of ventricular contraction and thereby the cardiac output. On the other hand, para sympathetic nerve ending release acetylcholine which decreases the rate of heart, speed of conduction of action potential and thereby the cardiac output.

The adrenal medulla secretes two hormones called adrenaline and noradrenaline. Both the hormones are rapidly secreted in response to stress of any kind and during emergency situation. These hormones increase the heart beat and the strength of heart contraction. Thus adrenal medullary hormones can also increase the cardiac output.

DISORDERS OF CIRCULATORY SYSTEM

(i) High blood pressure (Hypertension)

Hypertension is the term for blood pressure that is higher than normal. A **blood pressure** of **120/80** is considered normal. In this **measurement**, 120 mm Hg (millimeter of mercury) is the **systolic** of pumping pressure and 80 mm Hg is the diastolic or resting pressure. If repeated checks of blood pressure of an individual is 140/90 or higher, it shows hypertension which leads to heart diseases and also affects vital organs like brain and kidney.

(ii) Angina pectoris

A symptom of acute chest pain appears when no enough oxygen is reaching the heart muscle. The term **angina pectoris** means chest pain. It can occur both in men and women of any age but is more common among the middle-aged elderly people. It occurs due to conditions that affect the blood flow.

(iii) Heart failure

It is the state of heart when it does not pump blood effectively enough to meet the needs of the body. It is sometimes called congestive heart failure because congestion of the lungs is one of the main symptoms of this disease.

(iv) Heart attack

Heart attack occurs when the heart muscles are suddenly damaged by an inadequate blood supply.

(v) Cardiac arrest

Cardiac arrest means complete stoppage of the heart beat i.e., when the heart stops beating.

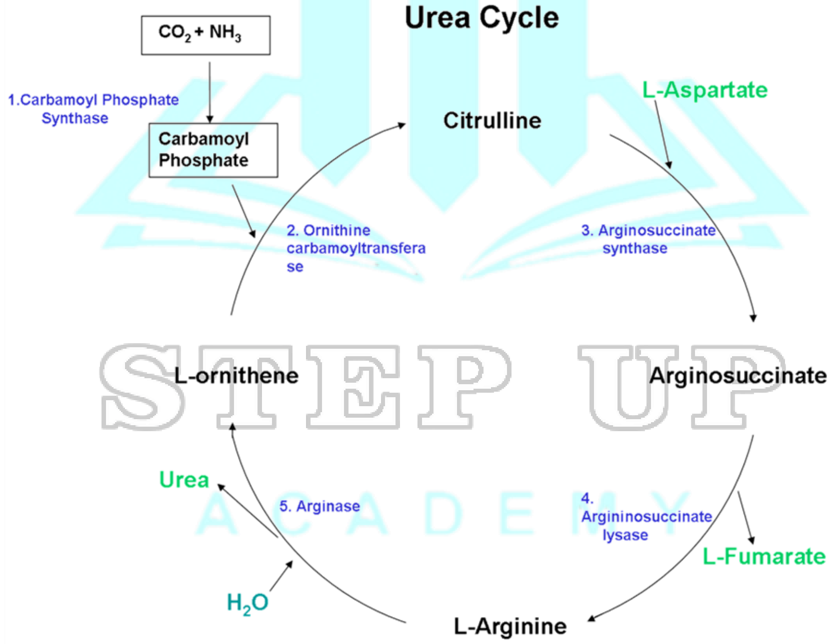
(vi) Coronary Artery Disease (CAD)

Coronary Artery Disease, often referred to as atherosclerosis. affects the vessels that supply blood the heart muscle. it is caused due to the depositions of calcium, fat, cholesterol and fibrous tissues in the arteries supplying the heart musculature. These depositions make the lumen of arteries narrower.

Chapter 16
Excretory Products and their Elements

(i) **Ammonotelism :** Ammonia is the most toxic form and requires large amount of water for its elimination. This process of excreting ammonia is called Ammonotelism. Many **bony fishes, aquatic amphibians** and **aquatic insects** are ammoniotelic in nature.

Ureotelism : Terrestrial adaptation necessitated the production of lesser toxic nitrogenous wastes like urea and uric acid for conservation of water. Urea can be tolerated in much more concentrated form because it is 100,000 times less toxic than ammonia. **Mammals**, many **terrestrial amphibians** and **marine fishes** mainly excrete urea and are called ureotelic animals. Excretion of urea is known as ureotelism. Ammonia produced by metabolism is converted into urea in the liver of these animals and released into the blood which is filtered and excreted out by the kidneys. Some amount of urea may be retained in the kidney matrix of some of these animals to maintain a desired osmolarity.



Urea Synthesis (The Ornithine cycle) is the biochemical aspect of excretion also called kreb-Henseleit cycle, it occurs in liver and includes :

(i) Formation of carbamoyl phosphate by the combination CO2 and ATP.

(ii) Carbamoyl phosphate combines with ornithine to form citrulline.

(iii) Citrulline joins aspartic acid and changes to argininosuccinic acid.

(iv) The letter breaks into **fumaric acid** and **arginine**.

(v) With the help of enzyme arginase, arginine is hydrolysed to urea ornithine (which is thus, regenerated and re-used in the cycle).

Uricotelic : **Reptiles, birds, land snails** and **insects** excrete nitrogenous wastes as uric acid in the form of pellet or paste with a minimum loss of water and are called uricotelic animals. Excretion of uric acid is Known as uricotelism.

A survey of animal kingdom presents a variety of excretory structures. In most of the invertebrates these structures are simple tubular forms. Whereas, vertebrates have complex tubular organs called kidneys.

Some of the excretory structures found in animal kingdom are mentioned here :

1. **Protonephridia or flame cells :** These are the excretory structures in Platyhelminthes (**flatworms**, e.g., Planaria), **rotifers**, some **annelids** and the **cephalochordate**- *Amphioxus*. Protonephridia are primarily concerned with ionic and fluid volume regulation, i.e. osmoregulation.
2. **Nephridia :** These are the tubular excretory structures of earthworms and other annelids. Nephridia help to remove nitrogenous wastes and maintain a fluid and ionic balance.
3. **Malpighian tubules :** These are the excretory structures of most of the insects including cockroaches. Malpighian tubules help in the removal of nitrogenous wastes and osmoregulation.
4. **Antennal glands or green gland :** These perform the excretory function in crustaceans like prawns.

HUMAN EXCRETORY SYSTEM

In human's the excretory system consists of a pair of kidneys, one pair of **ureters**, a urinary bladder and a urethra.

KIDNEYS

Shape and size : Kidneys are reddish brown, bean-shaped structures situated between the levels of last **thoracic** and third lumbar vertebra close to the dorsal inner wall of the abdominal cavity. Each kidney of an about human measures 10-20 cm in length, 5-7 cm in width, 2-3 cm in thickness with an average weight of 120-170 g. **Left kidney is little higher than the right one because of more space being occupied by the liver on right side.**

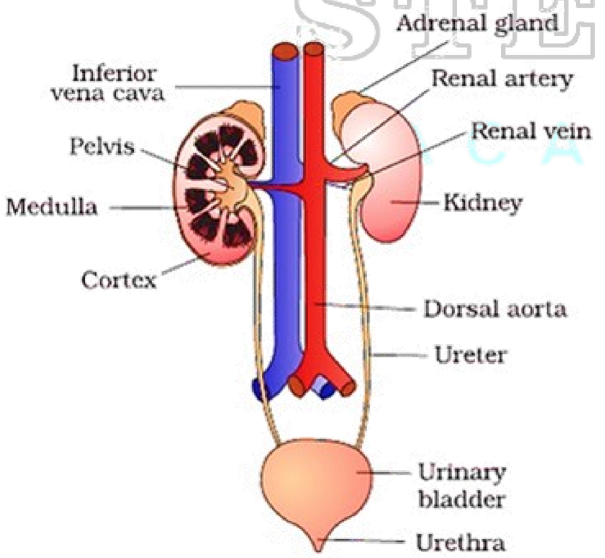


Fig. : Human Urinary system

Towards the centre of the inner concave surface of the kidney is a notch called helium through which ureter blood vessels and nerves pass.

Internal structure : Inner to the helium is a broad funnel-shaped space called the renal pelvis with projections called calyces. Inside the kidney, there are two zones, an outer cortex and an inner medulla. The medulla is divided into a few conical masses (medullary pyramids) projecting into the calyces (sing: calyx). The cortex extends in between the medullary pyramids as renal columns called **Columns of Bertini.**

Each renal pyramid has a broad base towards cortical side. Apex in pointed and is called renal papilla. 1-3 renal papillae project into a cavity called minor calyx, which join up and form major calyces. Interstitial fluid of medulla region has a higher osmotic concentration equal to some 1200 mOsm/L. due to higher quantity of two solutes NaCl and urea. The major calyces open into broad funnel-shaped structure called renal pelvis placed inner to hilum. It lined by transitional epithelium. It leads into ureter.

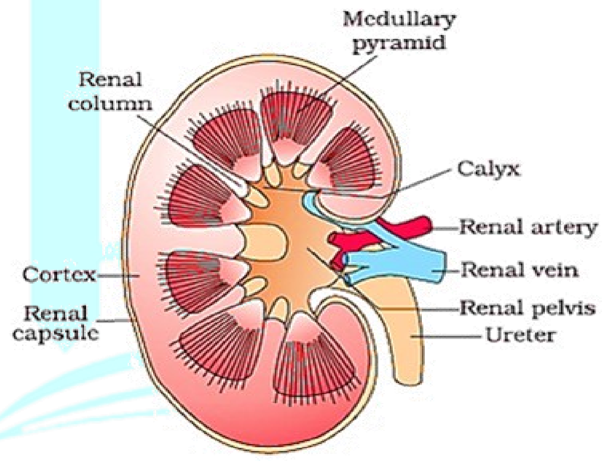


Fig. : Longitudinal section (Diagrammatic) of Kidney

Ureters : They are a pair of fine whitish distensible muscular tubes of 25 - 30 cm length, about 3 mm in diameter. Ureters develop from hilum part of the kidneys, descend along the abdominal wall, bend obliquely inwards and upwards to open in to urinary bladder in the region of trigone by oblique slits, one on each side.

Urinary Bladder : It is a median **pyriform sac** which varies in shape, size and position according to the amount of urine contained in it. The fully distended bladder becomes ovoid in outline.

Neck region possesses two sphincters, involuntary **internal sphincter** and voluntary **external sphincter.** Neck leads into urethra.

Urethra : It is present only in mammals. It starts from the neck of the urinary bladder and opens outside the body. In female, it short (2-4 cm), straight and concerned with the release of urine through an aperture called urethral orifice or urinary aperture present in the vulva front of the veginal aperture. However, in male it is quite long (20 cm), passes through the prostate gland, Cowper's glands and penis. It is concerned with the release of urine as well as semen (sperms+ glandular secretion) through an aperture called urinogenital aperture at the tip of the penis.

NEPHRON

Nephron or uriniferous tubule is the structural and functional unit of kidney. Each nephron consists of two part the **glomerulus** and the **renal tubule**.

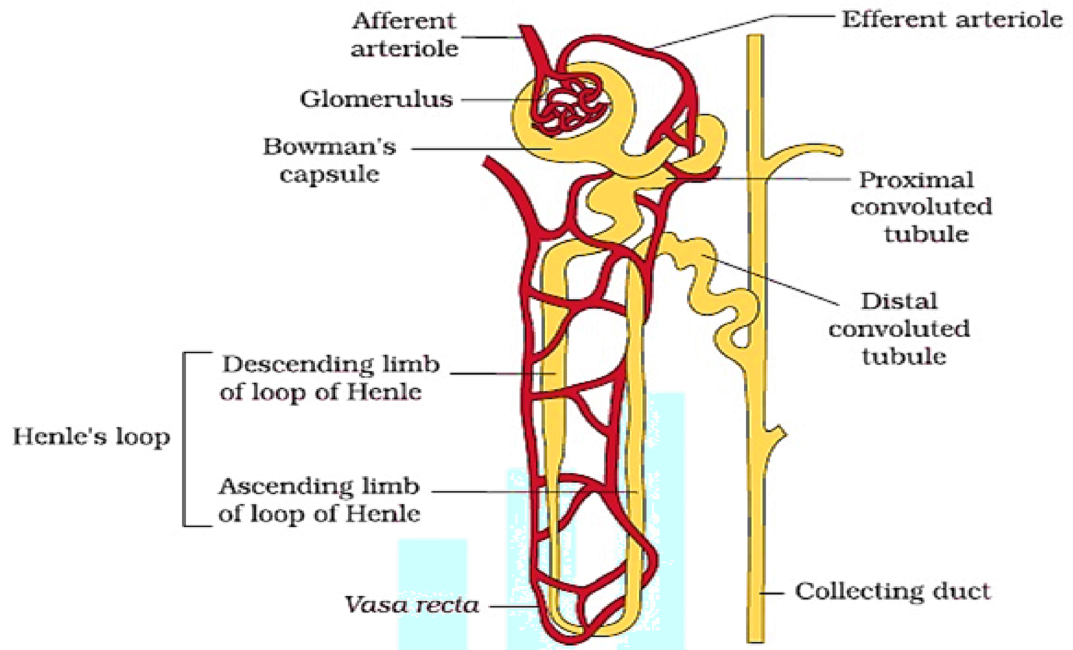


Fig. : A diagrammatic representation of a nephron showing vessels duct and tubule

(a) Glomerulus : It is a **tuft** of capillaries formed by the branching of afferent arteriole which is a fine branch of renal artery. Glomerular capillaries join to form efferent arteriole.

(b) Renal tubule : It begins with Bowman's capsule which encloses glomerulus.

Bowman's Capsule : It is blind double-walled cup-shaped structure. The two walls of Bowman's capsule are inner visceral and outer parietal. Both are single-layered and are supported over basement membrane.

(i) Visceral layer (inner wall) : It consists of flat squamous epithelial cells on the periphery and specialised podocytes in the remaining part. A podocyte has a number of interdigitated invaginations called **pedicels** or **feet**. The pedicels rest over the basement membrane. They enclose slit process of filtration slits.

(ii) Parietal layer (outer wall) : It consists of flat squamous epithelium. The space between the two layers of Bowman's capsule is called lumen or capsular space.

Malpighian body (renal corpuscle): Glomerulus along with Bowman's capsule is called malpighian body or renal corpuscle.

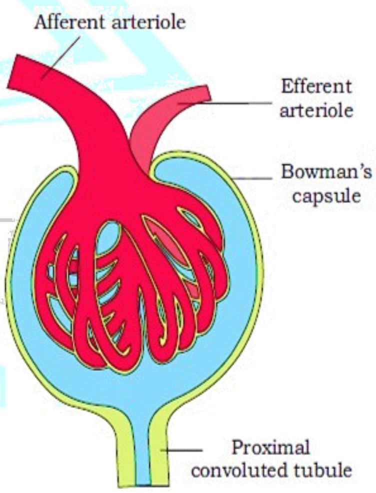


Fig. : Malpighian body (renal corpuscle)

Proximal Convoluted Tubule (PCT) : Lower of Bowman's capsule leads into PCT. The latter is present in the cortex. It highly coiled and surrounded by **peri tubular** blood capillaries. PCT is lined by cuboidal epithelium having borders with long microvilli for increasing absorptive area. The cells contain abundant mitochondria and food reserve for providing energy to perform active absorption and secretion.

Loop of Henle : Its hair-pin loop like tubular part of nephron which descends into renal medulla. Loop of Henle is made of two parallel limbs joined by curved base. There is a descending limb and ascending limb.

Distal Convoluted Tubule (DCT) : The ascending limb of Henle's loop continues as DCT. DCT is highly coiled part of nephron and lies close to Malpighian body.

Collecting ducts : The DCTs of many nephrons open into a straight tube called collecting duct, many to which converge and open into the renal pelvis through medullary pyramids in the calyces.

Vasa recta : The efferent arteriole emerging form the glomerulus forms a fine capillary network around the renal tubule called peritubular capillaries. A minute of this network runs parallel to the Henle's loop forming a U-shaped vasa recta. Vasa recta is absent or highly reduced in cortical nephrons.

These are two types, i.e., cortical and juxta medullary nephrons.

(i) **Cortical nephrons :** In majority of nephrons, the loop of **Henle** is too short and extends only very little into the medulla. Such nephrons are called cortical nephrons.

(ii) **Juxta-medullary nephrons :** In some of the nephrons, the loop of Henle is very long and runs deep into the medulla. These nephrons are called juxta medullary nephrons.

URINE FORMATION

It involves three main processes namely, glomerular filtration, reabsorption and secretion, that takes place in different parts of the nephron.

Glomerular filtration

The first step in urine formation is the filtration of blood, which is carried out by the glomerular filtration. On an average 1100-1200 mL of blood is filtered by the kidneys per minute which constitute roughly $1/5^{th}$ of the blood pumped out by each ventricle of the heart in minute.

The glomerular capillary blood pressure causes filtration of blood through three layers, i.e.,

(i) **The endothelium of glomerular blood vessels.**

(ii) **The epithelium of Bowman's capsule.**

(iii) **A basement membrane between these two layers.**

These three structures form filtration membrane.

The epithelial cells of Bowman's capsule called podocytes are arranged in an **intricate manner** so as to leave some minute spaces called filtration slits or slit pores.

Blood is filtered so finely through these membrane, that almost all the constituents of the plasma except the proteins pass into the lumen of the Bowman's capsule. Therefore, it is considered as a process of **ultrafiltration.**

$$\begin{aligned} GFP &= GHP - (BCOP + CHP) \\ &= 60 - (30+20) \\ &= 10 \text{ mm Hg} \end{aligned}$$

The amount of the filtrate formed by the kidneys per minute is called glomerular filtration rate (GFR). GFR in a healthy individual is approximately 125 ml/min, i.e., 180 liters per day.

Tubular Reabsorption

A **comparison** of the volume of the **filtrate** formed per day (180 liters per day) with that of the urine released (1.5 liters), suggest that nearly 99 percent of the filtrate has to be reabsorbed by the renal tubules. This process is called re absorption. The tubular epithelial cells in different segments of nephron perform this either by active or passive mechanisms. For example, substances like glucose, amino acids, Na^+etc. in the filtrate are reabsorbed actively. Whereas, the nitrogenous wastes are absorbed by passive transport. Reabsorption of water also occurs passively in the initial segments of the nephron.

Tubular Secretion

The phenomenon of secretion of metabolic wastes by tubular cells into the filtrate is known as tubular secretion. It includes secretion of K^+, H^+, ammonia and some wastes like hippuric acid, creatinine, drugs, pigments, toxins etc. It is the only mode of excretion in animals which do not have glomeruli e.g. dessert amphibians, marine fishes. Tubular secretion is also an important step in urine formation as it helps in the maintenance of ionic and acid-base balance of body fluids.

FUNCTIONS OF THE TUBULES

Proximal convoluted tubule (PCT)

It is lined by simple cuboidal brush border epithelium which increases the surface area for reabsorption. Nearly, all of the essential nutrients, and 70-80% of electrolytes and water are reabsorbed by this segment. PCT also helps to maintain the pH and ionic balance of the body fluids by selective secretion of hydrogen ions and ammonia into the filtrate and by absorption of HCO_3^- form it.

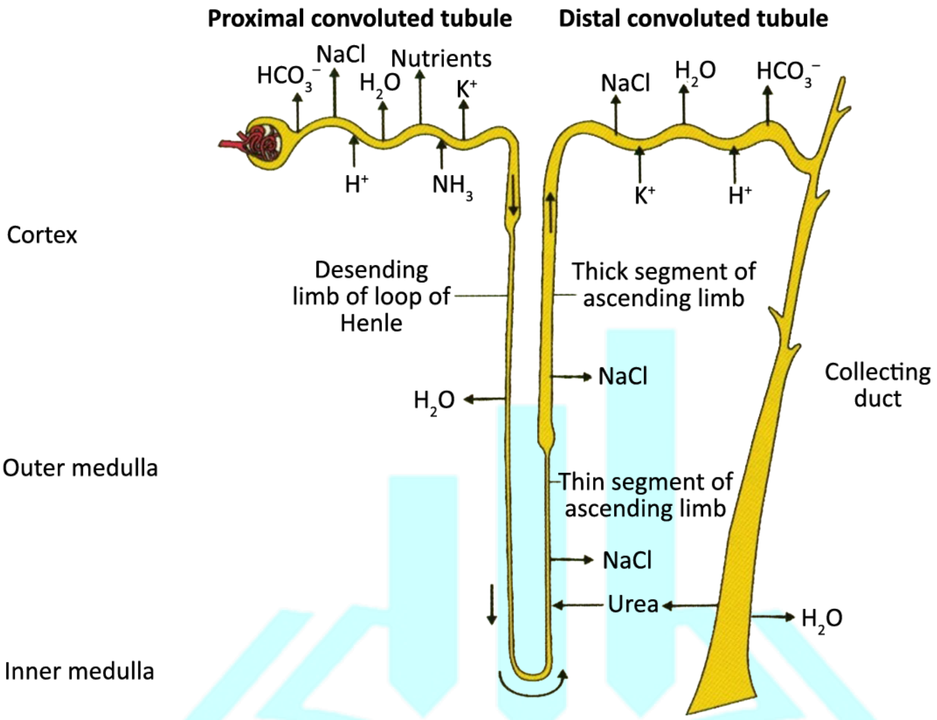
Loop of Henle

Reabsorption is minimum in ascending limb of loop of Henle. However, this region plays a significant role in the maintenance of high osmolarity of medullary interstitial fluid. The descending limb of loop of Henle is permeable to water but almost impermeable to electrolytes. this concentrates the filtrate as it moves down. The ascending limb is impermeable to water but allows transport of electrolyte actively or passively. Therefore, as the concentrated filtrate pass upward, it gets diluted due to the passage of electrolytes to the medullary fluid.

Distal convoluted tubule (DCT)

Conditional reabsorption of Na^+ and water takes place in the segment. DCT is also capable of reabsorption of HCO_3^- and selective secretion of hydrogen and potassium ions and NH_3 to maintain the pH and sodium potassium balance in blood.

REABSORPTION AND SECRETION OF MAJOR SUBSTANCES AT DIFFERENT PARTS OF THE NEPHRON (ARROWS INDICATE DIRECTION OF MOVEMENT OF MATERIALS)



Collecting duct

This long duct extends from the cortex of the kidney to the inner parts of the medulla. Large amounts of water could be reabsorbed form this region to produce a concentrated urine. The segment allows passage of small amounts of urea into the medullary interstitium to keep up the osmolarity. It also plays a role in the maintenance of pH and balance of blood by the selective secretion of H+ and K+ ions (explained in figure).

