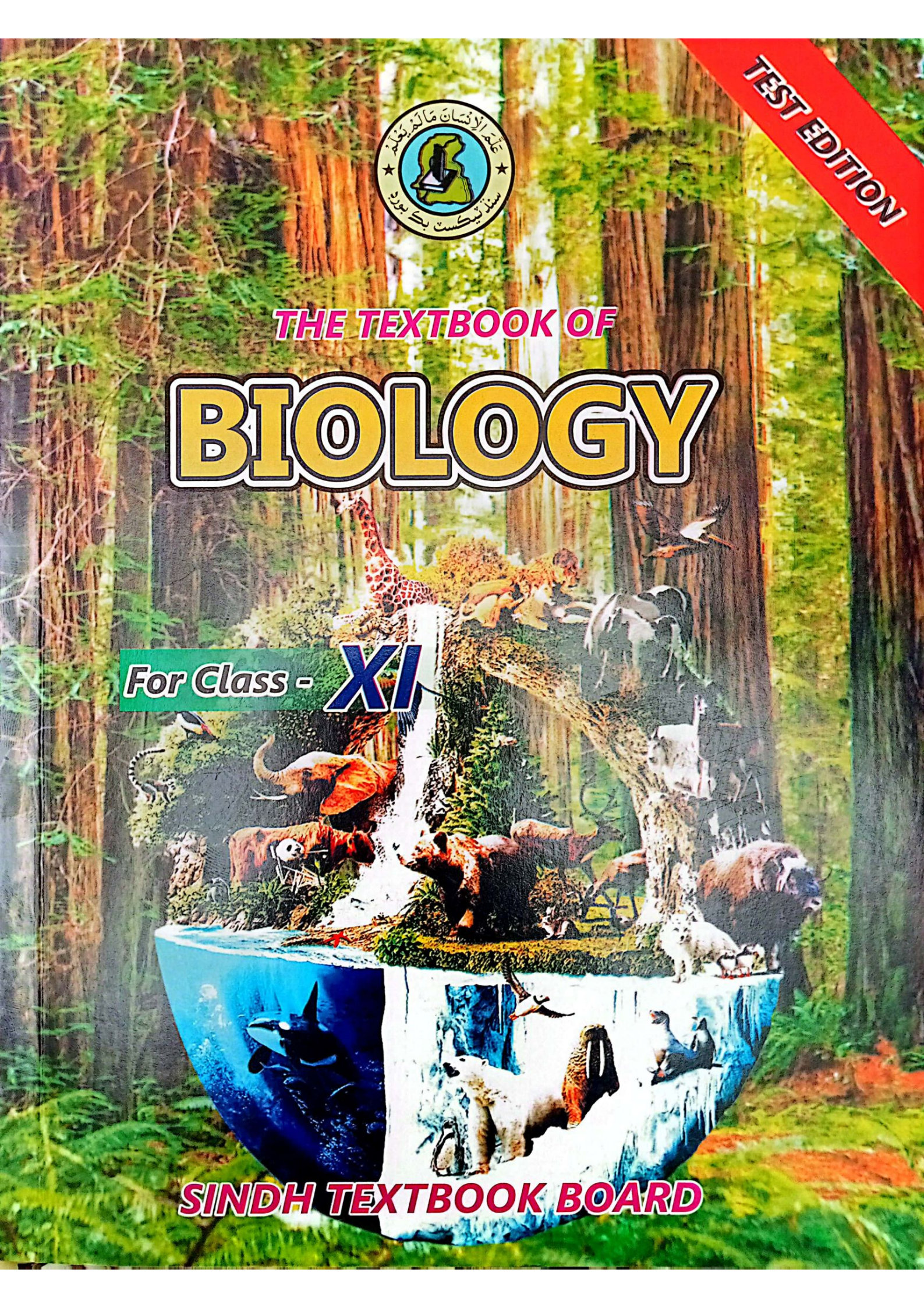
TEST EDITION

THE TEXTBOOK OF

# BIOLOGY

For Class - XI



SINDH TEXTBOOK BOARD

TEST EDITION

THE TEXTBOOK OF

# BIOLOGY

## For Class - XI

Sindh Textbook Board, Jamshoro

Published by

Urdu Academy Sindh, Karachi

Prepared by SINDH TEXTBOOK, BOARD, JAMSHORO.
Reviewed by Directorate of Curriculum Assessment and Research Sindh, Jamshoro
Prescribed by the Board of Intermediate and Secondary Education Hyderabad, Sukkur,
Shaheed Benazirabad, Larkana, Mirpurkhas and Karachi for Secondary School Examination.
Approved by the Education and Literacy Department, Government of Sindh.

**Patron-in-Chief**

**Agha Suhail Ahmed**
Chairman, Sindh Textbook Board.

**Chief Supervisors**
Daryush Kafi
Yousuf Ahmed Shaikh
Sindh Textbook Board, Jamshoro

**Subject Consultant**
Muhammad Khan Gopang
Sindh Textbook Board, Jamshoro

**AUTHORS**

- Prof. Dr. Nasiruddin Shaikh
- Prof.Muhammad Saleem Mughal
- Dr. Navaid Rab
- Dr. Syed Ikhlaq Hussain
- Mr. Laiq Ahmed

**REVIEWERS**

- Prof. Dr. Nasiruddin Shaikh
- Prof. Muhammad Saleem Mughal
- Dr. Riffat Sultana
- Prof. Altaf Ahmed Memon
- Mr. Muhammad Junaid Khilji
- Mr. Piaro Khan Saharan
- Sayed Saleh Muhammad Shah

**EDITOR**

- Prof Dr. Nasiruddin Shaikh

**Technical Assistance**

- Mr. M. Arslan Shafaat Gaddi
- Mr. Toqeer Ahmed Mahar

**Printed at: Academic Offset Press Karachi.**

# PREFACE

The era we are living in, is the era of science and technology wherein Biology along with its connected disciplines play a pivotal role for the development of society in general and technology in particular, in order to guarantee continuous progress of humankind.

To keep the students abreast of the fundamental knowledge of Biology in a very enlightened manner, this latest edition of The Textbook of Biology for class XI is being unveiled and is expected to serve for the cause.

This Textbook is the result of countless endeavors put in by the authors that fundamentally emphasizes on improving the learning skills of students. The book is designed according to the national curriculum and precisely focuses on the concepts of Biology in a student-friendly language and a well-organized manner.

At the beginning of each chapter, students and teachers both will found the objectives of learning about all concepts discussed in the chapter. The text is presented with numerous illustrations and information tables. Also, at the end of each chapter there are several multiple choice and reasoning questions provided to test the learned concepts.

The study material presented in this book covers the subject in accordance with the revised curriculum prepared by the Ministry of Education, Govt of Sindh and is reviewed by independent team of Dirctorate of Curriculum Assessment and Research Jamshoro Sindh. Every topic is covered in the same level of detail that is considered prerequisites for the professional studies at undergraduate level.

Last but not the least, I am grateful to the learned authors, reviewers and editors of this Textbook especially Prof. Dr. Nasiruddin Shaikh (First V.C of GCU Hyd.) who played major role as author, reviewer and editor to give this shape of book by his untiring efforts. I also admire Director Technical and subject specialists of Sindh Textbook board for his day and night effort for the nation cause to develop future nation.

*Chairman*
**Sindh Textbook Board, Jamshoro**

# CONTENTS

# BIOLOGICAL MOLECULES

Chapter 1

## Major Concept

### In this Unit you will learn:

- Introduction of Biological Molecules
- Importance of water molecules
- Carbohydrates
- Proteins
- Lipids
- Nucleic acids
- Conjugated molecules

**Introduction of Biochemistry:**

The branch of biology which explains the biochemical basis of life is called **Biochemistry**. It is one of the most important branch of biology due some reasons given below:

- It provides information about all the processes carried-out in the living organisms from construction of body structures to flow of information from nucleus, especially DNA for enzyme/ protein synthesis and control of all the mechanisms.
- It provides information about abnormal mechanisms which lead to diseases. It ultimately open doors to the development of medicines and medical equipment to elucidate these abnormalities.
- The recent concept and technologies of biochemistry enabled us to investigate and understand most challenging and fundamental problems of biology and medicine e.g. how does cells find each other to form a complex organ? How does the growth of cells controlled? What are the causes of cancer? What is the mechanism of memory? Biochemistry is the only branch of science which answer these questions properly.