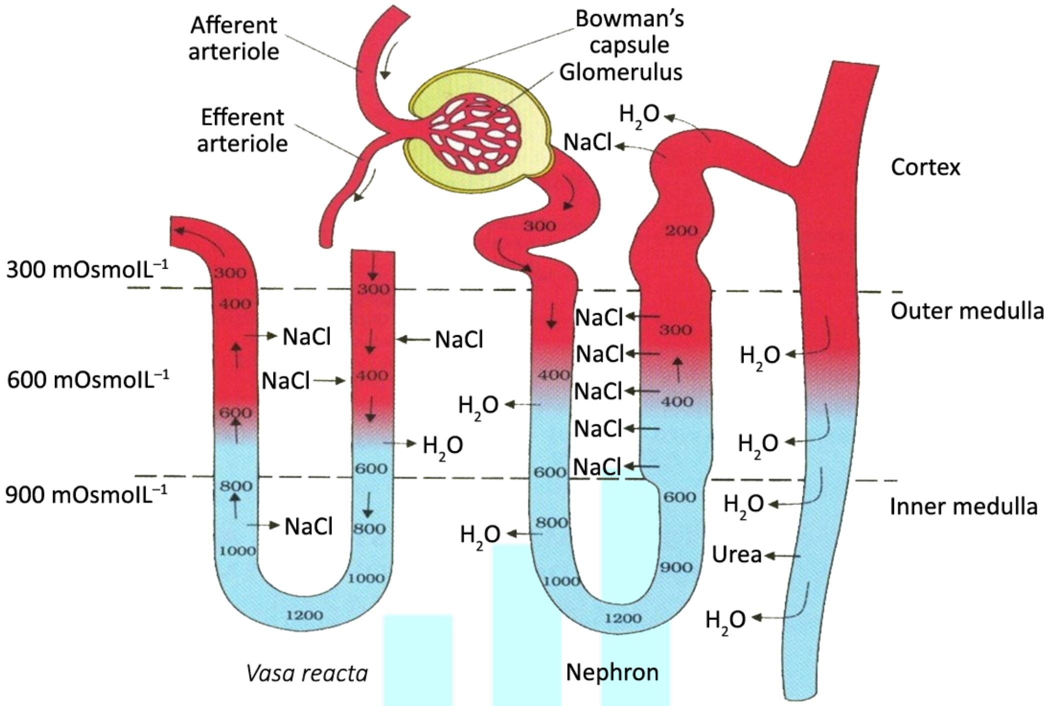
MECHANISM OF CONCENTRATION OF THE FILTRATE

Mammals have the ability to produce a concentrated urine. The capability of concentrating the urine is related to the length of the loop of Henle. Vasa recta also helps in concentrating urine. The flow of filtrate the two limbs of Henle's loop is in opposite directions and thus forms a counter current. The flow of blood through the two limbs of vasa recta is also a counter current pattern.

The proximity between the Henle's loop and vasa recta, as well as counter current in them help in maintain an increasing osmolarity towards the inner medullary **interstitium**, i.e., form 300 $mOsmL^{-1}$ in the cortex about 1200 $mOsmL^{-1}$ in the inner medulla. This gradient is mainly caused by NaCl and urea.

NaCl is transported by the ascending limb of loop of Henle which is exchanged with the descending branch of vasa recta. NaCl is returned to the interstitium by the ascending portion of vasa recta. Similarly, small amount of urea enter the thin segment of the ascending limb of Henle's loop which is transported back to the interstitium by the collecting tubule. This transport of substances facilitated by the special arrangement of Henle's loop and vasa recta is called the counter current mechanism. This Mechanism helps to maintain a concentration gradient in the medullary interstitium, which helps in an easy passage of water from the collecting tubule thereby concentrating the filtrate (urine). Human kidneys can produce urine nearly four times concentrated than the initial filtrate formed (1200 mOsm/L).

DIAGRAMMATIC REPRESENTATION OF A NEPHRON AND VASA RECTA SHOWING COUNTER CURRENT MECHANISMS



REGULATION OF KIDNEY FUNCTION

The functioning of the kidneys is efficiently monitored and regulated by hormonal feedback mechanisms involving the hypothalamus , JGA (Juxtaglomerular Apparatus) and to a certain extent the heart.

Control by ADH : Osmoreceptors in the body are activated by change in blood volume, body fluid volume and ionic concentration. As excessive loss of fluid from the body can activate these receptors which stimulate the hypothalamus to release antidiuretic hormone (ADH) or vasopressin from the neurohypophysis. ADH facilitates water reabsorption from latter parts of the tubule thereby preventing diuresis (excessive urination). An increase in body fluid volume can switch off the osmoreceptors and suppress the ADH release to complete the feedback.

ADH can also affect the kidney function by its **constrictor effects** on blood vessels. This causes and increase in blood pressure. An increase in blood pressure can increase the glomerular blood flow and thereby the GFR.

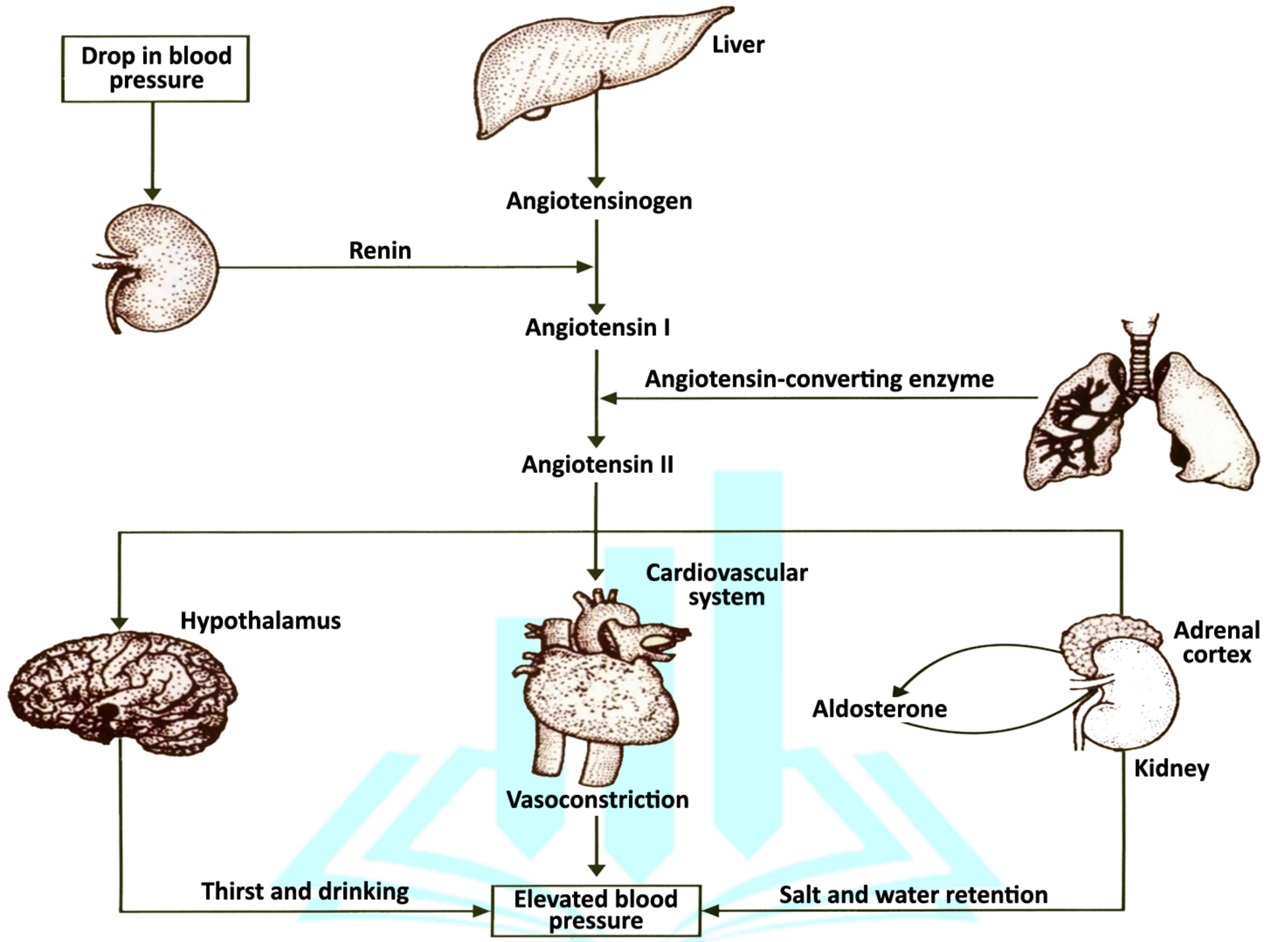
Control by juxtaglomerular Apparatus (JGA)

JGA operates a multi hormonal **Renin-Angiotensin-Aldosterone System (RAAS)**. A fall in glomerular blood flow glomerular blood pressure/GFR can activate the JG cells to release renin which converts angiotensinogen in blood to angiotensin I and further to angiotensin II increases glomerular blood pressure by causing arterioles to constrict. It also increases blood volume in two ways. Firstly, by **signaling** the PCT to reabsorb more NaCl and water and secondly, by stimulating the adrenal gland to release aldosterone a hormone that induces the distal parts of tubule to reabsorb more Na+ and water. This leads to an increases in blood volume and pressure, completing the feedback circuit by supporting the release of renin.

Analysis of urine helps in clinical diagnosis of many metabolic disorders as well as malfunctioning of the kidney. for example, presence of glucose (glycosuria) and ketone bodies (Ketonuria) in urine are indicative of diabetes mellitus. Diabetes mellitus is caused by the hyposecretion (less secretion) of insulin hormone which is secreted from the endocrine part of pancreas.

Other than the kidneys, lungs, liver and skin also help in the elimination wastes.

AUTOREGULATION BY KIDNEYS



Lungs

Our lungs remove large amounts of CO_2 (200mL/min) and also significant quantities of water every day in normal resting condition. Water loss via lungs is small in hot humid climate and large in cold dry climates. The rate of ventilation and ventilation pattern (i.e., breathing through mouth or nose) also affect the water loss through the lungs. Different volatile materials are also readily eliminated through the lungs.

Liver

Liver is the largest gland of our body. It is the main site for elimination of cholesterol, bile pigments (bilirubin and biliverdin) degraded steroid hormones, some vitamins and many drugs. Liver secretes these substances in the bile. Bile, in turn, carries these materials of the intestine, which are ultimately eliminated with the faeces.

Skin

The sweat and sebaceous glands in the skin can eliminate certain substances through their secretions, i.e., sweat and sebum respectively. Sweat produced by sweat glands in a watery fluid contain in NaCl, small amount of urea, amino acids and **glucose** etc. Though the primary function of sweat is to facilitate a cooling effect in the body surface, it also helps in removal of some of the wastes mentioned above.

Sebaceous glands eliminate certain substances like **sterols**, hydrocarbons and waxes through sebum. Sebum is a waxy protective secretion which provides a protective only covering for the skin.

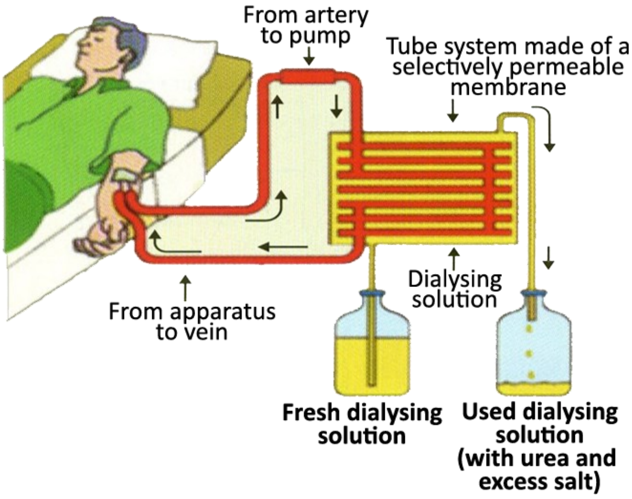
DISORDERS OF THE EXCRETORY SYSTEM

Malfunctioning on kidneys can lead to accumulation of urea in blood, a condition called uremia, which is highly harmful and may lead to kidney failure.

Haemodialysis

In such patients, urea can be removed by a process called haemodialysis. Blood is taken out from an artery of the patient, **cooled** to 0^0C, mixed with an anticoagulant such as heparin and then pumped into the apparatus called the artificial kidney. In this apparatus, blood flows through channels or tubes bounded by cellophane membrane. This membrane is impermeable to macromolecules such as plasma proteins but permeable to small solutes such as urea, uric acid, creatinine and mineral ions. The membrane separates the blood flowing inside the channels or tubes form a dialysing fluid flowing outside the membrane. The dialysing fluid contains some small solutes and mineral ions, but does not contain nitrogenous waste products such as urea, uric acid and creatinine. So, these wastes diffuse form the blood to the dialysing fluid across the cellophane membrane following the concentration gradient. Thus, the blood is considerably cleared nitrogenous waste products without losing plasma proteins. Such a process of separating small solutes from macromolecular colloids with the help of a selectively permeable membrane is called dialysis.The blood coming out to the artificial kidney is warmed to body temperature mixed with antiheparin to restore its normal coagulability and returned to a vein of the patient. Haemodialysis saves and prolongs the life of many uremia patients.

HAEMODIALYSIS



Kidney Transplantation

Kidney Transplantation is the ultimate method in the correction of acute renal failures (Kidney failure). A functioning kidney is used in Transplantation from a donor preferably a close relative to minimize its chances of rejection by the immune system of the host.

Diseases of Excretory System

1. **Nephritis :** The infection is caused by bacteria which results in inflammation of the kidney.
2. **Glomerulonephritis :** Inflammation of glomeruli .
3. **Pyelonephritis :** Inflammation of the tissue of kidneys in the pelvis region.
4. **Cystitis :** Inflammation of the urinary bladder.
5. **Renal Calculi :** Stone of insoluble mass of crystllized salts (oxalate etc.) formed within kidney.
6. **Polyurea :** Amount of urine passed out is more.
7. **Uremia :** The concentration of urea is increased in blood.
8. **Alkaptonuria :** It is a genetic disease in which **homogentisic acid** in excreted out with urine.
9. **Pyuria :** Presence of pus in the urine.
10. **Haematuria** : Presence of blood in the urine.

Chapter 17
Locomotion and Movement

Introduction:

Movement is a change in posture or position. It is essential and significant feature of living organisms and hence both unicellular and multicellular organisms show movement. For example, unicellular organism such as *Amoeba* move with the help of pseudopodia thus, streaming of protoplasm (pseudopodia) in *Amoeba* is simple form of movement. In many other organism's different structures such as cilia, flagella, limbs, jaw, eyelid, tongue etc. show movement. The movement which result in the change of **place** or **location** are called **locomotion**.

Types of Movement

On the basis of structure three basic types of movement occur in the cells of human body namely **amoeboid, ciliary** and **muscular**.

Movement

- Amoeboid or Pesudopodial movement
- Ciliary Movement
- Muscular Movement

(i) Amoeboid or Pesudopodial Movement : Due to the streaming of protoplasm or cytoplasm the surface of the cell forms false feet or pseudopodia. The pseudopodia are replaced by the new pseudopodia and therefore the formation and withdrawal of it allows the cell to change its shape regularly. As Amoeba WBC and macrophages show pseudopodial movement they do not have a fixed shape. The leucocytes and macrophages reach each and every part of the body and engulf the antigens or pathogens through these pseudopodia.

(ii) Ciliary Movement : The free surface of the cells have short fine hair-like projections called **cilia.** The movement of these projections (cilia) is called **ciliary movement.** The **oar-like** activity of the cilia creates a water current which helps in movement of various structures of human body such as respiratory tract, reproductive tract are lined ciliated epithelium and help in the movement of various substances. In oviduct, cilia provide the motive force for the passage of ova. Coordinated movement of cilia in the trachea help in the removal of dust particles inhaled along with atmospheric air. Spermatozoa and protozoa have **flagella for** locomotion and movement.

(i) **Muscular Movement:** In human movement of limbs, jaw, tongue and other body parts occur due to contraction of muscles. The muscles contract and relax rhythmically to produce movement and are used effectively for locomotion.

LOCOMOTION

The movement of an individual form one place to another is called locomotion. It occurs in both unicellular and multicellular organisms with help of different structures. There are certain structures which are essential for both movement and locomotion of internal and external body parts.

For example: *Hydra* uses tentacles for capturing its prey/food as for locomotion. ***Paramecium*** uses cilia for movement of food (ingestion) and locomotion and amoeba uses pseudopodia for the same. Human uses limbs for changes in body postures and locomotion.

This suggest that movement and locomotion are not different entities rather they are said to be inter dependent on each other. Hence, it can also be said that all locomotion are movements but all movement are not locomotion.

Functions of locomotion

Locomotion is performed for the following processes:

(i) Procurement of food.
(ii) Searching and building of shelter.
(iii) Finding mate.
(iv) Protection from predators.
(v) Search of suitable breeding grounds.
(vi) Migration.

MUSCLES

Muscle is a specialized tissue originated from the germ layer, **mesoderm.** it brings about different types of movement is internal and external body parts. A human body is made up of 639 muscles which have unique properties like **contractibility**, **excitability**, **elasticity** and **extensibility**. They make about 40-50 percent of body weight in adult human.

Structure of Muscle

A muscle is covered by a sheath of connective tissue called **epimysium**. Inside the epimysium, a muscle has many muscle fibres arranged in a bundle called **fasciculi** (singular-fasciculus or fascicle). Each fasciculus is surrounded by a sheath of connective tissue called **perimysium**. The muscle fibres are parallel to each other in the fasciculus and is surrounded by a connective tissue called **endomysium**.

Types of Muscles

Muscles can be classified on various criteria namely location, appearance, nature of regulation of their activities. Based upon location, the muscles and be of following types:

(i) **Skeletal muscle or striped or striated or voluntary muscles:** These muscles are attached to the skeleton component of the body and primarily involved in the locomotory actions and changes of the body posture. When observed under a microscope, alternate light and dark bands are observed on the muscle fibers. Due to the striated appearance of the muscle fibers, these muscles are called striated or striped muscles. These muscles are voluntary as they are under the control of animals will or conscious. For example: muscles of hindlimbs, forelimbs, body wall, tongue, pharynx and beginning of oesophagus etc.

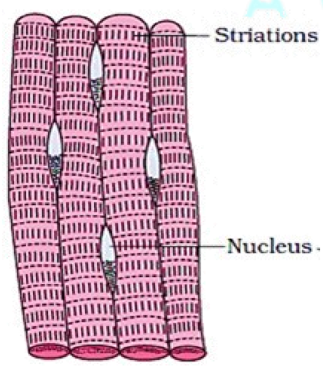
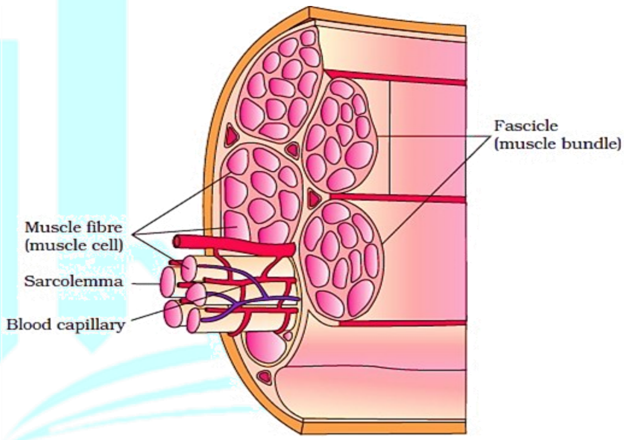


Fig. : Skeletal (striated) muscle tissue

(ii) **Smooth or non-striated or non-striped or involuntary muscles :** The cells of these muscles are elongated, spindle-shaped, broad from the middle and have tapering ends. These muscles do not have alternate light or dark bands on their muscle fibers and hence give a smooth appearance when observed under a microscope. Their fibers are not organized into parallel arrays.

These muscles lines the hollow organs and are involuntary. e.g., posterior region of oesophagus, stomach, intestine, lungs, urinary bladder, urinogenital tract.

(ii) **Cardiac muscle :** Cardiac muscle heart, hence muscles of the heart are called cardiac muscle. The cells of cardiac muscle assemble in a branching pattern. These are striated in nature i.e., alternate light and dark bands could be observed on the muscle fiber then kept under the microscope. These are involuntary in nature as they generate their own impulse or excitation and hence allow heart to continue its pumping activity of rhythmic contraction and relaxation.



Diagrammatic cross-sectional view of a muscle showing muscle bundles and muscle fibres

Ultrastructure of Striated Muscles

Skeletal muscle consists of many muscle fibers, anatomical unit of muscle. Muscle fiber is covered by a plasma membrane called **sarcolemma**. The sarcolemma encloses the **sarcoplasm** which contains many nuclei.

The muscle fibres contain parallelly arranged myofibrils which have the alternate light and dark bands. The sarcolemma invaginates to form T-tubules i.e., transverse tubules. These T-tubules are formed over the myofibrils (**like a curtain**).

A single myofibril is made up to two types of **myofilaments**- thick myofilament and thin myofilament. The thick myofilament consists mainly of myosin protein and myofilament consists of mainly actin protein. The endoplasmic reticulum present in the sarcoplasm is called **sarcoplasmic reticulum**. It is the store house of calcium required during muscle contraction.

The dark band present on the myofibril is called **'A-band'** or **anisotropic band** and the light band present on the myofibril is called **I- band or isotropic band.**

At the center of the dark A-band, a **comparatively** light band called **'H-band'** or Hensen's zone is present. **A dark M-line** passes through the center of H-band.

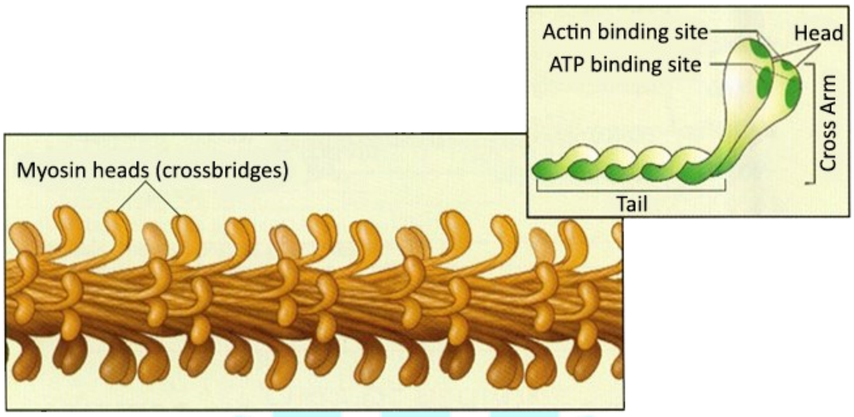
The light I-band consists of a dark line which passes through the centre called Z-line. The part of myofibril between the two successive Z-line is called **sarcomere**. The sarcomere is the structural and functional unit of myofibril. A **sarcomere** hence comprises of a **single A-band** and **half of each adjacent I-band**.

Structure of Contractile proteins

(i) Thick myofilament : The thick myofilaments are made up polymerised protein called **myosin**. the monomeric proteins called **meromyosins** polymerized to form the myosin protein.

Each meromyosins has two parts-a globular head with a short arm and a tail. The globular head along with the short arm is called heavy meromyosin (HMM) and the tail is called light meromyosin (LMM). The globular head has a site for binding of actin and ATP. The globular head act as an ATPase enzyme.

Thick Filament



(ii) Thin filament : The thin myofilament is made up of three proteins-actin, tropomyosin and troponin.

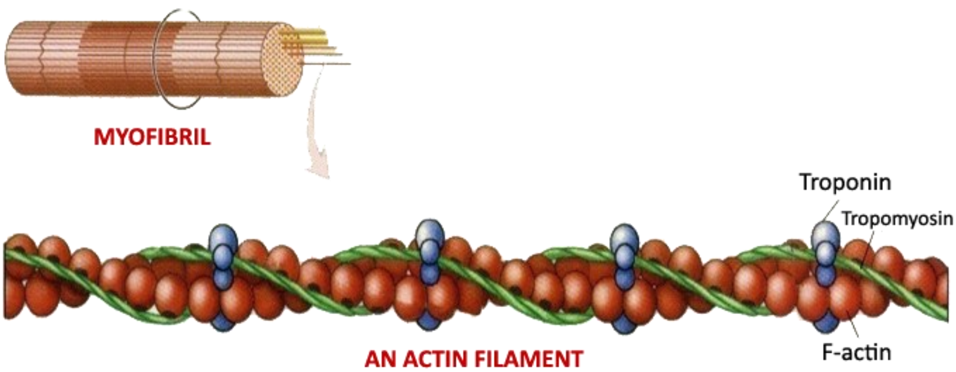
Actin : Actin is a globular protein which has a low molecular weight. It occurs in two forms-monomeric G-actin and polymeric F-actin. The G-actin polymerises to form the F-actin in the presence of magnesium ion.

- In filament and hence prevents the formation of cross bridges which in turn prevents the contraction of muscle fiber.

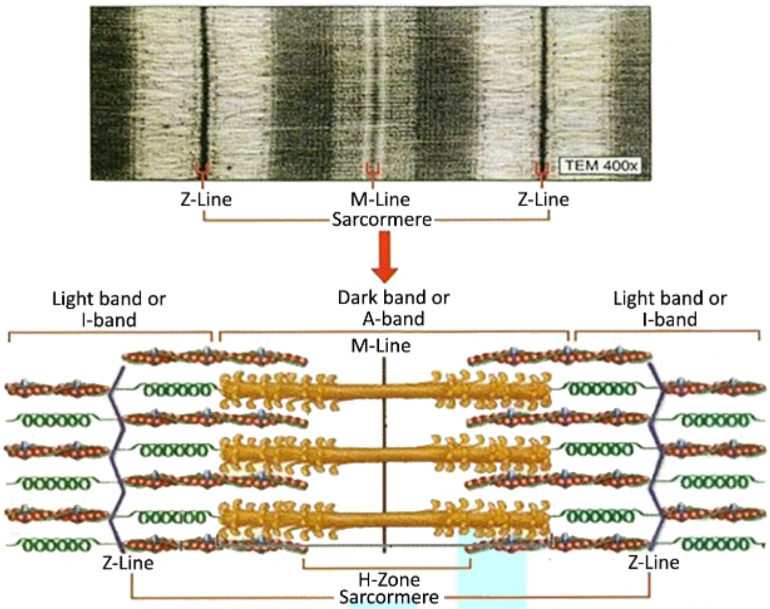
- **Troponin :** At regular intervals of tropomyosin, a complex protein called troponin is present. It masks the active binding sites for myosin on actin filament. A troponin is a trimeric protein i.e. it has three units which acts as the binding sites for three different components. The three units of troponin are :

1. **Troponin I :** It inhibits actin-myosin interaction and binds to other components of troponin.
2. **Troponin T :** It is the binding site for tropomyosin.
3. **Troponin C :** It is the binding site for calcium.

Thin Filament



ANATOMY OF A MUSCLE FIBRE SHOWING A SARCOMERE



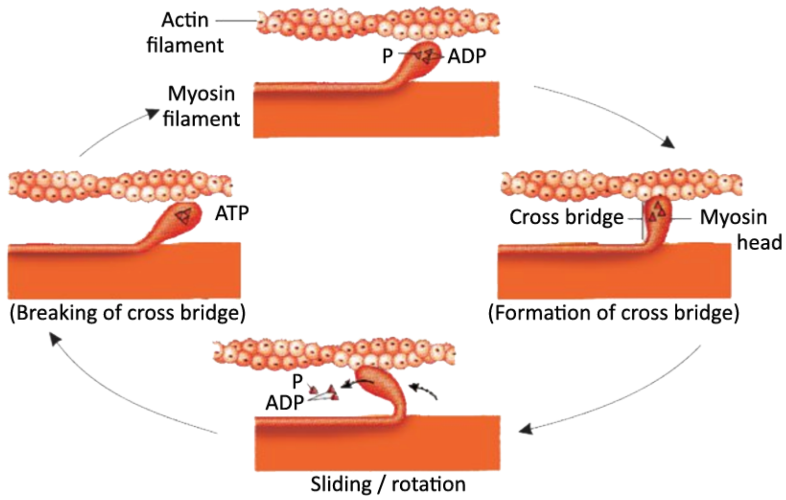
MECHANISM OF MUSCLE CONTRACTION

The mechanism of muscle contraction is explained by a theory called **sliding filament theory.** According to this theory, the contraction of muscle fiber occurs when thin filament i.e., actin filament slides over thick filament i.e. the myosin filament.

1. The contraction of the muscle is initiated by the signal sent by CNS via a motor neuron. The nerve impulse given by the CNS travels through the motor neuron. When the impulse reaches the axon terminal or neuromuscular junction, vesicles containing neurotransmitters fuses with the axon membrane. After fusion with the axon membrane they release the neurotransmitter, acetylcholine, which travels through synaptic cleft and generate action potential in the sarcolemma.
2. The impulse or action potential generated then spread from sarcolemma to the T-tubules. The impulse then stimulates the sarcoplasmic reticulum to release calcium ion into the sarcoplasm.
3. An increase in Ca^{2+}concentration in the sarcoplasm starts filament sliding, while a decrease turns off the sliding process.

   When a muscle fiber is relaxed (not contracting) the concentration of Ca^{2+} in its sarcoplasm is low. This is because the sarcoplasmic reticulum (SR) membrane contains **Ca^{2+}active transport pumps** that move Ca^{2+} from the sarcoplasm into the SR. Ca^{2+} is stored or sequestered inside the SR. As a muscle action potential travels along the sarcolemma and into the transverse tubule system. however, Ca^{2+} release channels open in the SR membrane. As a result, Ca^{2+} floods into the sarcoplasm around the thick and thin filaments. The Ca^{2+} released from the sarcoplasmic reticulum combine with troponin causing it to change shape. This shape change moves the troponin - tropomyosin complex away from the myosin-binding sites on action.
4. The globular head of myosin acts as an ATPase and hydrolyses ATP molecule. The energy derived from the hydrolysis of ATP is used by myosin to bind the exposed active site on actin filament to form a cross bridge.
5. This pulls the actin filament (attached) towards the centre of 'A-band'. The Z-line attached to these actins are also pulled inwards thereby causing a shortening of the sarcomere i.e. contraction. The thin myofilaments move past the thick myofilament due to which the H-zone narrows. This reduces the length of I-band but retain the length of A-band. The myosin then release ADP+Pi and goes back to its relaxed state. Again the ATP binds to the myosin and connection or cross bridge between myosin and acting is broken. The ATP is again hydrolyzed and the cycle of formation and breakage of cross-bridges is repeated causing sliding. The process continues till the calcium ion is pumped back into the sarcoplasmic reticulum.

   This causes the return of 'Z' lines back to their original position i.e. relaxation occurs.



Nerve Impulse
↓
Sarcoplasmic Reticulum
↓
Release of Calcium ion
↓
Cross –Bridge Formation
↓
Action-Myosin Complex
↓
Muscle Contraction

Flow chart of Muscle Contractions

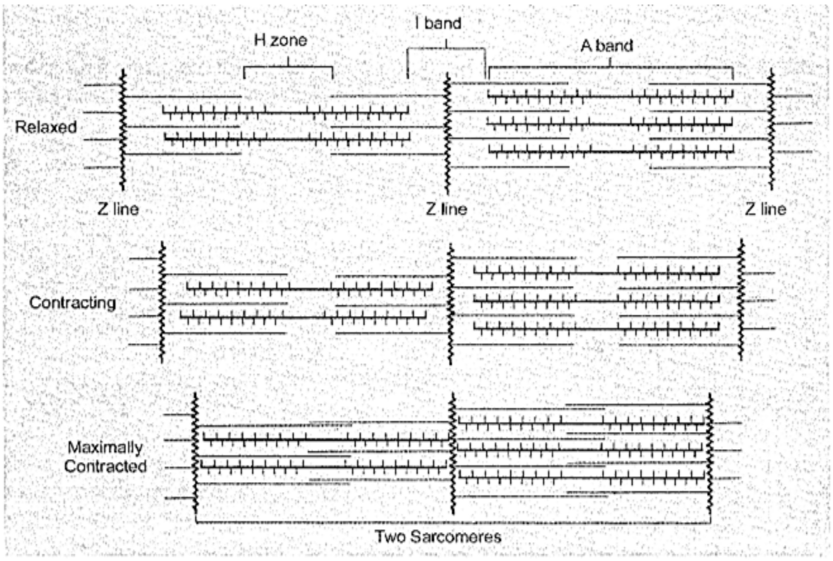


Fig. : Sliding-filament theory of muscle contraction
(movement of the thin filaments and the relative size of the l-band and H-zones)

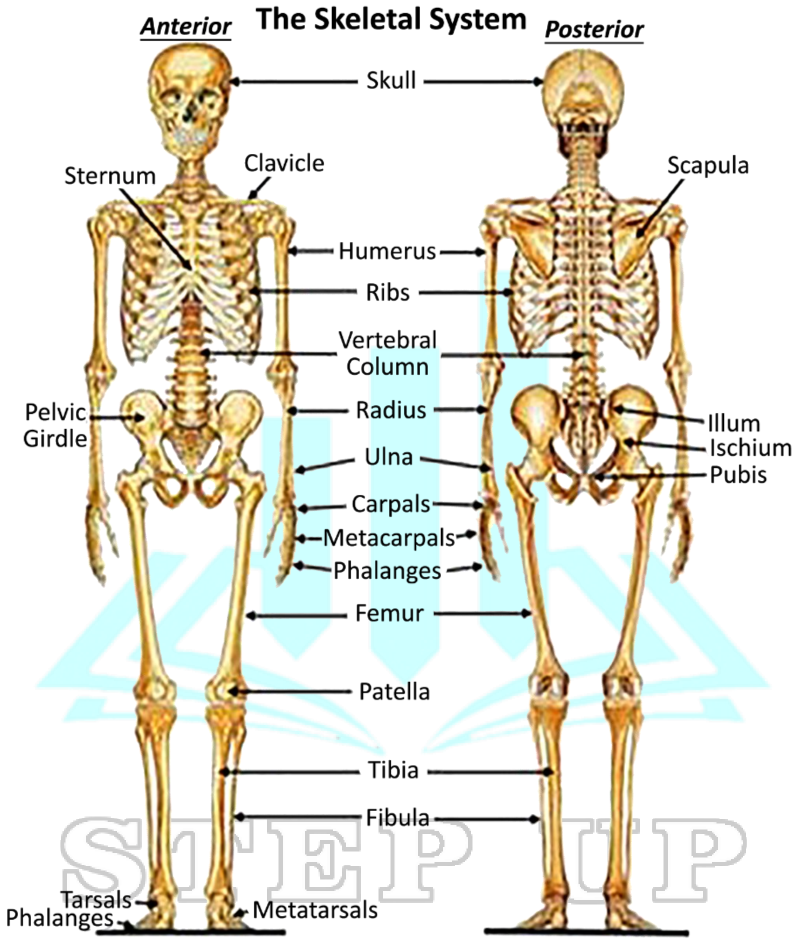
MUSCLE RELAXATION

After the contraction of muscle the calcium moves back into the sarcoplasmic. The troponin undergoes change in shape and the tropomyosin and troponin attain their earlier position and sate. This blocks the active site of myosin on actin and myosin dose not bind to actin. This causes relaxation of muscle.

Contraction is Smooth Muscles : In comparison with contraction in a skeletal muscle fiber contraction a smooth muscle fiber starts more slowly and lasts much longer Troponin is absent in smooth muscle they have regulator protein called Calmodulin that binds to Ca^{2+} in the cytosol. Using ATP myosin part can bind to actin & contraction can occur. Most smooth muscle fibers contract or relax in response action potentials from the autonomic nervous system.

SKELETAL SYSTEM

Skeletal system is system of **external** and **internal**, **living** or **dead**, hardened structures which form the supportive, protective and **jointed** framework of the body. Hard or flexible, internal or external structures of the animal body such as bones and cartilage constitutes the skeleton. The skeleton system is responsible for movement or locomotion of various body part.



Human Skeleton anterior view

Skeletal System in Man

On the basis of different skeletal structures present in the body of the organism endoskeleton is divided into two principal divisions :

A. Axial skeleton .

B. Appendicular skeleton.

Skeleton

- Axial skeleton (80)
  - Skull (29)
    - Facial Bone (14)
    - Cranium (8)
    - Ear Ossicles (6)
  - Vertebral column (26)
  - Ribs + Sterum (24+1)
  - Hyoid Bone (i)
- Appendicular skeleton (126)
  - Girdle bones (6)
    - Pelvic girdle (2)
    - Pectoral girdle (4)
  - Limb bones (4 x 30)

A. **Axial Skeleton :** The axial skeleton runs along the middle longitudinal axis of the body. It comprises 80 bones which distribute along the main axis and form four structures such as skull, vertebral column, sternum and ribs.

(a) **Skull :**

Skull (Bicondylar)

Cranium	:	8 Bones
Frontal	:	1
Parietal	:	2
Temporal	:	2
Occipital	:	1
Sphenoid	:	1
Ethmoid	:	1

Face	:	14 Bones
Nasal	:	2
Maxilla	:	2
Zygomatic	:	2
Lacrimal	:	2
Palatine	:	2
Inferior nasal conchae	:	2
Vomer	:	1
Mandible	:	1

The skeleton of the head is called skull. It rests on the upper end of the vertebral column and the body structure of the skull consists of four parts such as cranium, facial bones, hyoid and ear bones.

(i) **Cranium :** Cranium is a hollow and nearly rounded body structure which protects the brain. It is made up of eight bones called cranial bones. These bones fuse together and form sutures.

Base of the skull has a large opening called foramen magnum through which the brain communicates with the spinal cord. There are two faces called occipital condyles on both sides of the foramen magnum. Because of the presence of two condyles the human skull is called bicondylar.

(ii) **Ear ossicles :** The middle ear has three bones called ear ossicles which helps in amplification of sound. These bones are:

1. Malleus (Hammer shaped)
2. Incus (Anvil shaped)
3. Stapes (Stirrup shaped)

(iii) **Facial bone :** Facial bones constitute front part of the skull, skeleton of lower jaw, hard palate and nose.

(iv) **Hyoid bone :** The hyoid bone is a U-shaped bone which is present at the base of buccal cavity i.e., at the base of the tongue and above the larynx. The hyoid bone together with the tongue forms the hyoid apparatus.

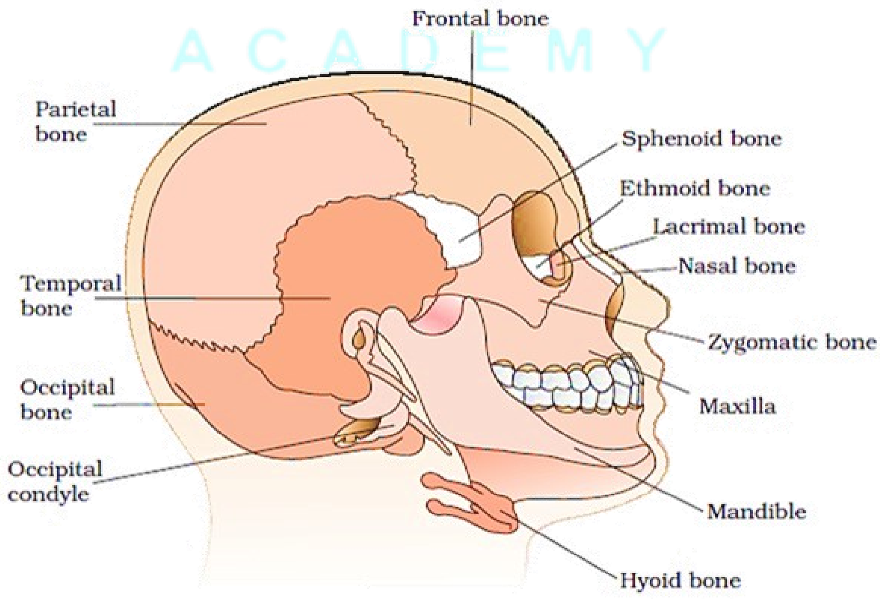


Fig. : Diagrammatic view of human skull

Cranial Bones	Number	Location
Frontal bone	1	Anterior part of cranium and forms forehead
Parietal bone	2	Greater portion of sides and roof of cranial cavity
Temporal	2	Inferior lateral aspect of cranium and part of cranial floor
Occipital	1	Posterior part and most of the base of cranium. A large aperture, foramen magnum is in the inferior part of the bone through which medulla oblongata connects with spinal cord.
Sphenoid	1	Lies at the middle part of the base of skull and holds all the cranial bones together. It has saddle shaped structure, Salla turcica to enclose pituitary gland.
Ethmoid	1	Sponge like in appearance located on the midline in the anterior part of cranial floor. The cribriform plate forms roof of nasal cavity through which olfactory nerve passes to brain. Perpendicular plate forms superior portion of nasal septum.

Facial bone	Number	Location
Nasal bone	2	Bridge of nose
Maxillae	2	Upper jaw, articulates with every bone of face except mandible
Zygomatic	2	Prominence of cheek
Lacrimal	2	Thin bone houses lacrimal sec.
Palatine	2	Make posterior part of hard palate and form floor and lateral wall of nasal cavity
Inferior nasal Conchae	2	Form part of inferior lateral wall of nasal cavity, clear air that passes through nose
Vomer	1	Triangular bone forms inferior portion of nasal septum
Mandible	1	Lower Jaw is the largest and strongest facial bone.

Functions of the skull

1. The most important functions of the skull are to protect the brain. This function is mainly carried out by the cranium.
2. The skull bears jaws which help the animal in cutting and masticating its food.
3. Ear bones help in amplification of sound.
4. It protects and supports the special sense organs.

VERTEBRAE

Vertebral column protects the spinal cord, supports the head and serves as the point of attachment for the ribs and musculature of the back.

Vertebrae type	Foetal stage	Adult
Cervical	7	8
Thoracic	12	12
Lumbar	5	5
Sacral	5	1
Coccyx	4	1
	33	26

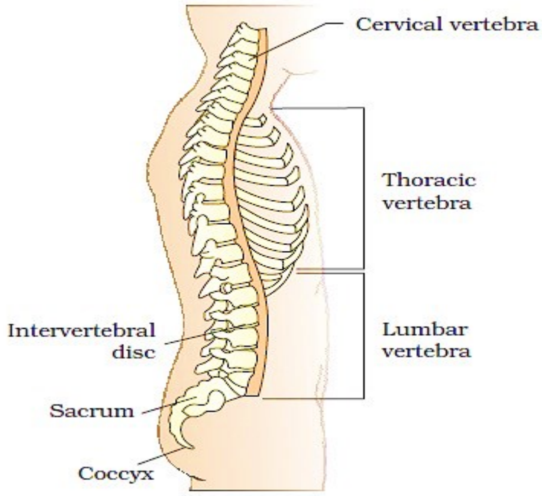


Fig. : Vertebral column (right lateral view)

Function of the Vertebral column

1. It protects the spinal cord, supports the head and serves as the point of attachment for rib and musculature of back .
2. It carries the weight of the body during as well as in standing position.
3. The atlas and axis vertebrae of the vertebral column allows movement of head in different directions.

Sternum

Sternum is a flat bone present on the ventral midline of the ventral midline of the thorax. It is present just under the skin in the middle of the chest The sternum forms protective covering which protects the internal organs present in the thoracic region. It provides a surface where muscles attach to the respiratory mechanism.

(d) **Ribs :** Rib is a thin flat bone which is dorsally connected to the vertebral column and ventrally to the sternum. there are 12 pairs of ribs which form the lateral walls of the thoracic cage.

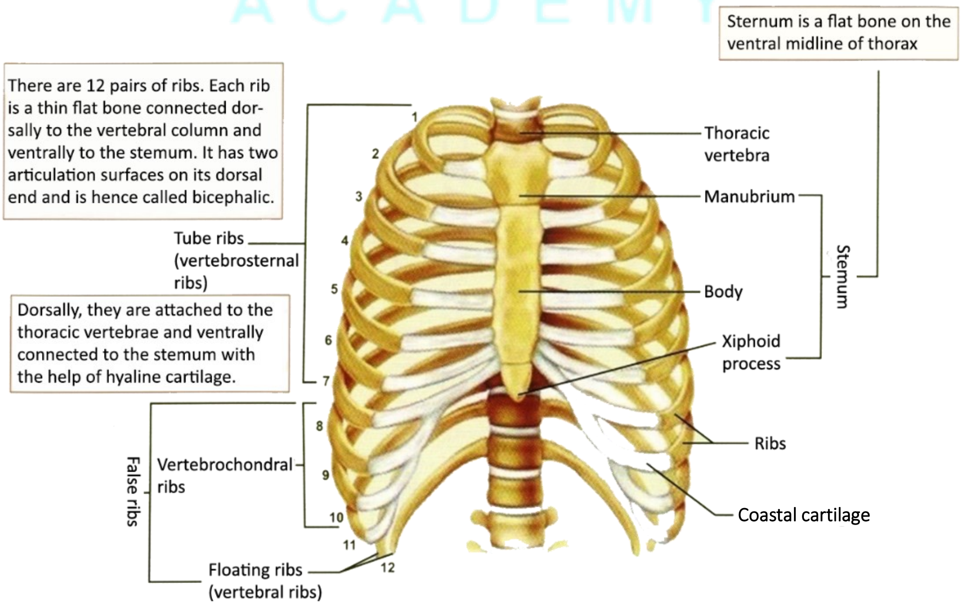
Ribs are of three types

(i) **True ribs (Vertebro sternal ribs) :** the first seven pairs of ribs are called true ribs. They are dorsally attached to the thoracic vertebrae and are ventrally connected to the sternum with help of hyaline cartilage.

(ii) **False ribs (Vertebro sternal ribs) :** The three pairs of ribs i.e. 8th, 9th and 10th pair do not directly articulate with the sternum rather it joins the 7th pair of ribs and hence are called false ribs because ribs generally articulate with both **thoracic vertebrae** and sternum but these ribs do not articulate with the sternum directly.

(iii) **Floating ribs (Vertebral ribs) :** The 10th and 12th pair of ribs are called floating ribs because one end of the rib is attached to the vertebral column and the other and is free. The floating ribs play an important role to protect kidneys.

RIBS AND RIB CAGE



Appendicular Skeleton : The appendicular skeleton system includes the skeleton of the limbs the pectoral and pelvic gridle which support and suspend the skeleton of limbs from the vertebral column. The girdle which supports the forelimb is called pectoral girdle and the girdle which supports the hindlimbs is called pelvic girdle. Hence, the bones of limbs, pelvic girdle and pectoral girdle constitute the appendicular skeleton.

1. The pectoral girdle provides the glenoid cavity which articulates with the head of the humerus.
2. It is also meant for attachment of the arm muscles. This protects the delicate internal organs present in these areas.

Pelvic of hip girdle

Pelvic girdle is an irregular rough-shaped supporting bone. It occurs between the hindlimbs and the axial skeleton. The pelvic girdle is attached posteriorly to sacrum. The sacrum and coccyx form the basin- shaped pelvis.

Functions of the pelvic girdle

1. The two pelvic girdle joins to form a wider hollow space called pelvis. The pelvis supports and protects the abdominal visceral structures.
2. It is the site for the attachment of leg muscles.
3. It is the site for the attachment of hind limb bones.
4. It provides strength to the sacral region.
5. It transfers weight of whole body on the hind limbs.