As we know that organisms are made up to tissues and cells while cells are made up of molecules, molecules are chemically bonded atoms. It means that fundamentally living things or organisms are made up to chemicals which explains the second postulate of cell theory i.e. structure and function of cell are dependent upon their chemical composition.

Therefore it is necessary to study the chemical composition of cell and reactions which carry down in these cells to understand the different structures and metabolisms of an organism.

## 1.1 CHEMICAL COMPOSITION OF CELL:

It is already established that all living organisms are structurally composed of cells and living cell contains a living matter called Protoplasm. The actual chemical composition of protoplasm is still not known perfectly. However, chemically it contains 70% to 90% of $H_2O$. If the water is evaporated, the remaining mass of cell is called **Dry Weight** of cell, consist of many carbon containing long chain molecules called **Biomolecules** which are the types of organic molecules. So, the compounds produced by living organisms are called biomolecules.

The elements which are involved in the synthesis of biomolecules are mainly six i.e. carbon, hydrogen, oxygen, nitrogen, phosphorus and sulphur.

The form approximately 98% of the biomolecules.

### 1.1.2 Fundamental types of Biomolecules:

Biomolecules can be divided into following groups according to variability in their structures and functions in cells and organisms i.e.

1. Carbohydrates
2. Proteins
3. Lipids
4. Nucleic Acids
5. Conjugated Molecules

**Table 1.1 Biomolecules their units and linkages**

| Biomolecules | Units | Linkages |
|---|---|---|
| Carbohydrates (oligo & Polysaccharide) | Monosaccharides | Glycoside linkage |
| Proteins | Amino Acids | Peptide linkage |
| Lipids | | |
| Fats & Oils | Glycerol & Fatty Acids | Ester linkages |
| Phospholipids | Glycerol, Fatty acids, Phosphate & Choline. | Ester & c-c linkages |
| Terpenoids | Isoprenoids units | c-c linkages |
| Nucleic Acids | | |
| DNA | Deoxyribonucleotides | Phosphoester linkages |
| RNA | Ribonucleotides | Phosphoester linkages |
| Conjugated molecules | Different biomolecules | Different linkages |

There is a variation found in literature about the percentage of biomolecules present in the cell. It is because, different cells within the same body have different amount of biomolecules. Therefore, these values are always taken as average values. Approximate percentage of chemical composition of a typical bacterial and a typical mammalian cell is given in table 1.2.

**Table 1.2 Chemical compositions of cells (in %)**

| Molecules | Bacterial Cell | Mammalian Cell |
|---|---|---|
| Water | 70 | 70 |
| Protein | 15 | 18 |
| Carbohydrates | 3 | 4 |
| Lipids | 2 | 3 |
| DNA | 1 | 0.25 |
| RNA | 6 | 1.10 |
| Other Organic Compounds | 2 | 2 |
| Inorganic Ions | 1 | 1 |

### 1.1.3 Synthesis and Breakdown of macromolecules (Polymers):

**(a) Synthesis of macromolecules (polymers) by Condensation:**

Molecules which form the structure and carry out activities of the cells are large in size and highly organized molecules called **macromolecules** which are made up of large numbers of low molecular weight, small molecules the subunits called **monomers** or building block. Therefore the macromolecules are also called **polymers** (poly = many, mers = parts). Biomolecules which are mentioned above are all macromolecules or polymers.

Macromolecules are constructed from monomers by a process that resembles coupling of rail cars onto a train. The basic structure of each group of macromolecule is very similar in all organisms from bacteria to human beings. In this process monomers are joined together by removing -OH from one monomer and $^{+}H$ from another monomer so both monomers form a new covalent bond between them, this process of joining two monomers by removing water molecule is called **condensation** or **dehydration synthesis**. Condensation always takes place by proper enzymes and energy expense.