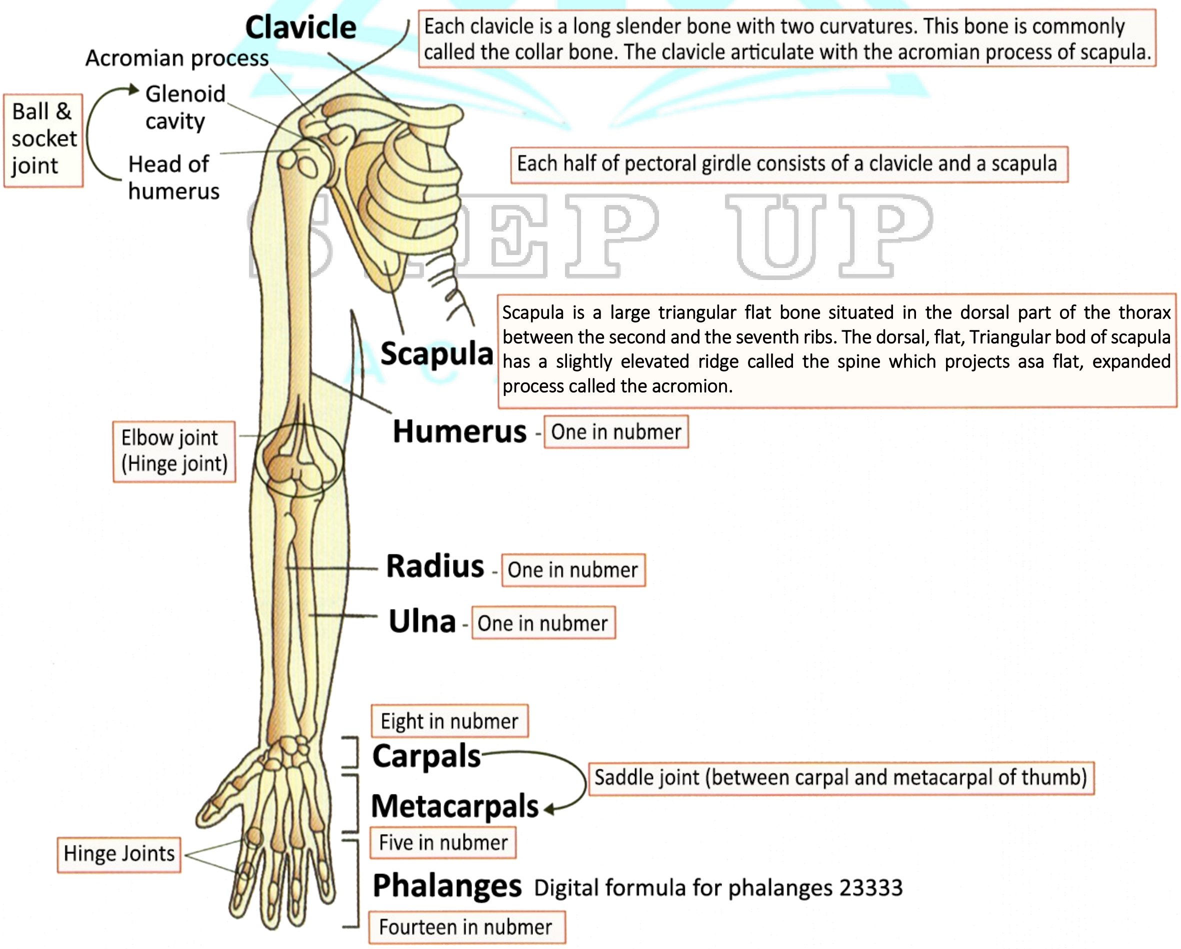
LIMB BONES

There are two pairs of limbs present in our body-forelimbs and hindlimbs. Both the forelimbs and hind limbs contain 30 bones each.

(i) **Forelimb :** In humans a pair of forelimbs are present. Each forelimb has 30 bones which form the three different parts of an arm namely upper arm, lower or forearm and hand.

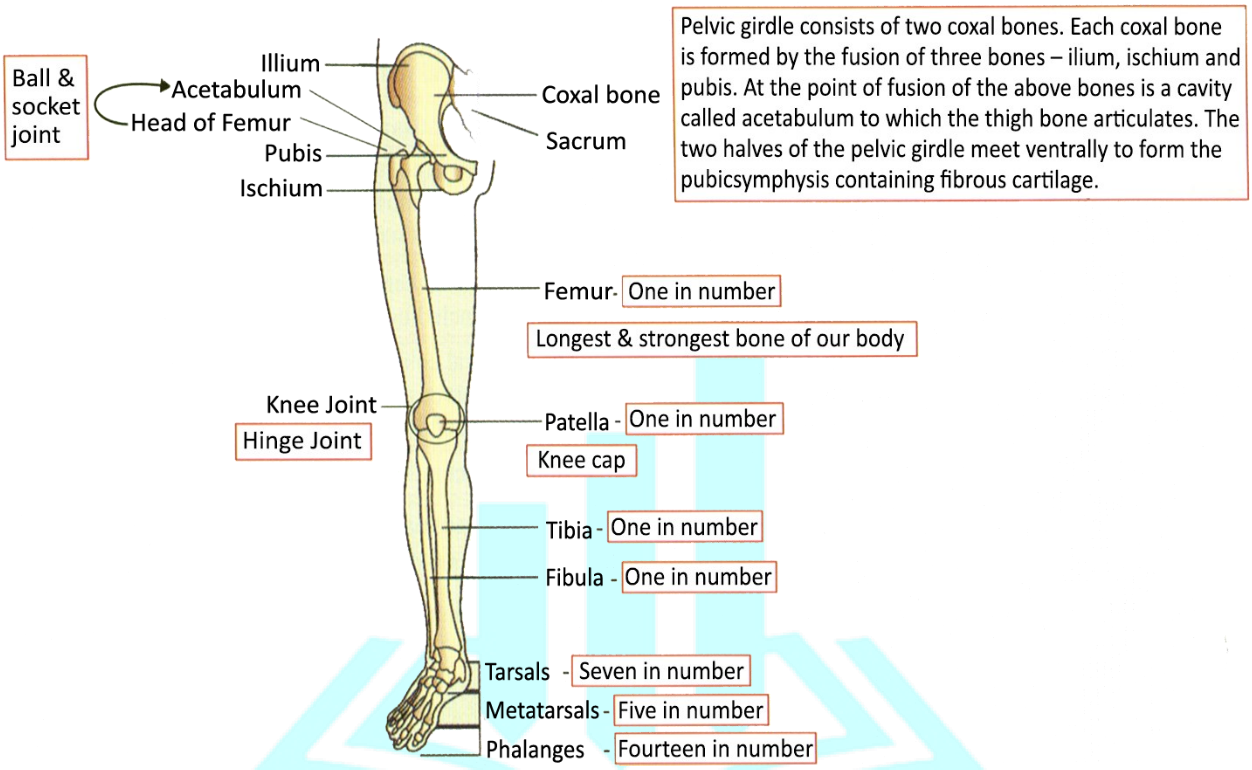
The single long bone of the upper arm is called **humerus**. The two bones present at the lower arm are ulna and radius. These two bones are either parallel or cross each other. The radius is shorter than ulna. The hand has 27 bones where 8 bones are present in wrist region, 5 bones are present in palm region and 14 bones are present in fingers. The 8 bones of the wrist are called **carpals**, the 5 bones of the palm are called **metacarpals** and the 14 bones of the fingers are called **phalanges**.

RIGHT PECTORAL GIRDLE AND UPPER ARM. (FRONTAL VIEW)



Hind limb : In humans, a pair of hindlimbs are present. Each hindlimb has 30 bones which forms thigh, shank, knee and foot. The single longest and strongest bone present in the thigh is called femur. The two bones present in the shank region are **tibia** and **fibula**. The 7 bones of the ankle are called **tarsal**, the 5 bones of the are called **metatarsal** and the 14 bones that form the those are called **phalanges**.

RIGHT PELVIC GIRDLE AND LOWER LIMB BONES (FRONTAL VIEW)



JOINTS

Joints are structural arrangement where two bones articulate i.e. meet each other. The framework of the body consists of separate skeletal elements which are joins or articulated with one another by different types of joints. They are essential for the movement of different skeletal structures i.e. all the bones present in the body produce movement due to the movement of these joints. Locomotory movements occur due to these joints where these act as lever or fulcrum.

The movability in joints varies. On the basis of movability joints are classified into three major joints

Joints
- Fibrous joint
- Cartilaginous joint
- Synovial joint
  - Ball and socket joint
  - Ellipsoid or angular joint
  - Hinge joint
  - Pivot joint
  - Gliding joint
  - Saddle joint

A. Fibrous or immovable or Fixed or Synarthroses Joint

These joints do not allow any movement because the bones are firmly fixed together by strong collagen fibres. These joints in the skull are called **sutures**. The attachment of tooth with socket in jaw is also an example of fixed joints.

B. Cartilaginous or imperfect or Amphiarthroses or Slightly Movable Joints

In these joints, the two bones are joined together with help of a disc or pad of white fibrous cartilage. The disc of cartilage restricts the movement in these joints due to which these joints show limited or slight movement. The movement in these joints are only possible because of compression of the pads of cartilage present on the articulated or ends of the bone taking part in the joints. The cartilaginous joint is present between the adjacent vertebrae of cerebral column and hence allows limited movement. They are also present in sternum, ribs, pubic symphysis etc.

Synovial or free movable or Diarthroses joints

Synovial joints are freely movable joint which allow movement in one or more directions. The bones of these joints are covered by a membrane called synovial membrane. Inside the membrane and between the two articulating surfaces of the bone, synovial cavity is present. This cavity is filled with synovial fluid that acts as a lubricant which nourishes the bones with nutrients and also acts as cushion to absorb shocks. The of the bone's movement of bones in all possible directions and also provide stability to the joint. Both the ends of the bones forming the joint is covered by hyaline cartilage called articular cartilage. It prevents the ends of the bones form being separated.

Ball and Socket joint: shoulder joint and hip joint

Hinge joint e.g. elbow joint, knee joint.

Pivot joint : e.g. joint between the radius and ulna just below the elbow and between atlas and axis.

Gliding joint : e.g. between carpals and metacarpals of human thumb.

Saddle joint : e.g. between carpals and metacarpals of human thumb.

Angular or condyloid or ellipsoid join : e.g. back and forth or side to side

Disorder of muscular and skeletal system

(i) Myasthenia Gravis : It is an autoimmune disorder affecting neuromuscular junction leading to fatigue, weakening and paralysis of skeletal muscle.

(ii) Muscular Dystrophy : It is a genetic disorder in which a protein **dystrophin** is not formed . Dystrophy is a large protein in the form of a rod that connects the thin actin filaments to sarcolemma.

(iii) Tetany : It is rapid spasm in muscle due to lesser Ca^{+2} in body fluid.

(iv) Arthritis : It is a disorder in which inflammation of the joints occur. It is characterised by pain, swelling, redness, heat.

(v) Gout : It is a type of arthritis where inflammation of joint occurs due to accumulation of uric acid crystals. Excessive formation of uric acid occurs in the body which gets deposited in the synovial joints as monosodium salt. In the patients of gout there is an error in the uric metabolism due to which over secretion of uric acid occurs.

(vi) Osteoporosis : Osteoporosis is a skeletal disorder. The loss of minerals and fibres form the matrix decreases the bone mass and causes osteoporosis.

(vii) The Rheumatoid Arthritis : It is diagnosed by the presence of rheumatoid factor (a type of immunoglobulin I_gM). The primary symptom is inflammation of synovial membrane. If it is untreated then the membrane. thickens and synovial fluid increases, exerting pressure that causes pain.

(viii) Osteoarthritis : It is a degenerative joint disease characterised by the degeneration of the articular cartilage and proliferation of new bones. Usually, affected joints are of spine, knees and hands.

(ix) Osteomalacia and Rickets : Osteomalacia called rickets when it occurs in childhood. In this disease disorder these bones contain insufficient amounts of calcium and phosphorus. The cause of kidney disease, vitamin D deficiency, and an inherited defect.

(x) **Dislocation :** A dislocation is displacement of the articular surfaces of a joint it usually involves as damage to the ligaments surrounding the joint.

(xi) Sprain and Strains : A sprain is a twisting of a joint without dislocating it. Such an injury causes damage to ligaments and also often damages tendons, muscles, blood vessels, and nerves. Severe sprains are quite painful and require immobilization during the healing process.

Chapter 18
Neural Control and Coordination

What dose coordination mean:

The function of the different organs or organ system must be coordinated to maintain a steady and stable environment inside the body. This maintenance of steady and stable internal environment is called homeostasis. So, **coordination** is the process through which two or more organs interact and complement the functions of one another.

In our body two co-ordination systems **neural system** and **endocrine system** function in a synchronized way to integrate all activities.

In our body the **neural system** and **endocrine system** jointly **coordinate** and integrate all the activities of the organs so the function in a synchronized fashion.

NEURAL SYSTEM

The neural system of all animals is composed of highly specialized cells called neurons. The neurons are also called as the nerve cells. Touch, pain, heat, cold, sound, light, smell, taste, vibrations etc. are some of the stimuli to be mentioned. There must be some structures present in our body which can detect and receive these different kinds of stimuli. This function is performed by the specialized cells called neurons which can detect, receive and transmit different kinds of stimuli. These detecting and receiving neurons are present in sensory organs which are also called receptors. Thereafter these stimuli are integrated to determine the mode of response of the living body. Different animals possess different levels of neural organizations. The neural organization is very simple in lower invertebrates. For example, in Hydra, the neurons are linked to one another forming a nerve net or plexus. The neural system is better organized in insects, where a brain is present along with a number of ganglia and neural tissues. The vertebrates have a more developed neural system having several divisions of the neural system.

HUMAN NEURAL SYSTEM

Human has an elaborate and well-developed neural system. The ability of man to control his own body is largely because of the specialized neural system. The human neural system is divided into two parts.

(a) The central neural system (CNS)

(b) The peripheral neural system (PNS)

(a) Central neural system (CNS) : The CNS lies along the central axis of the body. It includes the brain and the spinal cord. All information of the external and internal environment is received by the various sensory receptors present in the body. Thereafter, this information in transmitted to the central neural system. The CNS is the site of processing of the information reaching it. Processing the information means the interpretation and evaluation the sensory information. On the basis of evaluation of the sensory information the CNS responds accordingly and controls the body.

(b) Peripheral Neural system (PNS) : The PNS lies along the peripheries of the body. The PNS comprises of all the nerves of the body associated with the CNS (brain and spinal card). A nerve is formed by the collection of many nerve fibers. Hence, many nerve fibers or axons clustered together form a nerve. The nerves are the components of the PNS.

Types of nerve fibers of the PNS

The nerve fibers or the PNS are of two types:

(a) Afferent fibers : The afferent nerve fibers impulses form tissues/organs to the CNS. The afferent nerve fibres are also called the sensory nerve fibers. The function of these nerve fibres is to carry the sensory information from various tissues/organs of the body towards the CNS so that the CNS accordingly respond and control the body.

(b) Efferent fibres : The efferent nerve fibres transmit the regulatory impulses from the CNS to the concerned peripheral tissues/organs. The efferent nerve fibers are also called the motor nerve fibres. The function of these nerve fibres is to carry the regulatory information form CNS to the concerned peripheral tissues/organs through which the response of the body is shown.

Divisions of PNS

The peripheral neural system is further divided into two divisions:

(a) Somatic neural system

(b) Autonomic neural system

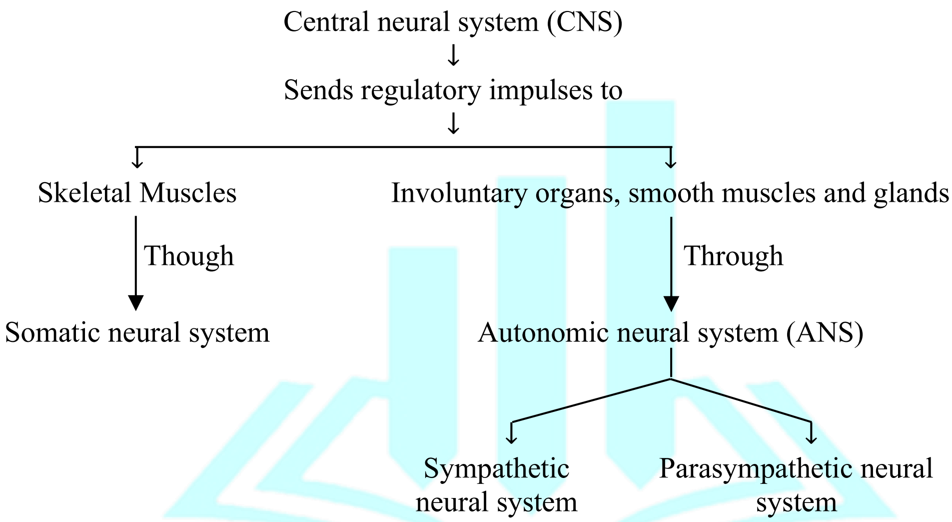
The somatic neural system relays impulses from the CNS to the skeletal (voluntary) muscles of the body. The somatic neural system consists of those efferent nerve fibers which transmit the regulatory impulses from the CNS to the concerned skeletal (Voluntary) muscle of the body.

Autonomic neural system (ANS)

The autonomic neural system is a division of the PNS which plays an important role in the fine tuning of the body's internal environment. Structurally and functionally, the ANS further classified into two separate subsystems called

(a) Sympathetic neural system

(b) Parasympathetic neural system



NEURON AS STRUCTURAL AND FUNCTIONAL UNIT OF NEURAL SYSTEM

Neurons are also called the nerve cells. Neurons are the structural as well as the functional unit of neural system. On an average the human brain is made up of more than 100 billion (10^{10}) neurons. Similarly other parts of the neural system, whether of CNS or of PNS, are structurally made up of a large number of neurons. these neurons are further inter linked with each other or are linked with other cells of the body forming complex neural connection for the exchange of neural information's.

Neurons are called the functions units of the neural system because the various functions of the neural system are basically the functions of the neurons.

Structure of a neuron

A neuron is a microscopic structure. A neuron is composed of three major parts :

(a) Cell body or soma

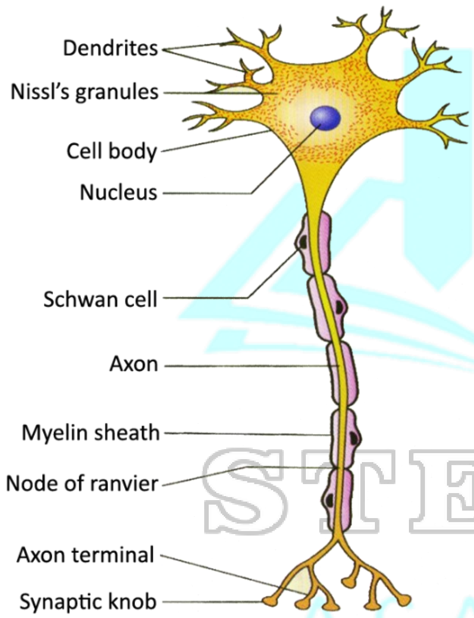
(b) Dendrites

(c) Axon

(a) Cell body: Cell body is the controlling part of the neuron. The cell body contains cytoplasm with a nucleus in the center. The cytoplasm also contains certain granular bodies called Nissl's granular bodies give a sight colour appearance to the cytoplasm of cell body. The function of Nissl's granules is supposed to be the protein synthesis in the body of neurons.

Dendrites : Form the cell body short fibers arise out. These short fibers which arise out cell body are called the dendrites. The dendrites branch repeatedly to further give rise to smaller fibers. The dendrites also contain the Nissl's granules like the cell body. The dendrites of one neuron receive the electrical impulses from different sources i.e., other neurons and then transmit these impulses towards the cell body of the neuron to which they belong.

Axon : Next major part of the neuron is the axon. The axon is also called as the nerve fibre. The axon is a long fiber which arises from the cell body. Each neuron may have many dendrites but has only one long fiber-like axon. The distal end of the axon shows branching. The distal end of the axon is divided into certain branches which are celled the axon terminals. Each axon terminal terminates as a bulb-like structure called the synaptic knob. These bulb-like structures are called the synaptic knobs because these knobs participate in the synapse formation which will be discussed later. The cytoplasm present inside the axon is called the axoplasm. The synaptic knobs also possess the axoplasm. In the axoplasm present inside the synaptic knobs numerous tiny, rounded bag-like or sac-like structures are present called as synaptic vesicles. Each synaptic vesicle contains neuro transmitter. Which are involved in the transmission of the nerve impulse form one neuron or another cell. Like the dendrites transmit the nerve impulses towards the cell body, the axons transmit the nerve impulse away from the cell body to a synapse or to synapse or to a neuromuscular junction depending upon whether the information is being sent to another neuron or to a muscle fiber respectively. Hence, the axons take away the information from the cell body of the neuron to which belong.



Types of neurons on the basis of number of axon and dendrites

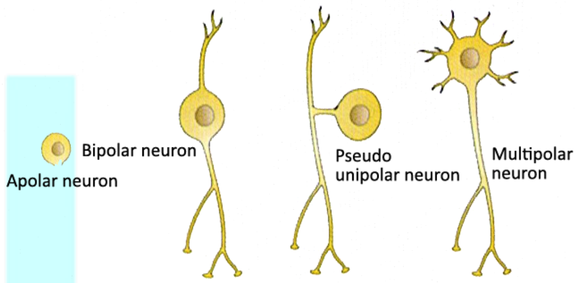
Various types of neurons are present in the human body. The neurons are divided into three major types on the basis of the number of axon and dendrites present in them.

(a) Multi polar neurons : These possess cell body with one axon and two more dendrites. These neurons are called the multi polar neurons because they possess many poles. The dendrites of these neurons transmit nerve impulses towards the cell body whereas the axon transmits nerve impulses away from the cell body. The multi polar neurons are present in the cerebral cortex.

(b) Bipolar neurons : These possess cell body with one axon and one dendrite. These are called the bipolar neurons because they possess two places. Here, also the dendrite transmits the nerve impulse towards the cell body and axon transmits the nerve impulse away from the cell body. Bipolar neurons are found in the retina layer of the eye.

(c) Unipolar neurons : These possess cell body with one axon only. No dendrites are present. These are called the unipolar neurons because they possess single pole i.e. axon. Unipolar neurons are found usually in the embryonic stage. These unipolar neurons later develop the other poles and become bipolar and multi polar.

(d) Pseudo unipolar nerve cells with the cell body on a side-branch of the main axon (e.g., cells of dorsal root ganglion).



Types of Axons on the basis of presence or absence of the Myelin Sheath

These cells spirally wrap their own plasma membranes around the axon many times to produce a series of layers called the myelin sheath. This is not a continues sheath. Certain gaps/intervals are present between adjacent sheathes of a single axon. These gaps which are present between two adjacent myelin sheaths are called the **nodes of Ranvier.**

Function of myelin sheath and nodes of Ranvier : The myelin sheath acts as a biological electrical insulation. As it is well known that the information travels through an axon in the form of an electrical impulse just like the electrical current that flows through a wire. The wrapping of the lipid-rich myelin sheath acts like a biological insulator for the flow of electrical impulse through an axon.

Non-myelinated axons/unmyelinated axons: Un myelinated nerve fibres are also enclosed by the Schwann cells. But these Schwann cells do not produce a myelin sheath around these axons. Hence, nodes of Ranvier are absent in the un myelinated axons.

Generation and Conduction of Nerve impulse

The membrane around the neuron is called the neural membrane and the membrane around the axon (part of neuron) is called the axonal membrane. The cytoplasm present inside the axon is called the axoplasm. The neurons are the structural and functional units of the neural system. The neurons are surrounded by fluid outside them called extracellular fluid. The fluid inside as well as outside the neurons possess ions like sodium ions (Na^+), potassium ions (K^+), chloride ions (Cl^-), calcium ions (Ca^{2+}) etc. Some are positively charged while others are negatively charged. Because of differential concentrations of the ions on the two sides of the axonal membrane i.e., on the inner side (towards axoplasm) and on the other side (outside the neuron) the membranes of the neurons are said to be polarized. Hence, the development of positive and negative poles across an axonal membrane makes the membrane praised.

Ion channels

The neural membrane contains a variety of passages called the ion channels. These ion channels are actually the pores formed by the proteins present in the membrane of neuron. These ion channels are selectively permeable to different ions. It means that the ion channels are not equally permeable to all the ions. The channels allow the passage of only one type of ion say Na^+ or K^+ or Ca^{2+} or Cl^- and resist others.

The Resting Potential: The Neuron at Rest

When the charge separation across the axonal membrane is maintained. the neuron is said to be at rest. This condition is called resting potential. A resting neuron is negatively charged on the inside and positively charged on the outside. Such a charge separation is called polarization and thus resting neuron is said to be polarized.

At resting potential, the axonal membrane is comparatively more permeable to potassium ions (K+) and nearly impermeable to sodium ions (Na^+). Similarly, the membrane is impermeable to negatively charged proteins present in the axoplasm. The axoplasm contains high concentrations of K^+ and negatively charged proteins and low concentrations of Na^+. In contrast the extracellular fluid contains high concentration of Na^+ and low concentration of K^+. These ionic gradients across the resting membrane are maintained by active transport of ions by the sodium-potassium pump which transports $3Na^+$ outwards for $2K^+$ into the cell on the cost of one ATP. Turns the outer surface of axonal membrane possess a positive charge while its inner surface becomes negatively charged.

EXCITING STAGE

- Once the event of depolarization occurs, a nerve impulse or spike is initiated. **Action potential** is another name of **nerve impulse.** This is generated by a change in the sodium ions channels. These channels, and some of the potassium ion channels, are known as **voltage gated channel,** meaning they can be opened or closed with change in voltage. In resting state these channels are closed due to binding of Ca^{++}.
- A potential is generated and it cause sudden opening of the sodium gates. Opening of gates increases the permeability of the axon membrane to sodium ions which enter by diffusion. This increases the number of positive ions inside the axon.
- A change of + 10mV in potential difference from RMP through influx is sufficiently significant to trigger a rapid influx of Na^+ ions leading to generation of action potential. This change of + 10 mV is called a **threshold stimulus.**
- At the point where membrane (Axolemma) is completely depolarized due to rapid influx of Na^+ ions, the negative potential is first cancelled out and become **"O"**.
- Due to further entry of Na^+, the membrane potential "over shoots" beyond the zero and becomes positive up to +30 to +45 mV.
- This potential is called as **action potential.** In this state, the inner surface of axon lemma becomes positively charged and outer surface becomes negatively charged. The rise in the stimulus-induced permeability to Na^+ is extremely short lived. It is quickly followed by a rise in permeability to K^+

REPOLARISATION

- After a fraction of second, the sodium gates get closed. Depolarization of the axon membrane causes potassium gates to open.
- Within a fraction of a second, K^+ diffuses outside the membrane and restores the resting potential of the membrane at the site of excitation and the fiber becomes once more responsive to further stimulation.
- Since potassium is positively charged, its exit makes the inside of cell less positive, or more negative and the process of repolarization or return to the original resting potential begins.
- The repolarization period returns the cell to its resting potential (-70 mV). The neuron is now prepared to receive another stimulus and conduct it in the same manner.
- The time taken for restoration of resting potential is called **refractory period,** because during the periods the membrane is incapable of receiving another impulse.
- Nerve impulse as action potential which passes along the axon as a wave of depolarization.

The whole process of depolarization and repolarisation is very fast. It takes only about 1 to 5 milli seconds (ms)

Saltatory Conduction

- This type of conduction occurs in **myelinated fiber.**
- This means, in effect that the action potential jumps from node to node and passes along the myelinated axon faster as compared to the series of small local circuits in a non-myelinated axon. This type types of conduction are called **saltatory conduction.** Leakage of ions takes place only in nodes of Ranvier and less energy required for salutatory conduction.

Transmissions of impulses

Till now you are acquainted with the generation and conduction of nerve impulses in axon. The nerve impulses generated and conducted through axons need to be transferred. An action potential passing down an axon eventually reaches the end of the axon is often branched. The branched ends of axon may be associated with either:

(i) Dendrite of other neuron or

(ii) An axon of other neuron or

(iii) A cell body of other neuron or

(iv) With sites on muscles cells or

(v) With sites on secretary cells or

Synapse : A nerve impulse is transmitted from one neuron to another through junctions called synapses. A synapse is formed by the membranes of pre-synaptic neuron and a post-synaptic neuron which may or may not be separated by a gap called synaptic cleft. Now what is the meaning of a pre-synaptic and post-synaptic neuron synaptic cleft?

Pre-synaptic neuron: Every synapse has two neurons participating in the association. That neuron which is transmitting the impulse to the other neuron and is present before the synaptic cleft is called the pre-synaptic neuron. The axon of each pre-synaptic neuron has many axon terminals each axon terminal has synaptic knob. the plasma membrane of the synoptic knob of pre-synaptic neuron acts as the pre-synaptic membrane.

Post-pre-synaptic : That neuron which is present after the synaptic cleft and is receiving the nerve impulse from the other neuron (pre-synaptic neuron) is called the post synaptic neuron. In a post-synaptic neuron dendrite axon or cell body of the post-synaptic neuron.

Synaptic cleft : The space/gap present between the pre-synaptic membrane and post-synaptic membrane is called the synaptic cleft. The synaptic cleft is nearly 10 to 20 nanometers (nm) wide in most of the synapses.

Types of synapses

There are two types of synapses namely

(a) Electrical synapses: Electrical synapses are specialized for the rapid signal transmission from one neuron to another. At electrical synapses, the membranes of per-and post-synaptic neurons are in very close proximity. The electrical current or electrical impulse can flow directly from one neuron into the other across these synapses. The transmission of an impulse across electrical synapses is very similar to impulse conduction along a single axon because no special mechanism operates at electrical.

(b) Chemical synapses: At a chemical synapse the membranes of the pre and post synaptic neurons are separated by a fluid-filled space called the synaptic cleft. Chemical synapses are the common type of synapses consisting of a bulbous expansion of a nerve terminal called synoptic knob lying in close proximity to the membrane of a post synaptic neuron.

Mechanism of Impulse Transmission Across a Chemical Synapse

The cytoplasm of the synaptic knob contains tiny, round sacs called synaptic vesicles. Each synaptic vesicle contains an many as 10,000 molecules of a neurotransmitter substance. What are neurotransmitters? Neurotransmitters are the chemicals which are involved in the transmission of nerve impulses across chemical synapses. These chemicals do not participate in the transmission of never impulses at electrical synapses.

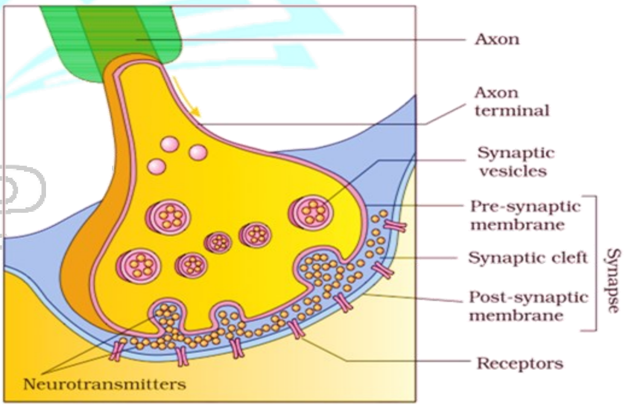


Fig. : Diagram showing axon terminal and synapse

This is a diagram of a chemical synapse showing its various part. The cut section of an axon terminal and synaptic knob is shown. The neurotransmitters are present inside the synaptic vesicles. When a wave of depolarisation reaches the pre-synaptic membrane Calcium channels (concentrated at the synapse) open up. Due to the opening of calcium channels Ca2+ diffuse inside the cytoplasm of synaptic knob form the extracellular fluid . The Ca2+, in some way stimulate the movement of synaptic vesicles towards the pre-synaptic membrane. Thereafter, the membrane of synaptic vesicles fuses with the plasma membrane of synaptic knob i.e. pre-synaptic membrane resulting in the rupture of the synaptic vesicles. This release of neuro transmitters in the synaptic cleft. These released neurotransmitters rapidly pass to the other side of the gap. This released neurotransmitters bind to their specific receptors no the post-synaptic membrane. This binding opens the ion channels in the post-synaptic neuron allowing the entry of ions. This entry of ions generates a new potential in the post-synaptic neuron. The great advantage of a chemical synapse compared with the different electrical synapse is that the nature of the messenger neurotransmitter can be different in different synapses. These different kinds of neurotransmitters permit different kinds of responses either excitatory or inhibitory in natures. The new potential developed in the post-synaptic neuron may be excitatory of inhibitory.

Step in the mechanism of transmission of nerve impulse through chemical synapse

Wave of depolarization reaches the pre synaptic membrane.

↓

Voltage-gated calcium channels open, Ca^{++} ions diffuse into the axon terminal forms the surrounding fluid.

↓

Ca^{++} stimulates fusion of synaptic vesicle which pre-synaptic membrane and release of neurotransmitter by exocytosis into synaptic cleft.

↓

Neurotransmitter bind with specific receptor molecules of post-synaptic membrane

↓

This binding opens sodium ion channels allowing the entry of Na^+ ions which can generate a new potential in the post-synaptic neuron.

↓

The new potential developed may be either excitatory or inhibitory depends upon neurotransmitter and post-synaptic membrane.

Examples of excitatory neurotransmitters: Acetylcholine, Epinephrine, Nor epinephrine Glutamate.

Examples of inhibitory neurotransmitters: Dopamine, Serotonin, Glycine, GABA.

Synaptic Delay: There is delay in the transmission of the nerve impulses at each synapse. The interval called the synaptic delay results from the time taken in releasing the neurotransmitter and in stimulating the next neuron by it.

Synaptic Fatigue: On repeated transmission of nerve impulses through a synapses there occurs a temporary suspension of impulse transmission at the synapse. This is called **SYNAPTIC FATIGUE.** It results from an exhaustion of the neurotransmitter in the synaptic vesicles of the axon terminals. After some time, the neurotransmitter accumulates again in the synaptic vesicles and the synapse regains its ability to transmit impulses.

CENTRAL NEURAL SYSTEM

CNS is the site of processing of information and control. Brain and spinal cord comprise the central neural system.

The structures of the CNS arise from its embryological components.

Pros encephalon

(i) Becomes the thalamus and hypothalamus components. **(diencephalon)**

(ii) The cerebral cortex, cortex, corpus striatum, hippocampus and amygdala **(telencephalon).**

Mesencephalon

Becomes mid brain.

Rhombencephalon develops into

(i) The medulla (myelencephalon)

(ii) The pons and cerebellum (mesencephalon)

Human Brain

The brain is the central information processing organ of our body. it acts as the 'command and central system of the body. This is because all systems in the body follow the commands given to them by the brain. The commands are delivered through the nerves.

Structure of human brain

Brain has a soft and delicate structure and looks like a walnut. It has wrinkled surface. The human brain is well protected by the skull. The skull is composed of two site of bones-cranial and facial. Cranial bones are eight in number and they form the hard protective outer covering cranium for the brain (The facial region is made up of 14 skeletal elements which from the front part of the skull) Insides the skull the brain is covered by protective layers called the **cranial meninges** (singular : meninx) which are three in number.

Cranial meninges :

(i) Duramater (Latin: Hard mother) : It is the other layer of the cranial meninges. It is thick and tough layer made up of a tough connective tissue called fibrous tissue.

(ii) Arachnoid: It is the middle meninge. It is a very thin layer made up of delicate connective tissue.

(iii) Piamater (Latin: Soft mother) : It is the inner meninge which is in contact with the brain tissue. It is also a thin layer and highly vascular.

Subdural space: A very narrow space the exists below duramater or between the duramater and arachnoid membrane is called the subdural space.

Subarachnoid space : A narrow space than exists below arachnoid membrane or between arachnoids membrane and piamater is called subarachnoid space. The subarachnoid space contains the cerebrospinal fluid (CSF). Structurally, the human brain can be divided into three major parts: forebrain, midbrain and hindbrain

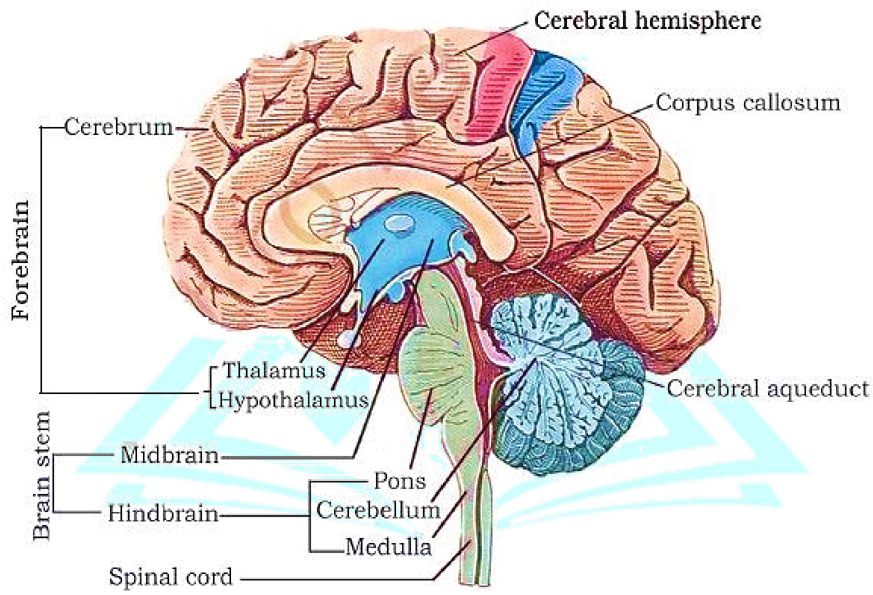


Fig. : Diagram showing sagittal section of the human brain

(i) Forebrain : The forebrain is front portion of the brain. The forebrain forms the major part of the brain and consists of cerebrum, thalamus and hypothalamus.

A. Cerebrum : Cerebrum is the most prominent portion of the forebrain as well as form the major part of the human brain. Cerebrum is a spherical structure and made up of two large, deeply convoluted (folded) part called cerebral hemispheres. These two halves. As this deep cleft passes longitudinally divides the cerebrum into two halves. As this deep cleft passes longitudinally through the cerebrum the two cerebral hemispheres formed are called the left and right **cerebral hemispheres.**

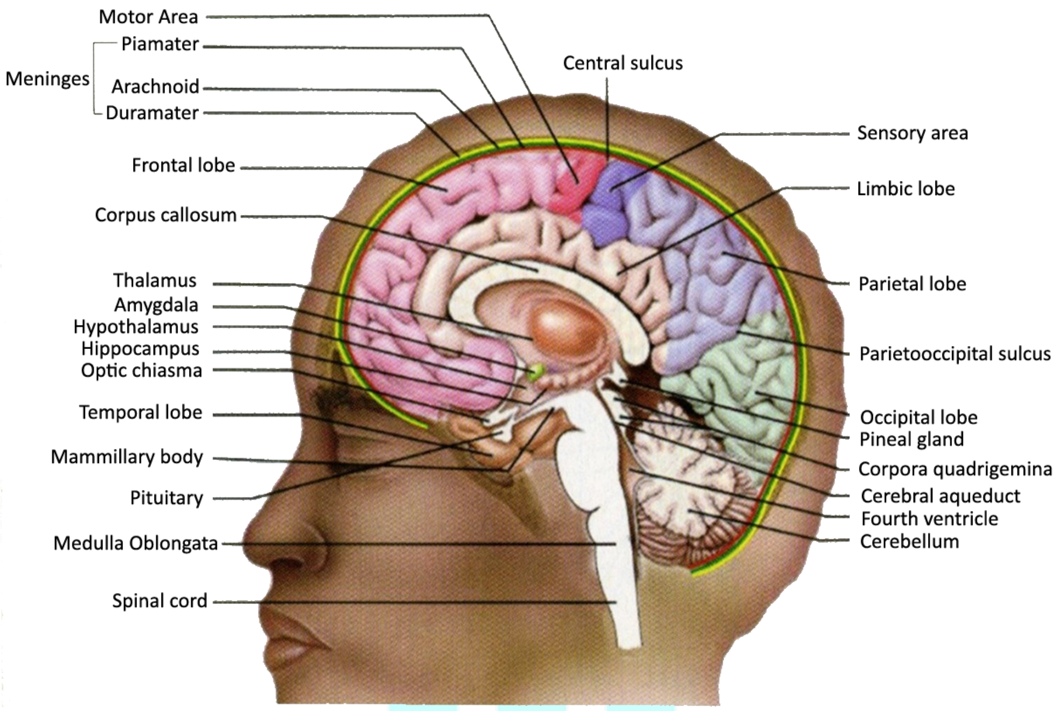
Each cerebral hemisphere is further divide into four lobes-frontal, parietal, occipital and temporal. Hence there are 2 frontal lobes, 2 parietal lobes, 2 occipital lodes and 2 temporal lobes in our cerebrum.

Did You Know?

Each lobe of the cerebrum serves different functions.

1. The **frontal lobe** is where your creative ideas originate and the translation of perceptions and memories into plans of muscle movement takes place. The voluntary motor activities are also under the control of frontal lobe of cerebrum.
2. The **parietal** lobe is where feelings about touch, hot and cold and pain are registered. It is this area that allows you to accurately follow directions on map, reading a clock or dressing yourself. These sensory massages, received by the parietal lobes of brain are organised and then directed to the frontal lobes for the appropriate muscle action.
3. The **temporal** lobe is where sounds are interpreted so that you can understand what is being spoken. Hence, temporal lobes help in decoding and interpretation of sound.
4. The **occipital** lobe reports the sensation of light. This area is not only related with receiving the sensations of light nut also with decoding the visual information (i.e., size shape and colour) of an object/ event. This information is then interpreted as what is being seen on the basis of previous memory and experience.

A SECTION OF HUMAN BRAIN



Corpus callosum : The left right cerebral hemispheres are connected to each other by about 10 cm long bundles of nerve fibres (about 200 million). The bundles of nerve fibres inside the CNS (brain and spinal cord) are called the tracts. Hence, we can say that the left and right cerebral hemispheres are connected to each other by a tract of nerve fibres. This tract if nerve fibres which connects the two cerebral hemispheres is called the **corpus callosum.** The anterior part of corpus callosum is curved and is called **genus** while the posterior part is called **splenium**. Each cerebral hemisphere is divided into four lobes. These are the **frontal** at the front the **parietal** towards the top of the head, the **temporal** on the side and the **occipital** at the rest.

Cerebral cortex (Gray matter) : The outer surface of cerebrum called the **cortex** is a layer only 2-4 millimeters thick. Because the six layers of it are packed with ten billion (10^9) pyramidal, spindle and stellate neurons with a greyish brown appearance, it is referred to as **grey matter.** The cerebral cortex contains roughly 10 percent of all neurons of brain. Much of the neural activities occur here e.g., from the touch of a feature to the movement of an arm. Unlike mouse brain, human brain is greatly convoluted. those convolutions or folds consist of sulci (sing. Sulcus : small groove), **fissures** (large grooves), and gyri (sing. Gyrus: bulge between adjacent sulci or fissures). These greatly enlarge the surface area of the cortex. in fact, two-thirds of the surface of the cortex is hidden in the sulci and fissures. Thus, their presence triples the area of the cerebral cortex. Beneath this run millions of axons comprising nerve fibre tracts, connecting the neurons of cerebral cortex with those located elsewhere in the brain. The large concentration of myelin gives this tissue and opaque white appearance. Hence, they are referred by the term **white mater.** By examining the effect of injuries or lesions and the effect of electrical stimulation on the behavior, it has been possible to map roughly the location of its various associative on the cerebral cortex. Each area is referred to as a specilised cortex.

Basal Ganglia: The inside of human brain is not so densely packed, but there are all kinds of different collections of neurons called **nuclei**, each with its pacific functions. These control different body activities automatically. **Basal ganglia** are a collection of **subcortical nuclei** in the forebrain at the base of the cortex. The largest nucleus in it the **corpus striatum.** It regulates planning and execution of stereo typed movement. Other basal ganglia perform at subconscious level lamed pattern of movement like slow and fast pedaling slow and fast writing/typing, etc.

The cerebral cortex contains three major types of areas :

(a) Motor areas

(b) sensory areas

(c) Association areas

Sensory areas receive the various types of sensations. Motor areas are concerned with the movement of skeletal elements. Association areas of cerebral cortex are neither clearly sensory nor motor in function. These association areas are responsible for certain complex functions like :

B. Thalamus: The cerebrum wraps around a structure called the thalamus. The thalamus is the "relay centre" of the cerebral cortex. It means sensory messages reaching the brain must pass through the thalamus in order to be sensed consciously, all motor messages delivered through the brain must pass through the thalamus. Hence, thalamus acts as a major coordinating center for sensory and motor signaling.

C. **Hypothalamus:** As the name implies hypothalamus nestles at the base of the thalamus and so of the brain. It is another very important part of the forebrain or brain. Hypothalamus serves a number of functions which are described as follows:

(i) The hypothalamus contains a number of centers which control body temperature, urge for eating and drinking, sexual drive, rage, anger, etc. it keeps the body temperature at roughly 37^{0} C by means of a complex thermostat system. It keeps the water content of the body constant by controlling the amount of urine and by controlling the thirst. Similarly, it controls the hunger by arousing the hunger pangs so that the person becomes aware of need of eating. The sexual drive, feeling of satiety (satisfaction), expressions of love, anger, rage, fear etc., are also controlled by the hypothalamus.

(ii) The hypothalamus not only has nervous activity, but also controls the **endocrine functions.** The hypothalamus contains several groups of neuro secretory cells, which secrete hormones. These cells are called neurosecretory cells because these are in fact the **hypothalamus neurons** which produce the hormones. The hormones secreted by hypothalamic neurons or neurosecretory cells are called the hypothalamic hormones. The hypothalamic hormones pass the axons of these neurons, anti-diuretic hormone (ADH) are some of the hypothalamic hormones. These hormones then control various bodily functions like growth, reproduction, urine concentration, etc.

Limbic system : The inner parts of cerebral hemispheres and a group of associated deep structures like amygdala, hippocampus, etc., from a complex structure called limbic lobe or limbic system. The limbic system looks like a wish bone or a fork. Along with the hypothalamus the limbic system is involved in the regulation of various aspects of human behavior. The various aspects of human behavior like regulation of sexual behavior, expression of emotional reactions (e.g., excitement, pleasure, rage and fear) and motivation etc. are the main functions of the limbic system performed with the hypothalamus. **Amygdala**, an almond shaped part of the brain controls the mobs, especially anger and rage, **Hippocampus** makes the lower portion of the limbic fork. The hippocampus deals with a strange mix of signals about smells and memories. The hippocampus function as a kind of index for recall of an event with its associated memory and converts information from short-term to long-term memory, essential in learning.

Midbrain: The midbrain is present between the thalamus/hippocampus of the forebrain and pons of the hindbrain. The dorsal portion of the midbrain consists mainly of four round swelling or lobes. These four lobes are collectively called the **corpora quadrigemina.** These four lobes in the mid brain are arranged such that two are present of the upper side and two are present on the lower side. The two upper lobes are called the **superior colliculi** whereas the lower lobes are called the **inferior colliculi**. The superior pair of colliculi receive sensory impulses from the eyes and muscles of the head and control **visual reflexes.** They control and coordinate the movement of the head and eye at the same time to fix and focus on an object.