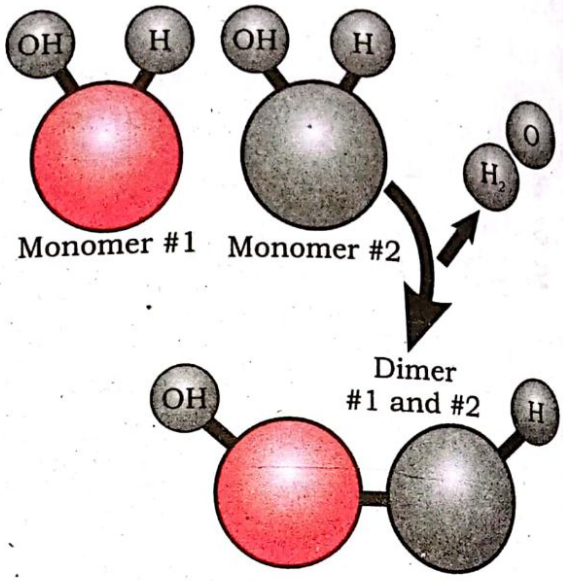



**Fig 1.1 Condensation reaction**

**(b) Break down of macromolecule by hydrolysis:**

Process where macromolecule (polymer) are broken down into their subunits (monomers) by addition of $H_2O$ molecule is called **hydrolysis**. It is just revers of condensation, during this process a water molecule breaks into $H^{+}$ and $OH^{-}$ ions with the help of enzyme, whereas OH group to one monomer and H attaches to the other by breaking linkage bond between two monomers. During this bond breaking energy is released and made available for other metabolic processes.

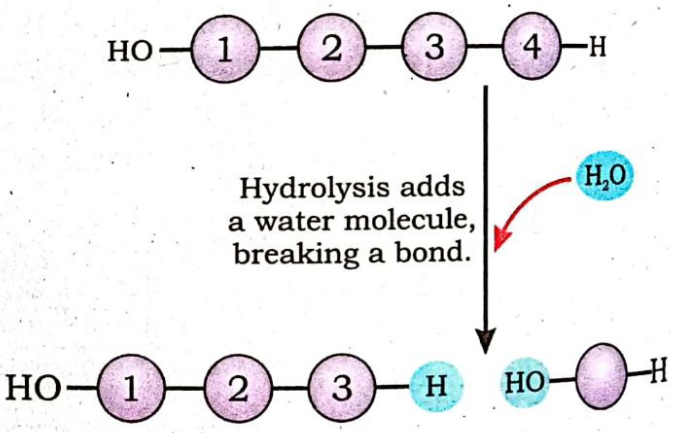



**Fig 1.2 Hydrolysis: breaking down a polymer**

During metabolism, macromolecules are either formed or broken down in the cell, when cell rebuild many of its structures. In heterotrophs, during digestion macromolecules broken into monomers by hydrolysis with the help of hydrolytic enzymes, these monomers when reach to cell again form macromolecules by the process of condensation. In autotrophs, cell produce monomers from inorganic molecules like $CO_2$, $H_2O$, $NO_3^{-1}$, $SO_4^{-2}$ etc. These monomers latter on assembled to form macromolecules in source or sink tissues by the process of condensation, while the other cell when require these molecules either for building purpose or to produce energy, these molecules break into monomers by the process of hydrolysis.

## 1.2 IMPORTANCE OF WATER:

Water is the most abundant component in living cell. Its amount varies approximately from 70% to 90%. It is the medium of life. Almost all reactions of a cell occur in the presence of water. It also takes part in many **biochemical** reactions such as hydrolysis, also provides raw material for photosynthesis.

The ability of water to play its wide variety of roles and the reasons for its importance in biological systems is due to the chemistry of $H_2O$ molecule. The chemical formula of water is $H_2O$, which means that the two atoms of hydrogen are joined to one atom of oxygen.

Water is a polar molecule. It means that it has partial negative charge ($\delta^-$) on oxygen and partial positive charge ($\delta^+$) on hydrogen atoms due to difference in electronegativities of hydrogen and oxygen atoms. This separation of electrical charges is called Dipole, which give the water molecule very important properties i.e. high polarity, formation of hydrogen bond, cohesion, adhesion, high specific heat, high heat of vaporization, hydrophobic exclusion, ionization and low density of ice. These properties make it best solvent and cradle of life.