A canal called cerebral aqueduct passes through the midbrain. This canal is a part of the ventricle system of the brain. Ventricles are the cavities present within the brain. There are four cavities present

within the brain that are called cerebral ventricles. The cerebral aqueduct is a canal that passes through the midbrain and connects the third ventricle with the fourth ventricle of the brain. Cerebral aqueduct is also called iter. The cerebrospinal fluid (CSF) finds its natural pathway through the cerebral ventricles and the canals connecting these ventricles.

Hindbrain : This is the posterior most part of brain, that is why it is called the hindbrain. The hindbrain comprises the pons, cerebellum and medulla oblongata.

Pons : Pons (Latin meaning : the bridge) consists of fibre tracts (remember that are the bundles of nerve fibres in CNS) that interconnect different regions of the brain. As the tracts of pons connect various regions of the brain, this is the reason for its name pons that literally means a bridge. Pons mainly acts as a neural link between the cerebral cortex and the cerebellum. A centre present in pons called penumotaxic centre can moderate the functions of the respiratory rhythm centre located in the medulla oblongata. Neural signal from the peneumotaxic center can reduce the duration of the inspiration phase and thereby can alter the rate (speed) of respiration.

Cerebellum : Cerebellum is the second largest part of the brain after the cerebrum. The word cerebellum simply means “little cerebrum”. The cerebellum is also made up two cerebellar hemispheres and a vermis and has its gray matter on the outer side and white matter on the inner side. Cerebellum has very convoluted surface in order to provide the additional space for many more neurons.

Functions of cerebellum : The cerebellum does not initiate the movements of the body but modulates or reorganizes the motor commands. Its most important function seems to be coordinating **locomotor activity** in the body which is actually initiated by the impulses arising in the motor area of the forebrain.

Medulla oblongata: Medulla oblongata is the posterior most part the connects various parts of the brain and the spinal cord. Though small in size, it is absolutely essential to life. The medulla contains. centres which control **respiration, cardiovascular reflexes** and **gastric secretions.**

To control respiration, there is a centre present in the medulla which is called the **respiratory rhythm center.** The function of this centre is to maintain the respiratory rhythm to suit the demands of the body.

The gastric secretions, i.e., the secretions of gastro-intestinal tract are also under the neural control of medullar.

Brain stem : Midbrain and hindbrain form the brain stem.

Ventricles of the Brain and Cerebrospinal Fluid

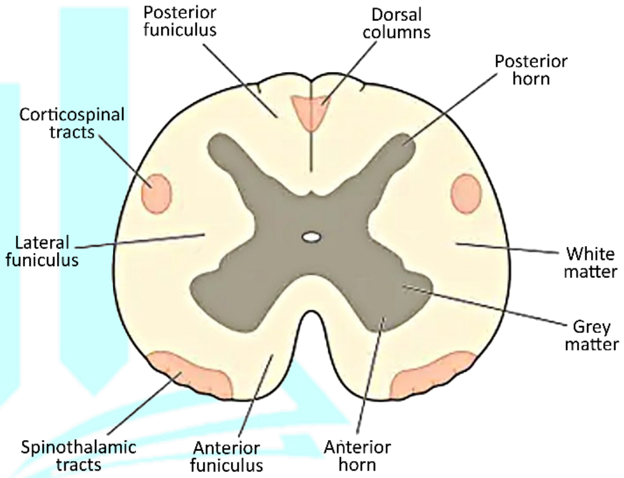
The ventricles consist of four hollow fluid filled spaces inside the brain. A lateral ventricle lies inside each hemisphere of the cerebrum. Each lateral ventricle is connected to the third ventricle by an **interventricular foramen (foramen of Monro).** The third ventricle consists of a narrow channel between the hemispheres through the area of the thalamus. It is connected by the cerebral aqueduct or aqueduct of Sylvius of iter in the midbrain portion of the brain stem to the fourth ventricle in the pons and medulla. The fourth **ventricle** continues with the central canal of the spinal cord. Three opening in the roof of the fourth ventricle, a pair of **lateral apertures** (foramina of Luschka) and a **median aperture** (foramen of **Magendie**) allow cerebrospinal fluid to move upward to the subarachnoid space that surrounds the brain and spinal cord.

The cerebrospinal fluid is secreted by anterior choroid plexus and posterior choroid plexus and is found inside.

The ventricles of the brain, the central canal of the spinal cord. The cerebrospinal fluid acts as a shock absorber for the brain and spinal cord and may also nourish brain tissue. It contains protein, glucose, chloride and water.

Spinal Cord

Spinal Cord is the other region of the CNS. In an adult human being, spinal cord is about 42-45 cm long and 2 cm thick. Spinal Cord is a glistening white cord which runs from the base of the brain down through the backbone.



A cross-section of the spinal cord reveals that only the outer portion the "white matter" of the cord is white. The inner portion is "gray matter". Running vertically through the gray matter is a central canal filled with CNF. This central canal connects with the cavities (ventricles) of the brain which are also filled with this fluid.

Reflex Pathway or Reflex Arc

Which structures in our body participate in the reflex action? This question can be answered by studying the reflex pathway or reflex arc. In a particular withdrawal reflex discussed above, the following actions are carried out:

1. The stimulus is detected by sensory receptors present in the skin

↓

2. These initiate nerve impulses in the sensory or afferent neurons leading form them to the spinal cord.

↓

3. These impulses enter the spinal cord and initiate impulses in more interneurons.

↓

4. Interneurons initiate impulses in one or more motor of efferent neurons.

↓

5. The motor neurons then early these imposes to the effectors or skeletal muscles in which response will be shown.

↓

Peripheral Nervous system

(A) Cranial Nerves

There are 12 pair of cranial nerves

I

II

III

IV

V

VI

VII

VII

IX

X

XI

XII

(B) Spinal Nerves : In man there are 31 pairs of spinal nerves. They are classified into groups They include 8 pairs of cervical nerves, 12 pairs of thoracic nerves, 5 pairs of lumbar nerves, 5 pairs of sacral nerves, and one pairs of coccygeal.

SENSORY RECEPTION AND PROCESSING

The sensory organs detect all types of change occurring in the environment and send appropriate signals to the CNS, where all inputs are processed and analysed.

Like the decoding of visual information occurs in the occipital lobe. Hence a kind of filtration of incoming signals is done and then they are sent to different centres of the brain.

(1) According to their position :

(i) Exteriorecptors - The external sense organs which receive the stimuli form outer environment

(ii) Proprioreceptors - Simple receptors present in joints, skeletal muscles, tendons etc. They receive not in direct contact with environment but are affected by the changes in the environment.

(iii) Visceroreceptors or **internal receptors** - The receptors present within the viscera. They receive stimuli originating within the body itself. They are simple and mostly represented by free nerve endings. perception is conscious awareness and interpretation of sensation.

(2) **According to the form of stimulus they receive,** the sense organs are classified into following types given in the table.

Tangoreceptors - They are the sense organs for touch, pressure, pain, heat or cold. They are located in the skin and include:

(i) Meissner's corpuscles: They are present immediately below the epidermis and receive the stimulus of touch/gentle pressure.

(ii) Pacinian corpuscles: Situated deep in the dermis of skin, joints, tendons and muscles. Each corpuscle has a nerve ending surrounded by connective tissue. They respond to pressure changes.

(iii) Merkel's disc occurs in the epidermis and are responsible for touch.

Name of Receptor	Types	Stimulated by	Examples
1. Mechanoreceptors (for mechanical stimuli)	(i) Tangoreceptors	Touch and pressure	Meissner's corpuscle, Merkel's Disc Basket Nerve ending, Pacinian Corpuscles
	(ii) Phonoreceptors	Sound waves	Organ of Corti in internal ear
	(iii) Statoreceptors	Angular and linear	Cristae and Maculae in internal ear
	(iv) Algesirecepotors	Pain	Free nerve endings
	(v) Proprioreceptors	Position of parts of body	Golgi-Mazzoni organs
	(vi) Rheoreceptors	Pressure and water currents	Lateral line sense organs in fish. (neuromast cells)
2. Photoreceptors (for visual stimuli)		Light wavelengths	Ommatidia in compound eyes of Arthropods
3. Chemoreceptors	(i) Gustato-receotors	Taste due to chemicals in solution	Taste buds of tongue
	(ii) Olfactory-receptors	Smell due to volatile chemicals	Olfactory epithelium
4. Thermoreceptors	(i) For cold	Low temperature (10-20°C)	End bulb of Krause in Skin
	(ii) For Heat	High Temperature 25-40°C)	Ruffian's organs in skin.

EYE

Our paired eyes are located in the sockets of the skull called orbits. Each eye weighs roughly 7 grams.

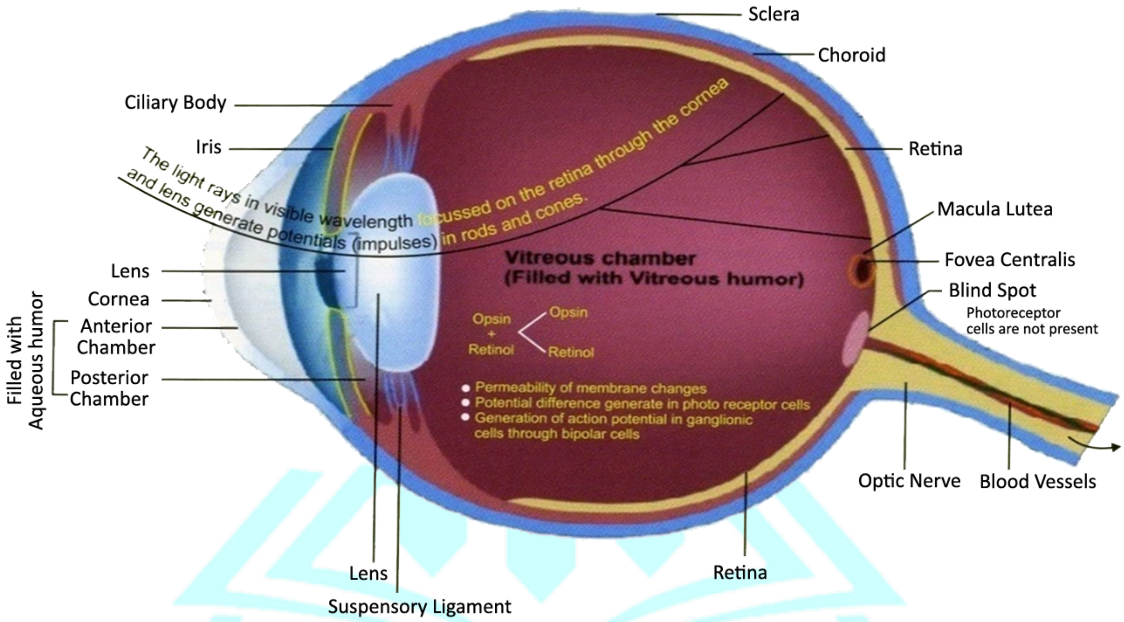
Structure of Human Eye

The adult human eyeball is roughly/nearly a spherical structure. The wall of the eyeball is composed of three concentric layers. The external layer is called sclera, middle layer is choroid and inner layer is called retina.

Sclera

Sclera is composed of a dense connective tissue and that is why it is a tough layer. It is milky white in colour (the "white" of the eye) except in the front. Here it forms the cornea which is transparent. Cornea is a dome shaped structure. The curved surface of the cornea acts as a refracting structure.

Therefore, cornea admits the light rays into the interior of the eye and bands the light rays so that they can be brought to a focus. The surface of the cornea is kept moist and dust-free by the secretion from the tear glands.



Choroid

The choroid layer in thin over the posterior two-thirds of the eye-ball but is becomes thick in the anterior part from the ciliary body. The ciliary body itself continues forward to form a pigmented and opaque structure called the iris. Iris is the visible coloured portion of the eye and is responsible for black, brown, green or blue "colour" of the eye. An opening or aperture is surrounded by the iris. This aperture is called the pupil. The diameter of the pupil is regulated by the muscle fibres of iris called iridial muscle. The size or the diameter of the pupil is variable and is under automatic control. In dim light, the pupil or the aperture enlarges, letting more light into the eye. In bright, the pupil narrows down.

Retina

The inner coat of the eyeball is the retina. It contains the actual light receptors, the rods and cones, and thus retina functions in the same way at the film of a camera does. Retina contains three layers of cells from inside to outside- ganglion cells, bipolar cells and photoreceptor cells. There are two types of photoreceptor cells, namely, rods and cones. These cells contain the light-sensitive proteins called the **photopigments.**

The retina consists of a pigment epithelium (nonvisual portion) and a neural portion (visual portion). the **pigment epithelium** is a sheet melanin-containing epithelial cells that lies between the choroid and the neural portion of the retina some histologists classify it as part of the choroid rather than the retina. Melanin in the choroid and the pigment epithelium absorbs stray light rays, which prevents reflection and scattering of light within the eyeball. This enables that the image cast on the retina by the cornea and lens remains sharp and clear. The pigments layer is continuous over choroid, ciliary body and lens remains sharp and clear. The pigmented layer is continuous over choroid, ciliary body and iris while the nervous layer terminates just before ciliary body. This point is called **Ora serrata. Albinos lack melanin pigment in all parts of the body, including the eye.**

Rods

There are approximately 100 million rods in each eye. Rode are used chiefly for vision in dim light that is why dim light (scotopic) vision is the function of the rods. For the light to be absorbed, there must be a light absorbing substance, a pigment. This light-absorbing pigment is called the photopigment. The rods contain a purplish-red protein called the **rhodopsin** or **visual purple.** The rhodopsin pigment is incorporated in the membranes of rods.

Cones

Unlike the rods, cones operate only in the bright. Furthermore, they enable us to see colours. Hence, the day light (photopic) vision and color vision are functions of cones. In the human eye, there are three types of cones which possess their own characteristic photopigments that respond to red, green and blue lights. the photopigments of cones are called cone pigments. Retinal is the prosthetic group for each of these. It is differences in the protein, opsin, to which the retinal is attached those accounts for the difference in absorption. Red, green and blue are the three primary colours.

Bipolar cells

Next to the layer of photoreceptor cells is the intermediate layer of short-sensory bipolar cells.

Bipolar cells are in fact the bipolar neurons (remember earlier we discussed that the bipolar neurons are present in the retina of eye) which have cell body with one axon and one dendrite.

Ganglion Cells

Inner to layer of bipolar cells, is the layer of retina ganglion cells. Bipolar cells synapse with the retinal ganglion cells. The axons of the retinal ganglion cells bundle together as the optic nerve.

Aqueous and Vitreous Chamber

The iris and lens divide the interior of the eyeball into two main chambers. The anterior between the cornea and the lens and is called the aqueous chamber. Hence, aqueous chamber is the space between the cornea and the lens. Aqueous chamber is filled with a thin watery fluid called the aqueous humor. This aqueous humor is finally drained into the blood. The posterior chamber is present between the lens and the retina. Vitreous humor is not drained out of the eye. Its function is supporting the eyeball.

Mechanism of Vision

Light rays in visible wavelength focused of the retina.

↓

Activation of photopigment of rods and cones.

↓

Light induces dissociation of the retinal from opsin resulting in the changes in the structure of the opsin.

↓

Membrane permeability of rods and cones changes.

↓

Potential difference generated in the photoreceptor cell.

↓

It generates action potential in the ganglionic cells through the bipolar cells.

↓

Action potentials are transmitted by the optic nerve to the visual cortex of brain.

↓

Image formed on the retina is recognized based on earlier memory and experience.

Disorders of Eye :

(1) **Myopia** or **Nearsightedness:** In this case, the eyeball is antero-posteriorly elongated so that the image of distant object is formed in front of yellow spot. The defect can be removed by using **concave glasses.**

(2) **Hypermetropia** or **long slightness:** The person can see distant objects clearly, but not those which are closer. This is due to antero-posterior shortening of the shortening of the eyeball, so that images are formed behind the yellow spot. The defect can be overcome by using **convex lens.**

(3) **Presbyopia :** A common defect in old age people due to the loss of elasticity of lens and reduced power of accommodation. The disorder can be corrected can be corrected by convex lenses.

(4) **Astigmatism:** The disorder due to rough curvature of cornea or lens which can be corrected by the use of **cylindrical glasses.**

(5) **Cataract :** The sight is impaired due to the lens becoming opaque. The defect can be cured by surgical removal of the defective lens.

(6) Glaucoma : It occurs due to increase in intra-ocular pressure as may develop due to blockage of chant of column. It exerts pressure on optic nerve causing its damage. Its damage. It leads to permanent blindness (Kala Motia).

EAR

Just now we discussed the structure of eye and the mechanism of vision. As the light traces in the form of **light rays,** similarly the sound travels in the form of **sound waves.** Ears are the sensory organs that detect and receive the sound waves and convert them into the nerve impulses hence help in hearing. However, hearing in not the sole function of the ears. The ears also maintain the body balance or body equilibrium. So, the ears perform two sensory functions :

(i) Hearing.

(ii) Maintenance of body balance.

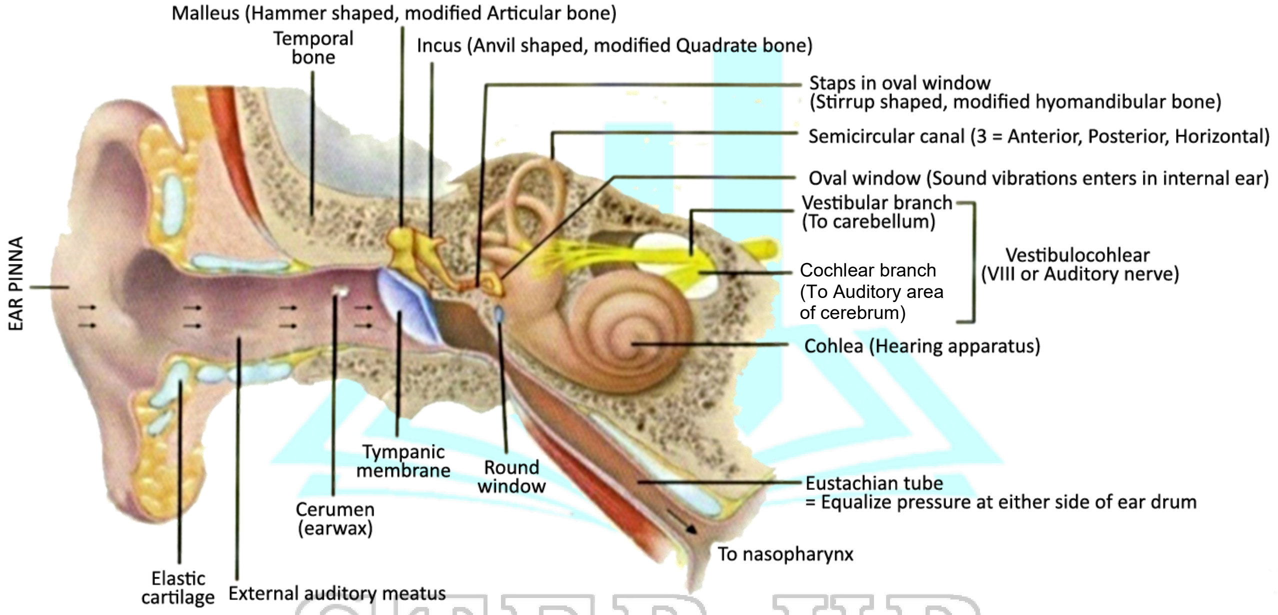
Structure of human ear :

Anatomically, the ear can be divided into three major sections called

(a) The outer ear

(b) The middle ear

DIAGRAM SHOWING PARTS OF AN EAR



outer ear consists of the **pinna** and **external auditory meatus** (canal). The pinna collects the vibrations in the air which produce sound. The external auditory meatus leads inwards and extends up to the **tympanic membrane** (the **ear drum**). There are very fine hairs and wax-secreting gland in the skin of the pinna and the meatus. The tympanic membrane composed of connective tissues covered with skin outside and with mucus membrane inside. The middle ear contains three ossicles called **malleus, incus** and **stapes** which are attached to one another in a chain-like fashion. The malleus is attached to the tympanic membrane and the stapes is attached to the **oval window** of the cochlea. The ear ossicles increase the efficiency of transmission of sound waves to the inner ear. A **Eustachian tube** connects the middle ear cavity with the pharynx. The Eustachian tube helps in equalizing the pressures on either sides of the ear drum.

The fluid-filled inner ear called **labyrinth** consists of two parts the bony and the membranous labyrinths. The bony labyrinth is a series of channels. Inside these channels lies the membranous labyrinth, which is surrounded by a fluid called perilymph. The membranous labyrinth is filled with a fluid called endolymph. The coiled portion of the labyrinth is called **cochlea**. The membranes constituting cochlea the Reisner's and basilar divide the surrounding perilymph filled bony labyrinth into an upper scala vestibuli and a lower scala tympani (Figure 21.8). The space within cochlea called scala media is filled with endolymph. At the base of the cochlea, the scala vestibuli ends at the oval window, while the scala tympani terminates at the round window which opens to the middle ear.

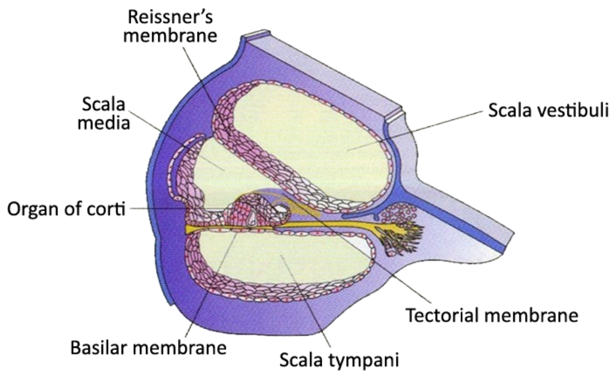


Fig. Diagrammatic representation of the sectional view of cochlea

The **organ of corti** is a structure located on the basilar membrane which contains **hair cells** that act as auditory receptors. The hair cells are present in rows on the internal side of the organ of corti. The basal end of the hair cell is in close contact with the afferent nerve fibres. A large number of processes called stereo cilia are projected from the apical part of each hair cell. Above the rows of the hair cells is a thin elastic membrane called **tectorial membrane.**

The inner ear also contains a complex system called **vestibular apparatus** located above the cochlea. The vestibular apparatus is composed of three **semi-circular canals** and the **otolith** (macula is the sensory part of saccule and utricle). Each semi-circular canal lies in a different plane at right angles to each other. The membranous canals are suspended in the perilymph of the bony canals. The base of canals is swollen and is called ampulla, which contains a projecting ridge called **crista ampullaris** which has hair cells. The saccule and utricle contain a projecting ridge called **macula**. The crista and macula are the specific receptors of the vestibular apparatus responsible for maintenance of balance of the body and posture.

Mechanism of Hearing

After you are familiarized with the structure of the ear, the next step is to study the mechanism of the hearing. How do ears convert sound waves into neural impulses, which are sensed and processed by the brain enabling us to recognise a sound?

The external ear collects and receives the sound waves and directs them to the ear drum or the tympanic membrane. The sound waves travel through the external auditory canal. After receiving the sound waves, the membranous ear drum vibrates in response. These vibrations generated in the ear drum are then passed onto the three ear ossicles (malleus, incus and stapes) in the middle ear. The ear ossicles increase the intensity of the sound vibrations and transmit them to the oval window. As we discussed earlier that the membrane covering the oval window acts like the door to the inner ear, i.e., to the labyrinth. When sound vibrations pass through the oval window to the cochlea, they generate waves in the lymph's present in the cochlea. Firstly, the waves are generated in the perilymph present in the scala vestibule. This is because scala vestibuli is indirect contact with oval window through which the sound vibrations are entering the inner ear. Afterwards the waves are transmitted to the endolymph present in the scala media. The sound vibrations generated in the endolymph of the scala media induce the ripple in the basilar membrane of the scala media.

External ear receives sound waves
↓
Directed towards the ear drum
↓
When the waves strike the tympanic membrane the alternate compression and decompression of the air cause the membrane to vibrate
↓
Vibration are transmitted through the ear ossicles (M → I → S) to oval window
↓
The movement of the oval window set up wave in the perilymph of scala vestibuli
↓
Vibration of endolymph of scala media
↓
The waves in the endolymph a ripple in the basilar membrane
↓
Basilar movements bend the hair cells pressing them against the tectorial membrane
↓
Nerve impulse generated in the associated afferent neurons
↓
Impulse transmitted to auditory region of brain via auditory nerve
↓
Impulse gets analyzed and sound recognized

Mechanism of maintaining the body balance :

Similarly, the static and dynamic balance are maintained whenever the body is tilted or displaced. The hair cells present in the macula and crista bend in response to the change in the position of head and this generates impulses in the afferent nerve fibres associated with the hair cells of macula and crista. These nerve impulses are then transmitted through the **vestibular branch** of the auditory nerve to the cerebellum of brain where these impulses are analyzed. The cerebellum processes this data and coordinates muscle movement in conjunction with the cortex and sends impulses to the muscles to adjust accordingly.

Chapter 19
Chemical Coordination and Integration

Introduction:

This cellular regulation is carried out by chemical messengers called hormones. hormones released by them form the endocrine system. The endocrine glands release their secretions directly into the blood and through blood these secretions reach each and every cell or the body and regulate their functions. Thus, both endocrine system and nervous system controls internal communication and regulates physiological functions of the animal body.

ENDOCRINE SYSTEM

'Endo' means within and 'krine' means to secrete, therefore endocrine system is a system of isolated glands which secrete chemicals called 'hormones' directly into lymph or venous blood for transport to target tissues, often located away from the site of secretion.

Hormones are defined a non-nutrient chemical which act as intercellular messengers they are produced in trace amounts.

Properties of Hormones

The hormones are secreted by living glandular endocrine cells and some other diffused tissues/cells.

These are released directly into the blood and are transported to different cells of the body through the circulatory system.

These are required in quantities.

HUMAN ENDOCRINE SYSTEM

The endocrine glands and hormone producing diffused tissue/cells located in different parts of our body constitute the endocrine system. It includes pituitary gland, pineal gland, thyroid gland, adrenal glands, pancreas, parathyroid glands, thymus and gonads (testis males and Ovary in females). In addition to these glands, certain other organ, e.g., gastrointestinal tract, liver, kidney, heart also produce hormones. In the following chapter we would look into the details of the above-mentioned endocrine glands and the hormones released by them.

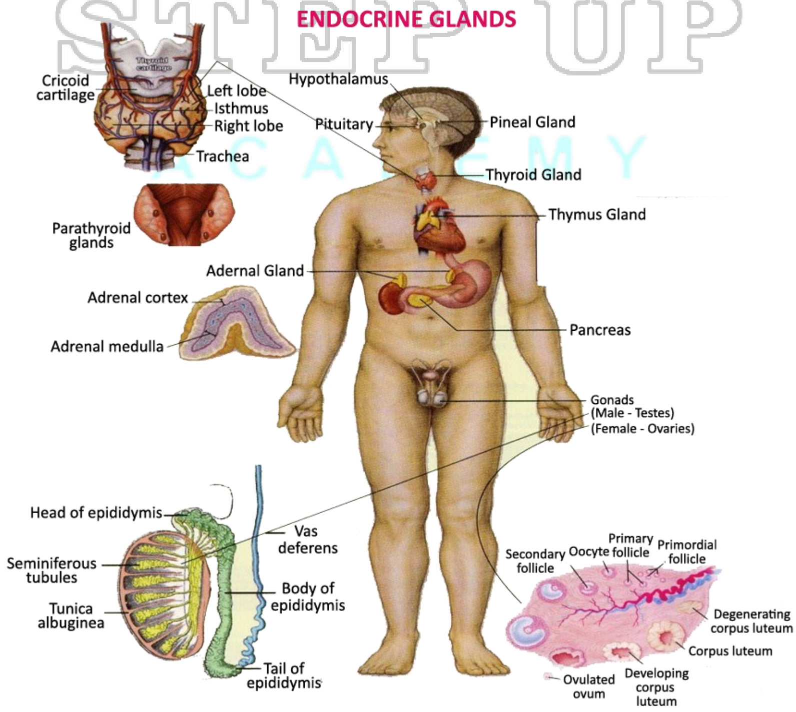


Fig. : Location of endocrine glands

1. **Hypothalamus**

Hypothalamus is an anatomical and physiological connection between the nervous system and the endocrine system. Hypothalamus is connected to the pituitary gland via infundibulum. Hypothalamus is the basal part of diencephalon. The hypothalamus contains several groups of neurosecretory cells called nuclei which produce hormones for regulating wide spectrum of body functions. There are several hormones released by neurosecretory cells of the hypothalamus which regulate the synthesis and secretion of anterior pituitary hormones i.e., hormones secretory by pituitary gland. The hormones produced by hypothalamus are of two types : releasing hormones (which stimulate the secretion of pituitary hormones) and inhibiting hormones (which inhibit the secretion of pituitary hormones).

The hypothalamus is connected to the anterior lobe of the pituitary gland by hypophyseal portal veins and to the posterior lobe of the pituitary gland by the axons of neurosecretory cells. Unmyelinated nerve fibres originating from neuronal cell bodies located within supraoptic and paraventricular nuclei of the hypothalamus form the **hypothalamo-hypophysial tract** within the pituitary stalk. These neurons synthesise predominantly two nano peptide hormones-**vasopressin** and **oxytocin.** respectively, which are then transported as neurophysin-proteins bound secretory granules down the nerve fibres. These chemicals synthesized by Neurosecretory cells of hypothalamic nuclei are called Neurohormones.

Some of the neurohormones released by the neurosecretory cells of the hypothalamus are:

For Example :

(i) Gonadotrophin-Releasing Hormone (GnRH) : GnRH is a hypothalamic hormone which stimulates the pituitary gland to synthesise and release the gonadotrophins. Therefore, GnRH is a releasing hormone.

(ii) Somatostatin : Somatostatin is hypothalamic hormone which inhibits the release of growth hormone from the pituitary gland. Hence, somatostatin is an inhibitory hormone.

The above hormones are produced in the neurons or neurosecretory cells of the hypothalamus and released through the nerve endings into the portal circulation. Through the portal circulation, these hormones reach the anterior pituitary to regulate the latter's functions. The posterior pituitary is under the direct control of the neurosecretory cells (neurons). The hormones reaching the posterior lobe of pituitary do not stimulate or inhibit any pituitary hormone, rather they are stored in posterior lobe and act on other body parts.

Releasing or Inhibiting Hormones of Hypothalamus and their Roles, Factors and specific Hormones they Control

Releasing of Inhibiting Hormone	Control and Regulation of Specific Hormone Secretion
Thyrotropin releasing hormone (TRH)	Stimulates thyrotropin stimulating hormone release
Growth hormone releasing hormone (GHRH) (Somatocrinin)	Stimulates growth hormone release
Growth hormone inhibiting hormone (GHIH) (Somatostatin)	Inhibits growth hormone release
Gonadotropin releasing hormone (GnRH)	Stimulates release of follicle stimulating hormone and luteinizing hormone
Prolactin releasing hormone (PRH)	Stimulates prolactin release
Prolactin inhibiting hormone (PIH)/ Dopamine (Produced by tubero-infundibular neurons)	Inhibits prolactin release
Adrenocorticotropic hormone releasing hormone (CRH)	Stimulates adrenocorticotropic hormone
Melanocyte stimulating hormone releasing hormone (MRH)	Stimulates melanocyte stimulating hormone release
Melanocyte stimulating hormone inhibiting hormone (MIH)	Inhibits melanocyte stimulating hormone release

Pituitary Gland (Hypophysis)

Pituitary gland is located in a bony cavity of the sphenoid bone of the skull called **Sella turcica.** It is attached to the hypothalamus (inferior surface) by a stalk called **infundibulum.** Anatomically the pituitary gland (hypophysis) is divided into adenohypophysis and neurohypophysis.

Pituitary gland is Ectodermal in origin.

It is a small, pear shaped gland, Red-grey in colour.

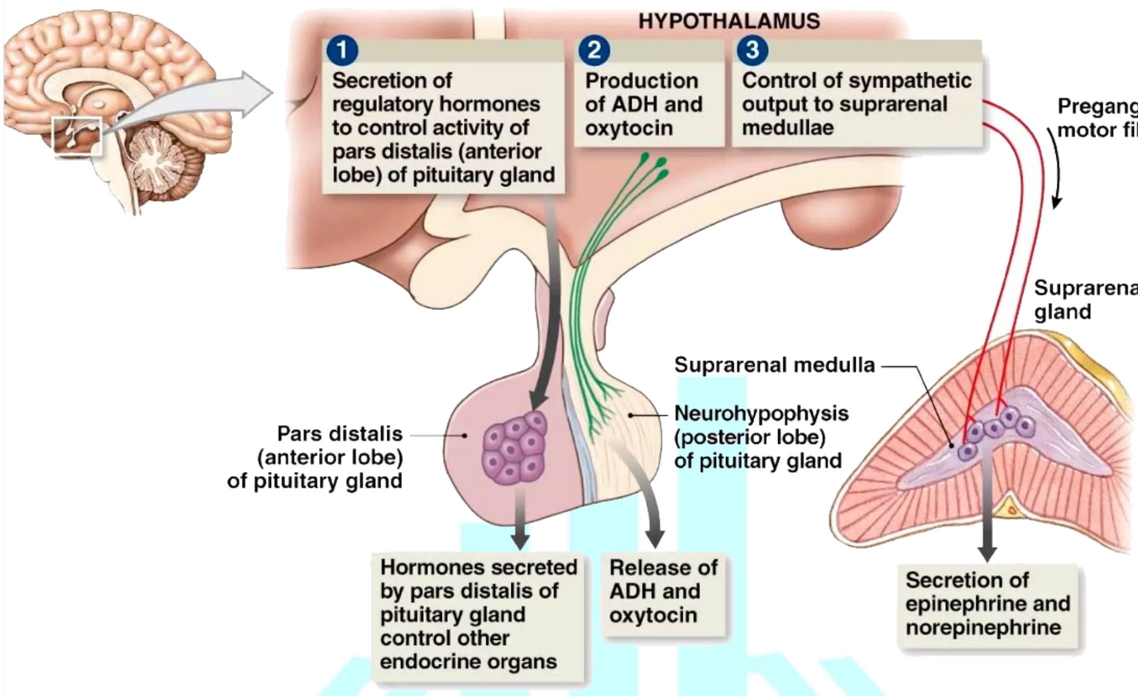
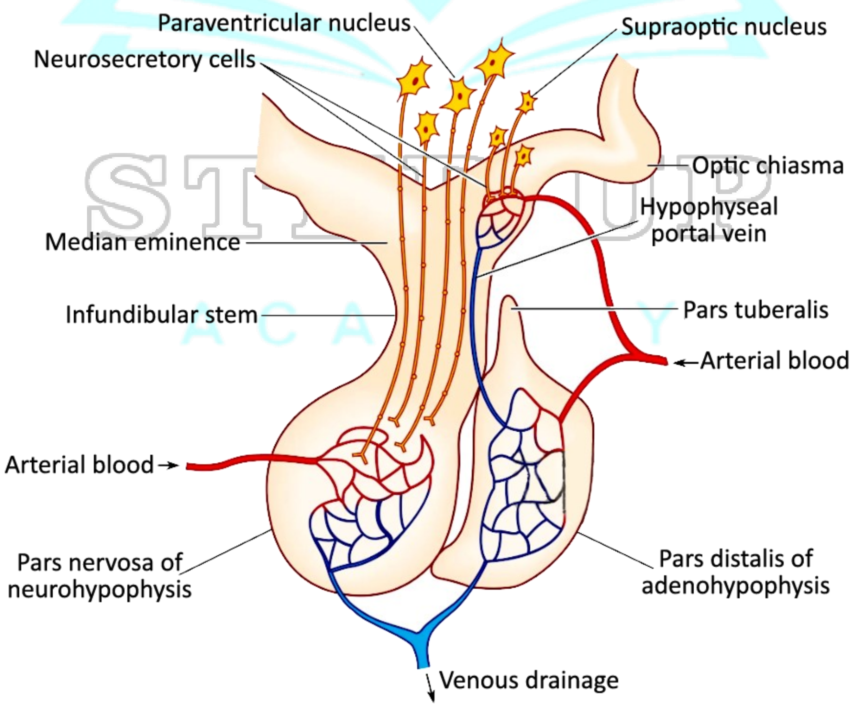


Fig. : Diagrammatic representation of pituitary and its relationship with hypothalamus



Adenohypophysis

It comprises of 75% part of pituitary gland. It highly cellular & vascular. It consists of two portions – **pars distalis** and **pars intermedia.** However, in humans, the pars intermedia is almost merged with the pars distalis.

The **pars distalis** region of pituitary is commonly called anterior pituitary. It produces GH (growth hormone), PRL (prolactin), TSH (thyroid-stimulating hormone), ACTH (adrenocorticotrophic hormone), LH (luteinizing hormone), FSH (follicle-stimulating hormone). **Pars**

intermedia releases only one hormone called melanocyte stimulating hormone (MSH). The functions of above-mentioned hormones are under the control of hypothalamus. The hormones released from the hypothalamus are carried to the adenohypophysis through the hypophyseal portal veins. The hormones synthesized and released from the adenohypophysis (anterior pituitary) are :

(i) Growth hormone : The growth hormone is also known as somatotrophin or somatotrophic hormone. "Soma" means body and "trophe" means nourishment. It regulates the growth of the body by promoting protein anabolism, intestinal absorption of calcium, conservation of glucose etc. It helps in synthesis and deposition of proteins, growth of long bones and other parts of the skeleton. Over and under secretion of growth hormone leads of many disorders such as :

- **Dwarfism :** The low secretion of growth hormone before puberty causes pituitary dwarfism. It leads to stunted growth due to premature stoppage of body growth and reduced development of skeleton. The dwarfism due to under secretion of GH is also called pituitary dwarfism. This dwarfism occurs before puberty i.e., in childhood. This dwarfism is called Ateliosis and the dwarfs are called Midgets.
- If deficiency of growth hormone occurs after puberty or adolescence then it causes **acromicria.** The person suffering from **acromicria** have normal body and intelligence but small hands, feet and face.
- **Gigantism :** Over secretion of growth hormone before puberty causes gigantism. The person suffering from gigantism has extra ordinary growth in height caused by abnormal elongation of long bones in childhood. The limbs are long the hands are also large.
- The gigantism occurs before puberty. But if over secretion of growth hormone occurs after puberty then the individual suffers from **acromegaly.** The persons suffering from acromegaly have enlarged hands, feet, jaws, nose and ears.
- Sometimes, a person develops hump due to bending of vertebral column. This is called Kyphosis.

(ii) Prolactin (PRL) : It was previously called luteotrophic hormone (LTH). Prolactin regulates the growth of mammary glands and milk production in them. It activates the growth of breasts during pregnancy and secretion of milk from mammary glands after child birth.

(iii) Thyroid stimulating hormone (TSH) : TSH stimulates the synthesis and secretion of thyroid hormones like thyroxine from the thyroid gland. It also controls the growth of thyroid gland.

(iv) Adrenocorticotrophic hormone (ACTH) : ACTH controls the structure and functioning of adrenal cortex especially secretions of glucocorticoids from it. It stimulates the synthesis and secretion of steroid hormones called glucocorticoids from the adrenal cortex.

(v) Gonadotrophic hormones : They are also called the gonadotrophins as they stimulate gonadal activity the anterior pituitary (pars distalis) releases following gonadotrophic hormones :

(a) Follicle stimulating hormone (FSH) : In males, FSH regulates spermatogenesis (formation of sperms) and in females, FSH stimulates growth and development of ovarian follicles and secretion of estrogen hormone.

(b) Luteinizing hormone (LH) : In males, LH is also called ICSH (interstitial cell stimulating hormone) which stimulates testes to synthesize and secrete androgens (testosterone). It activates Leydig cells of the testes to secrete testosterone. In females, LH stimulates the ovulation of the fully matured Graafian follicles and also maintains the corpus luteum, formed from the remnants of Graafian follicles after ovulation. The corpus luteum secretes progesterone and some estrogen under the action of LH.

The above hormones are released from the pars distalis and only one hormone is released from the pars intermedia, i.e., MSH (Melanocyte stimulating hormone).

Melanocyte Stimulating Hormone (MSH)

MSH acts on melanocytes (which contain melanin pigment) and regulates the pigmentation of skin. Stimulates the synthesis, secretion and dispersion of melanin pigment in skin.

Neurohypophysis : Neurohypophysis comprises of 25% portion of the pituitary gland. It is also called pars nervosa or posterior pituitary. It does not produce or secrete any hormone of its own. It receives neurohormones directly secreted from the neurosecretory cells (hypothalamic neurons) of the hypothalamus. The posterior pituitary is thus under the direct neural regulation of the hypothalamus. The axons of these neurons store the hypothalamic hormones in the vesicles present in them and from there these are released into the neurohypophysis. The two neurohormones synthesized in hypothalamus and secreted by neurohypophysis are:

(i) Oxytocin (Pitocin) : It is a hormone which acts on smooth muscles and stimulates their contraction. In females, it stimulates a vigorous contraction of the uterus at the time of child birth. It also causes contraction of mammary glands leading to milk ejection. Widening of uterus near the completion of pregnancy and suckling of nipples by young infant stimulates the hypophysis to release oxytocin. The oxytocin-induced contractions of the mammary gland muscles help in the flow of stored milk from the mammary gland to the mouth of the suckling infant. Even sight and sound of baby can cause a nursing mother to secrete this hormone. Therefore, oxytocin is also called **'milk ejection hormone'** and **'birth hormone'.**

(ii) Vasopressin or Antidiuretic hormone (ADH) : Vasopressin acts mainly on kidneys and stimulates the reabsorption of water and electrolytes. ADH acts on nephrons of kidneys and stimulates the reabsorption of water from the distal tubules i.e., distal convoluted tubules (DCT) and collecting tubules. It thereby reduces the water loss from the body. It prevents diuresis (water loss) therefore it is called anti-diuretic hormone (ADH). Failure of secretion of vasopressin leads to a reduced renal reabsorption of water and a consequent elimination of a large volume of very dilute (hypotonic) urine this disease is known **Diabetes Insipidus** although the volume of urine is increased, no glucose appears in the urine of such patients. Besides its antidiuretic effect of reducing the urinary volume, **vasopressin also enhances arterial blood pressure by causing constriction or narrowing of arterioles.**

Differences between vasopressin and oxytocin

S. No.	Vasopressin	Oxytocin
1.	It is vasoconstrictor.	Stimulates contraction of uterine muscles during birth.
2.	It tends to increase blood pressure.	It causes ejection of milk from mammary gland.
3.	It is helpful in concentrating the urine.	It has no such activity.
4.	Its secretion is stimulated by reduced quantity of body fluids.	Its secretion is stimulated by distension of uterus and suckling of breast in females.

Hormones of Pituitary Gland, their Actions and Targets

Parts of Pituitary	Hormones	Principal Actions	Target Organs
Adenohypophysis	Human growth hormones	Growth of body specially bones of limbs, stimulates protein synthesis and inhibits protein break down, hydrolysis of fats, retards use of blood glucose for ATP production	General
	Thyroid stimulating hormones (TSH)	Controls secretion of thyroid hormones	Thyroid gland
	Adrenocorticotrophic hormone (ACTH)	Controls secretion of adrenal cortex hormone (Glucocorticoids)	Adrenal cortex
	Melanocyte stimulating hormone (MSH)	Stimulates cutaneous pigmentation by dispersion of melanin granules	Melanocytes in skin
	Prolactin (PRL)	Stimulates production and secretion of milk, control of reproduction, growth and metabolism	Mammary glands
	Follicle stimulating hormone (FSH)	In males, stimulates spermatogenesis. In females, stimulates growth of ovarian follicles	Gonads
	Interstitial cell stimulating hormone (ICSH) : In males	Secretion of testosterone	Gonads

	Luteinizing hormone (LH) : In females	In females, together with FSH, it triggers ovulation, stimulates conversion of ovarian follicles into corpus luteum	Gonads
	Oxytocin (OT)	Stimulates contraction of uterine muscles during birth , initiates ejection of milk	Uterus and Mammary glands
Neurohypophysis (No hormones synthesized here. Its hormones are synthesized in hypothalamus)	Antidiuretic hormone (ADH) or vasopressin	Stimulates reabsorption of water and reduction of urine secretion, stimulates constriction of blood vessels and thus increases blood pressure.	Kidneys and blood vessels

Thyroid Gland

The thyroid gland is the largest endocrine gland which is butterfly shaped or H-shaped. It is composed of two lateral lobes which are located on either side of the trachea. These lobes are interconnected with a thin flap of connective tissue called isthmus. The thyroid gland is composed of follicles and stromal tissues. These follicles are held together by areolar connective tissue. Each thyroid follicle is composed of follicular cells, enclosing a cavity. The follicular cells present in the follicular synthesise two hormones. namely, tetraiodothyronine or thyroxine (T_3) and tri-iodothyronine (T_3). Both are iodinated forms of an amino-acid called tyrosine and remain stored in the jelly like semifluid material (colloid) in the lumen of follicles, T_3 is more active and several times more potent than T_4. Form the thyroid mainly T_4 is secreted and converted to T_3 in peripheral tissues e.g., Liver.

Thyroid disorders:-

1. Hypothyroidism

(i) Simple/Colloid goiter:- If there is deficiency of iodine in food then thyroid try to absorbs more and more iodine from blood and increase its size it is called **Simple goitre.**

Goitre is found more abundantly in the persons who live on mountain slopes, because iodine (at that place) flows along with water.

When most of the people show the symptoms of this disease then it is called **endemic goiter**. Persons who take sea foods, never show the symptoms of goitre.

(ii) Cretinism:- Hypothyroidism during pregnancy causes defective development and maturation of the growing baby leading to stunted growth (cretinism), mental retardation, low intelligence quotient, abnormal skin, deaf-mutism, etc.

Cretinism
↓

- **I Physical**
  - (A) Skeletal → Dwarf
  - (B) Muscular → Weak muscles
  - (C) Visceral → Not so retarded, hence potbellied
- **II Mental**
  - Idiocy/Imbecility
- **III Sexual**
  - (i) Infantile sex organs
  - (ii) No secondary sex characteristics

(iii) Thyroid myxoedema: In adults, hypothyroidism causes **Myxoedema**. (Gull's disease). In adults' women, menstrual cycle becomes irregular.

2. Hyperthyroidism:-

Due to cancer of thyroid gland or due to development of nodules of thyroid glands the rate of synthesis and secretion of thyroid hormone is increased to abnormal high levels leading to a condition called hyperthyroidism which adversely effects the body physiology.