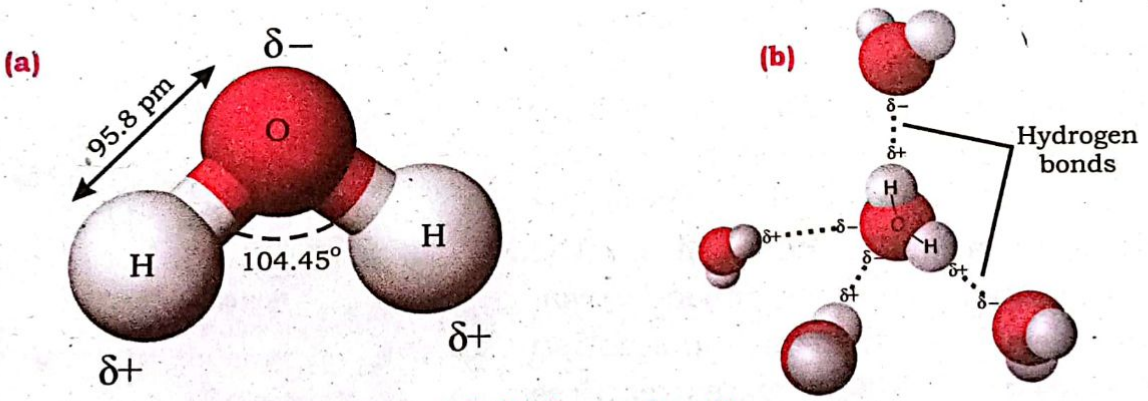



**Fig 1.3 Hydrogen bonding**

### 1.2.1 Hydrogen bond:

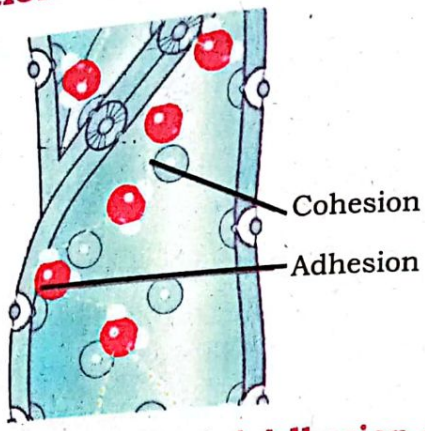
It is an intermolecular force of attraction formed between two molecule one of which contain partially charge $H^{+\delta}$ and other contain partial $O^{-\delta}$ charge as present in water. These charges attract two molecules, this force of attraction due to $H^{+\delta}$ and $O^{-\delta}$ is called Hydrogen bond. Due to this Hydrogen bonding two molecules have following two types of characters.

**(a) Cohesion or Cohesive force of attraction:**

The attractive force between similar molecules is called cohesive force of attraction. Due to polar nature water molecules attract each other and form H-bonds between them to form a long chain of water molecule, which help it in flowing freely. It flows as protoplasm in cell, as blood in blood vessels, as transporting fluid in the conducting tissues of plants.

**(b) Adhesive force of attraction or Adhesion:**

The attractive force between dissimilar molecules is called Adhesive force of attraction. Due to polar nature, water molecule attracts other charged molecules and attached with them. It can hold the water molecules in the vessels and prevent them from backward flow.




Cohesion and adhesion create tension within xylem that helps move water upward.

**Fig 1.4 Adhesion and cohesion**

### 1.2.2 High specific heat:

Specific heat of a substance is the amount of heat energy required to raise the temperature of 1gm of that substance by 1C° (e.g. 15C° to 16C°). The specific heat of water is high due to its polar nature and hydrogen bonding between their molecules. It means water required high amount of heat to make changes in its temperature or warm up. It works as temperature stabilizer for organism and hence protect protoplasm against sudden thermal charges.

### 1.2.3 High heat of vaporization:

The amount of heat required to change liquid state of water to vapor state is called heat of vaporization. Greater the heat of vaporization higher will be the chances of stability in state or vice versa. Water has very high heat of vaporization i.e. 574 kcal/kg, therefore water requires to absorb high heat to change its state from liquid to vapors. It gives stability to water molecules and its state in cell. It plays an important role in thermoregulation. It also provides cooling effect when evaporate during transpiration are perspiration.