* **Exophthalmic Goiter or Grave's disease, Basedow's disease or thyrotoxicosis: -**

Exophthalmic goiter is a form of hyperthyroidism, characterized by enlargement of the thyroid gland, protrusion of the eyeballs, increased basal metabolic rate, and weight loss also called **Graves' disease.**

PARATHYAROID GLAND

- It is **endodermal** in origin.
- These glands remain embedded in the dorsal surface of thyroid gland. They are two pairs in number.
- These glands secrete only one hormone – **parathormone** or **Collip's hormone** or PTH. It was obtained by **Collip** in its pure form.
- This hormone is proteinaceous in nature/Polypeptide hormone.
- Parathormone is essential for survival because it significantly contributes to "homeostasis" by regulating the amount of calcium and phosphate ions in ECF.
- Calcium is key element in many physiological functions like **proper permeability of cell membranes, muscular activities, nerve impulse conduction, heartbeat, blood coagulation, bone formation, fertilization of ova.**
- Calcium is most abundant of all minerals found in the body and about 99% of calcium and phosphorus are contained in the. (1% Ca^{+2} found in ECF).
- Maintenance of proper calcium level under "homeostasis" is in fact, a combined function of **parathormone, thyrocalcitonin** and **vitamin D_3 (cholecalciferol).**
- Parathormone is a hypercalcemic hormone that increase blood Ca^{+2} level by

(i) Stimulating the process of bone resorption/dissolution/demineralization.

(ii) Promoting the absorption of Ca^{+2} from food in the intestine.

(iii) Promoting the reabsorption from the nephrons in the kidneys.

- This calcium is then utilized by bone-forming cells, (Osteoblast) in bone formation under the influence of vitamin D_3.
- Parathormone stimulates the **osteoclast** cells to feed upon bones, these cells remove unnecessary parts of bones by dissolving and phagocytosis thus change asymmetrical bone into symmetrical bone. The **remolding** of bone is done by these cells life long. As a result of this, amount of Ca remains constant in blood in normal conditions.

THYMUS GLAND

- It is **endodermal** in origin.
- Thymus is a **bilobed gland** located between lungs (mediastinal space) behind sternum on the **ventral side of aorta.**
- It plays a major role in development of immune system.
- It is quite large at the time of birth but keep reducing in size with age and **by the time puberty is attained it reduces to a very small size. As a result, with the increase in age the immune response gradually become weak.**
- Its structure is just like a lymph gland. It is covered by connective tissue coat **capsule** and internally both the lobes are re dividing in to small lobules.
- The cortex consists of densely packed lymphocytes.
- The medulla consists of reticular epithelial cell, a few lymphocytes and the "**Corpuscles of Hassall"** or thymic corpuscles which are phagocytic in nature.

Hormones and functions of thymus gland:-

- Thymus gland secretes a peptide hormone called **thymosin or thymine hormone.**
- After the birth, **T – Cells or T – lymphocytes** are matured in thymus gland, then these lymphocytes are released by thymus gland, reach to lymphatic organs like spleen, payer's patches and lymph nodes & deposited in it.
- Thymosin hormone stimulates the maturation of lymphocytes to destroy the antigens produced by bacteria or pathogen.
- According to one of the theories of Ageing the decline a disappearance of Thymus gland by middle age is the primary cause of **ageing.**
- Thymus provide **cell mediated immunity** (Cellular immunity) and also promote production of antibodies to provide **humoral immunity.** So, thymus is also called **"Throne of immunity"** or **"Training school of T – lymphocytes".**

PINEAL BODY

Positions :-

- It is situated at the dorsal side of diencephalon (Epithalamus) or anterior part of brain. It is also known as **epiphysis cerebri. Pineal** body is a part of brain. It is **ectodermal** in origin.
- There are found pinealocyte cells (formed by the modification of nerve cells) and supporting interstitial cells or neuroglial cells in pineal body.

Hormone & Functions :-

- Pineal body secretes a hormone **melatonin,** which is an amino acid derivative.
- Melatonin plays a very important role in the regulating of a **diurnal/circadian rhythm,** for example normal rhythm of sleep wake cycle, body temperature etc.
- It is proved that the level of melatonin rises during periods of darkness and falls during periods of light.

- Melatonin also influence **metabolism, pigmentation, menstrual cycle & defense capability.**
- In amphibians and reptiles, this hormone is related with **metachrosis** (change in the colour of skin). It affects the Melano pores of skin, thus acts antagonistically to the MSH of pituitary i.e., it fairs the complexion of skin.
- Mid part of gland secretes **anti gonadal** hormone.
- The hormone controls the sexual behavior in mammals. Inhibits the sexual irritation, and also inhibits the development of genitalia and their functions.

Maximum development of pineal body up to 7yr & then it undergoes involution & at the age of 14 yr interstitial tissue and crystals of $CaCO_3$ or Ca_3PO_4 are deposited in it, these are called "**Brain sand**" or **Acervuli.**

Adrenal Gland

Also called suprarenal glands or glands of Emergency. These paired glands located at the anterior part of the kidneys. Each kidney has an adrenal gland on top of it. These glands have dual origin i.e., form Mesoderm and Ectoderm of embryo. Each adrenal gland is composed two types of tissues: adrenal medulla and adrenal cortex. The adrenal medulla is located at the center and the adrenal cortex lies outside the adrenal medulla. Hence, it can said that adrenal gland has two parts:

(i) Internal adrenal medulla.

(ii) External adrenal cortex.

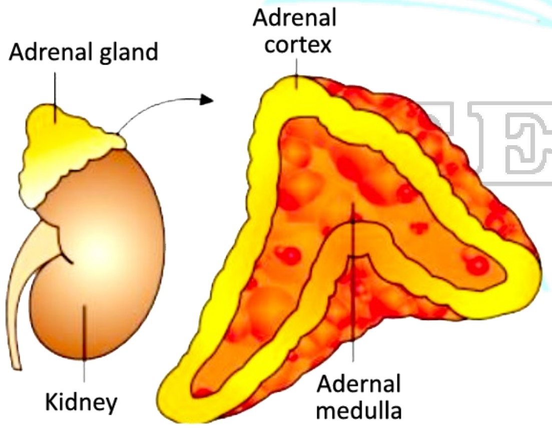


Fig: Diagrammatic representation of : (a) Adrenal gland on kidney (b) section showing two parts of adrenal gland

Adrenal Cortex is derived from mesoderm of embryo. It is the external or outer part of the adrenal gland. It is divides into three layers :

(i) Zona reticularis : It is the innermost layer of the adrenal cortex.

(ii) Zona fasciculata : It is the middle layer of the adrenal cortex.

(iii) Zona glomerulosa : It is the outermost layer of the adrenal cortex.

The adrenal cortex secretes over 20 steroid hormones commonly called cortical steroids or corticoids. These are grouped in three major categories namely mineral corticoids, glucocorticoids and sexcorticoids.

Disorder

1. **Addison's Disease :** A destruction of adrenal cortex by diseases like tuberculosis produces Addison's disease due to the deficiency of both glucocorticoids and mineral corticoids. Symptoms include a bronze like pigmentation of skin, low blood sugar, low plasma Na^+, high plasma K^+, increased urinary Na^+, nausea, vomiting and diarrhea.
2. **Cushing's Syndrome :** A tumor of the adrenal cortex may secrete too much cortisol to produce Cushing's syndrome. High blood sugar, appearance of sugar in the urine, obesity, wasting of limb muscle, rise in plasma Na^+, fall in plasma K^+, rise in blood volume and high blood pressure are observed in the patient. In males, excessive hair growth (Hirsutism), In females' masculinization with beard and moustache etc.
3. **Aldosteronism (Conn's Syndrome) :** Excessive secretion of aldosterone form and adrenal cortical tumor produces aldosteronism. This disease is characterized by a high plasma Na^+, low plasma K^+ rise in blood volume and high blood pressure, kidney damage hence polyuria.
4. **Adrenal Virilism:** An excessive secretion of sex corticoids produces the male-type external sex characters such as beard and moustaches and male voice in male voice in women. The disease is called adrenal virilism.

Hormones of Adrenal Glands and their Actions of the Target Cells

Adrenal Gland Hormones	Principal Action	Target Tissue
Mineralocorticoids : Aldosterone (mainly)	Control electrolyte and water metabolism : increase blood levels of Na^+ and water; decrease blood levels of K^+ by stimulating kidney tubules to reabsorb more Na^+, Cl^- and water and less K^+.	Kidney

Glucocorticoids : cortisol (mainly) corticosterone, cortisone	Raise blood glucose level: promote breakdown of protein and fast; increase availability of amino acids for enzyme synthesis, general resistance to long-term stress by anti-inflammatory and anti-allergic response.	Lever
Gonadocorticorticoids : androgens, estrogen	Development of secondary sexual characteristics, particularly those of the male ; concentrations secreted in adult are so low that their effects are usually insignificant.	Gonads
Adrenaline	Stimulates citation of blood glucose by converting liver glycogen to glucose; rise in blood pressure; acceleration of rate and force of heartbeat; increase in breakdown of lipids; increase in oxygen consumption; erection of hair; dilation of pupils; initiates stress responses.	Skeletal muscles, cardiac muscles, smooth muscles blood vessels, fat cells
Noradrenaline	Stimulates reactions similar to those produced by adrenaline.	Skeletal muscles, cardiac muscles, smooth muscles blood vessels, fat cells

PANCREAS

- It is **endodermal** in origin.
- **Position :-** Pancreas is a pink coloured mixed gland (heterocrine) situated in the backside of stomach in abdominal cavity. (Curve of Duodenum).
- Acini are found in pancreas which secrete digestive enzymes. Acini form **99%** part of pancreas gland. These are **exocrine** in nature. There are found numerous small endocrine glands scattered between the acini, these small endocrine glands, are called **Islets of Langerhans (1 or 2 million cell).** They form only **1%** part of the gland. These were discovered by **Langerhans.**
- Each islet of Langerhans has 4 types of cells

(A) **Alfa cells ($\alpha - cells$) :** These are the largest cells present in peripheral region these are approximately 25% of the total cells. They secrete **glucagon** hormone.

(B) Beta cells (β - cells) : These are the small cell present in central region. These are about 60-65% part of total cells. They secrete **Insulin** hormone.

(C) Delta cells (δ-cells) OR Gamma cells (γ-cells) : These cells are found in middle region. These are about 10% part of total cells, they secrete **somatostatin** hormone which regulates the activities of α-cells and β-cells.

(D) F cell or PP – cells : These cells secrete **pancreatic polypeptide** hormone. Which probably helps in reabsorption of food in intestine.

(1) Insulin : -

- It was first prepared / found by **Benting and Best.**
- Molecular structure of insulin was given by **A.F. Sanger** (with the help of cow's insulin)

The term insulin was also given by **A.F. Sanger.** Insulin is the first protein that is artificially synthesized in lab and is crystallized.

- Human insulin was synthesized by **"Tsan"** (Humulin)
- One molecule of Insulin is made up of **51 – amino acids** that has 2 chains.

(i) α-chain – It is made up of **21** amino acids

(ii) β - chain – It is made up of **30** amino acids. Both the branches or chains are bind together with cross bonds of disulphide bonds.

- **"A.F. Sanger"** was awarded by **Noble Prize** for it.

Functions of Insulin hormone :-

1. On membrane permeability : Except **brain cells, R.B.Cs, retina** and **genital epithelium,** insulin stimulates the permeability and consumption of glucose in all somatic cells.

2. Actions on Metabolism :-

(i) Carbohydrate :

(1) Insulin inhibits gluconeogenesis

(2) Promotes *glycogenesis.* These are two major sites of glycogenesis, **liver** and the **muscles.**

(3) Enhances peripheral utilization **(oxidation)** of glucose, causing the blood sugar level to fall.

(4) Inhibits glycogenolysis.

(ii) Fat : Insulin promotes *lipogenesis* and inhibits lipolysis. Insulin also inhibits formation of ketone bodies.

(iii) Protein : Insulin promotes protein synthesis by promoting uptake of amino acid by liver muscle cell.

(IV) Nucleic acid : Insulin promotes synthesis of DNA and RNA.

Normal concentration of sugar in blood is **90-100 ml.** of blood.

Hypo secretion of Insulin : - [diabetes mellitus (Sugar disease)]

1. Hyperglycemia

- Due to hyposecretion of insulin, body cells cannot use the sugar stored in blood. So, amount of sugar increases in blood and this is called **Hyperglycemia.**
- **Glycosuria :** Glucose is excreted urine, if amount of glucose exceeds from 180mg/dl in the blood, this is known as "**Glycosuria".**
- **Polyuria :** The amount of water increases (in this stage) in the urine, so intervals of urination reduced it is called **polyuria.**
- **Polydipsia : -** Due to excess excretion of urine (Urination at short intervals), probability of dehydration id enhanced. The patient feels excessive thirst called polydipsia.
- **Polyphagia :** excessive lunger.
- **Ketoacidosis :** Due to active and incomplete decomposition of fats in fatty tissues, ketone bodies are formed. These ketone bodies are toxic like acetone, aceto-acetic acid and beta hydroxyl butyrate.
- **Ketonuria :** Excretion of toxic ketone bodies through urine.
- The combined effect of ketoacidosis, dehydration and hyperglycemia may cause **diabetic coma** to the patient, patient becomes unconscious and even may die.
- Insulin hormone is given to the patient by injection **(subcutaneously)** in this disease, Insulin given orally is not effective, because it gets digested in the alimentary canal like other proteins.

Hypersecretion of Insulin : - (Hyperinsulinism)

- Due to hypersecretion of insulin amount of glucose decreases in blood. It is called **hypoglycemia.**
  In hypoglycemia stage, body cells take more and more glucose from blood. So, need of glucose for nervous system, retina of eye, genital epithelium is not fulfilled, as a result of that patient loses his reproductive power and sight. Due to excess irritation in brain cells, patients feel exhausted, unconsciousness, cramps and the patient may even die.

2. Glucagon

- This is secreted by α-cells.
- Glucagon is a **hyperglycemic factor.**
- It is made up of chain of polypeptide of 29 amino acids.
- It is antagonistic to insulin. It is secreted by the gland, when sugar level of blood reduces.
- Glucagon hormone increases the amount of sugar (glucose) in blood.
- It stimulates gluconeogenesis in liver, as a result of that amount of glucose in the blood increased.
- It stimulates lipolysis of fats in fatty tissues.
- It decomposes the glycogen into glucose in liver i.e., it stimulates glycogenolysis in liver.
- The secretion of insulin and glucagon is controlled by limit control feedback. When amount of sugar is increased in blood, then insulin is secreted by β-cells. As a result of it, when amount of glucose is reduced in blood. Then glucagon is secreted by α-cells.

GONANDS AND OTHER ORGNAS WHICH SECRETE HORMONES

Testis

A pair of testis is present in the scrotal sac (outside abdomen) of male individuals. Testis performs dual functions as a primary sex organ as well as an endocrine gland. Testis is composed of **seminiferous tubules** and **stromal or interstitial tissue.** The **Leydig cells** or **interstitial cells,** which are present in the intertubular spaces produce a group of hormones called **androgens** mainly **testosterone.**

Androgens regulate the development, maturation and functions of the male accessory sex organs like epididymis, vas deferens, seminal vesicles, prostate gland, urethra etc. These hormones stimulate muscular growth, of facial and axillary hair, aggressiveness, low pitch of voice etc.

Androgens play a major stimulatory role in the process of spermatogenesis (formation of spermatozoa).

These hormones produce anabolic (synthetic) effects on protein and carbohydrate metabolism.

Ovary

Females have a pair of ovaries located in the abdomen. Ovary is the primary female sex organ which produces one ovum during each menstrual cycle.

In addition, ovary also produces two groups of steroid hormones called **estrogen and progesterone.**

Ovary is composed of ovarian follicles and stromal tissues. The estrogen is synthesized and secreted mainly by the growing ovarian follicles.

After ovulation, the ruptured follicle is converted to a structure called **corpus luteum,** which secretes mainly **progesterone.**

Estrogens produce wide ranging actions such as stimulation of growth and activities of female secondary sex organs, development of growing ovarian follicles, appearance of female secondary sex characters (e.g., high pitch of voice, etc.). mammary gland development. Estrogens also regulate female sexual behavior. Progesterone supports pregnancy.

Progesterone also acts on the mammary glands and stimulates the formation of alveoli (sac-like structures which store milk) and milk secretion.

Actually, progesterone promotes alveolar growth in pregnancy and increases secretory surface of alveoli, thus it supports milk secretion in lactating mother.

Heart

The atrial wall of our heart secretes a very important peptide hormone called **atrial natriuretic factor (ANF),** which decreases blood pressure. When blood pressure is increased, ANF is secreted which causes dilation of the blood vessels. This reduces the blood pressure.

Kidney

The juxtaglomerular cells of kidney produce a peptide hormone called **erythropoietin** which stimulates erythropoiesis (formation or RBC).

Gastro intestinal tract hormone

Endocrine cells present in different parts of the gastro intestinal tract secrete four major peptide hormones, namely **gastrin, secretin, cholecystokinin (CCK) and gastric inhibitory peptide (GIP)**

- **Gastrin** acts on the gastric glands and stimulates the secretion of hydrochloric acid and pepsinogen.
- **Secretin** acts on the exocrine pancreas and stimulates secretion of water and bicarbonate ions.
- **CCK** acts on both pancreas and gall bladder and stimulates the secretion of pancreatic enzymes and bile juice/respectively.
- **GIP** inhibits gastric secretion and motility.
- Several other non-endocrine tissues secrete hormones called **growth factors.** These factors are essential for the normal growth of tissues and their repairing / regeneration.

MECHANISM OF HORMONE ACTION

Once a hormone enters the blood stream, it can reach almost every cell in the body. However, each hormone can show its effect on only certain types of cells. Those cells or that organ on which a particular hormone shows its effects form the hormone's target. Hormones are basically of two - lipid soluble (e.g., steroid hormones like testosterone, estrogen) and lipid Insoluble e.g., amino acid derivatives like adrenaline; plasma membranes of cells and directly enter the cells. Lipid insoluble hormones cannot directly pass through plasma membranes of cells and directly enter the cells. Lipid insoluble hormones cannot directly pass through the membranes and unusually require extracellular receptors for carrying out their cavity. On the basis of their chemical nature, the hormones can be grouped as :

(i) Peptide polypeptide and protein hormones - e.g., insulin, glucagon, thyrocalcitonin, pituitary hormones, hypothalamic hormones etc.

(ii) Steroid hormones - e.g., cortisol, testosterone, estradiol, progesterone etc.

(iii) iodothyronines- thyroid hormones ($T_3$and T_4)

(iv) Amino-acid derivatives' - e.g., epinephrine, nor epinephrine.

Hormones produce their effects on target tissues by binding to specific proteins called hormone receptors located in the target tissues only. The hormone receptors present on the cell membranes of the target cells are called membrane-bound receptors or extracellular and receptors present inside the target cells are called intracellular receptors : mostly nuclear receptors (present in the nucleus).

The hormone binds to the receptors and leads to the formation of a hormone-receptor. Each receptor is specific to one hormone only and hence, receptors are specific. The hormone-receptor complex formation leads to certain biochemical changes in the target tissue. Target tissue metabolism and hence physiological functions are regulated by hormones.

Mechanism of hormone action by interaction with extracellular (membrane-bound)receptor

The hormones which interact with the membrane-bound receptors normally do not enter the target cell, but generate second messengers. Peptide, polypeptide, protein hormones and catecholamine act through this mechanism. Such hormones circulating in tissue fluid, come in contact with the externa domain of the extracellular receptor present on the surface of the cell. The hormone binds to the receptor and forms a hormone-receptor complex which brings about conformational changes in the cytoplasmic part of the receptor. The cytoplasmic part of the receptor the produces second messengers such as Ca^{2+}, cyclic AMP, IP_3 etc. which activates the existing enzyme system of the cell and accelerates the biochemical reactions in the cell.

This way the cellular metabolism is regulated. The hormone which binds to the receptor forms the primary messenger and cAMP, $Ca2^{+}$ and IP_3 act as secondary or second messengers.

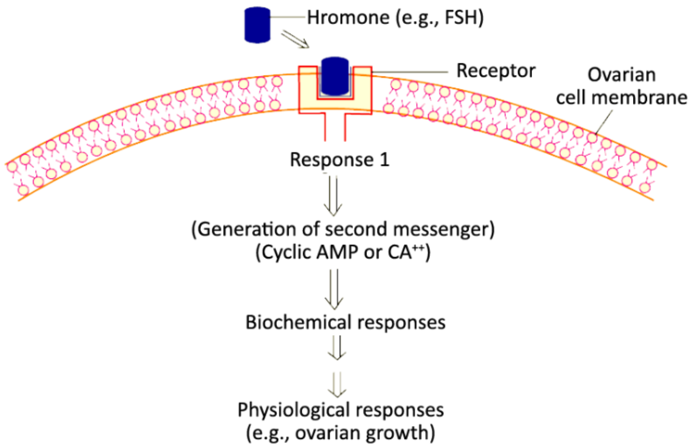


Fig. : Diagrammatic representation of the mechanism of action of a protein hormone

Extracellular Receptor: The membrane bound receptors of insulin is a heteroterameric protein consisting of four subunits, two subunits protrude out form surface of the cell and bind insulin and two B-subunits that span the membrane and protrude into the cytoplasm.

Binding to the receptor : Binding of insulin to the outer subunits of the receptor causes a conformational change in the membrane spanning B- subunits, which is also an enzyme, a tyrosine kinase. The activated B-submits add phosphate groups of specific tyrosine residues located in cytoplasmic domain of the receptor as well as to a variety of insulin receptor substrates.

Some hormones (like CCK, secretin) activate a transducer G-protein which activates enzyme breaks phosphodiesterase. This enzyme breaks phosphatidylinositoal 4, 5-biphosphate (PIP_2) into a pair of mediators : inositoltriphosphate (IP_3) and diacylglycerol (DG). In turn, IP_3, which is water-soluble, and so diffuses into cytoplasm and triggers the release of another messenger $Ca2^+$ ions for intracellular calcium-mediated processes While DG remains within the membrane where it activates an enzyme called protein kinase C which in turn activates many other enzymes such as pyruvate dehydrogenase and so brings about the physiological effects.

Mechanism of hormone action by interaction with intracellular receptors

The lipid-soluble hormones are able to cross the lipid bilayer of the plasma membrane and hence they move inside the target cell without any difficulty. After entering the cell i.e., in the cytoplasm they attach with their specific intracellular receptors. **Steroid hormones** and **iodothyronines** come in this category. The hormone-receptor complex stimulates the regulatory genes present on the chromosomes and regulates the gene expression or chromosome function. **Cumulative biochemical actions** result in physiological and developmental effects. Steroid hormones are slower but long lasting in responses as compared to the lipid insoluble hormones.

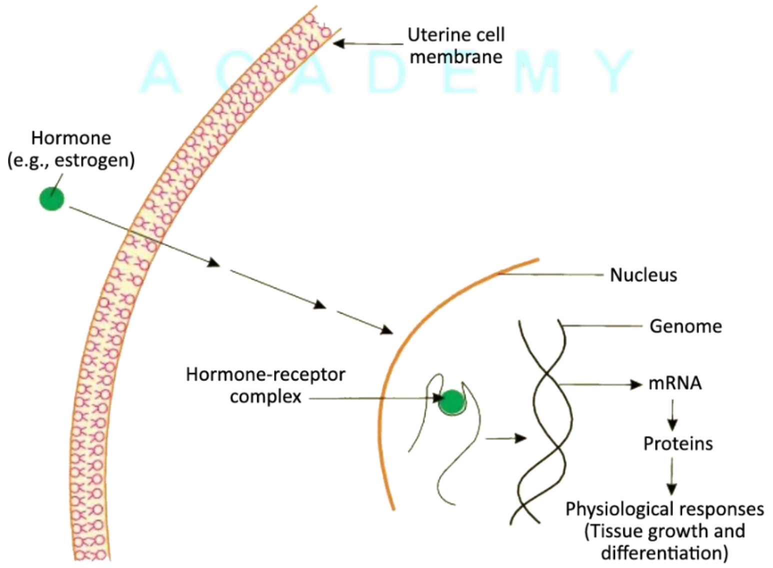


Fig. : Diagrammatic representation of the mechanism of hormone action : Steroid hormone