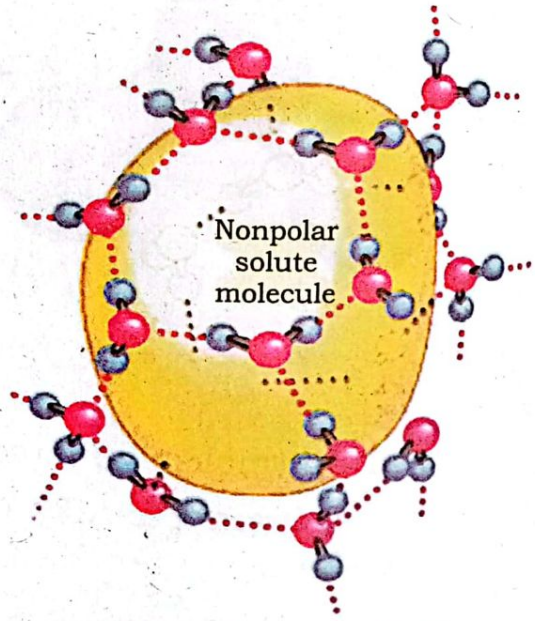



**Fig 1.5 Vaporization**

### 1.2.4 Hydrophobic exclusion:

It is the tendency of water to coalesce oil drop into large droplet. The water molecules have hydrogen bonding between them which are destroyed by the presence of hydrophobic oil and form new bonds. The water molecules then form more hydrogen bonds with themselves and the nonpolar molecules clump together. This excludes hydrophobic substance (oil) from water.

### 1.2.5 Ionization of water:

The water molecules ionize into $H^+$ and $OH^-$. This reaction is reversible and also maintain equilibrium. Due to ionization property water may behave as acid or base i.e. **Amphoteric** in nature. It also behaves as **buffer** due to this nature. It maintains pH for enzymatic activities in cells and organs.

### 1.2.6 Anomalous behavior of water:

Water shows different behavior below 4°C. Usually matter contract at low temperature but due to hydrogen bond below 4°C, water expands which decreases its density so at 0°C water expands maximally in ice condition. The low density water in ice become lighter, comes above the surface of high density water of liquid. It makes the life possible under frozen water.

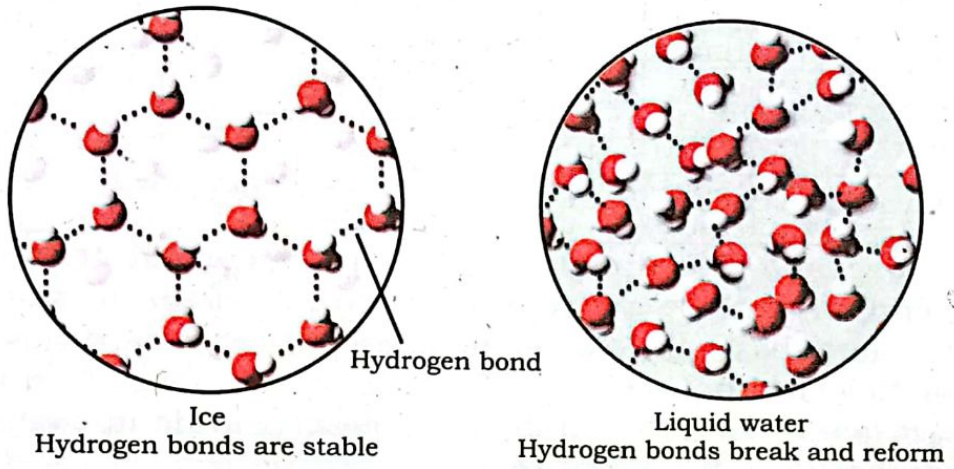



**Fig 1.6 Behavior of water**

## 1.3 CARBOHYDRATE (CARBO = CARBON, HYDRATE = WATER):

The literal meaning of word carbohydrate is hydrated carbon i.e. water containing carbon. Thus biomolecule contain C, H and O as element where the hydrogen and oxygen are present in the simple ration of 2:1 as present in water. The general formula of carbohydrate molecules is $C_nH_{2n}O_n$, whereas 'n' is the whole number. According to I.U.P.A.C carbohydrates are defined as "the polyhydroxy carbonyl compounds", carbonyls are aldehydes or Ketones.

Main source of carbohydrates are plants because they synthesize carbohydrate molecules as primary product during photosynthesis, other bio-molecules are produced from carbohydrate during different metabolic pathways.

They are sweet in taste if feels therefore called sacchrum or Saccharide. They are also called sugars.

Carbohydrate found abundantly in all organism, like cellulose in cell wall of plant, paper, starch is stored in cereal grains, tubers, sugar cane, etc. It plays both structural and functional role.

### 1.3.1 Classification of Carbohydrates

As we have discussed earlier that carbohydrate molecules are also called 'Saccharides' these Saccharides are classified into three group.

(i) Monosaccharide (ii) Oligosaccharide (iii) Polysaccharide

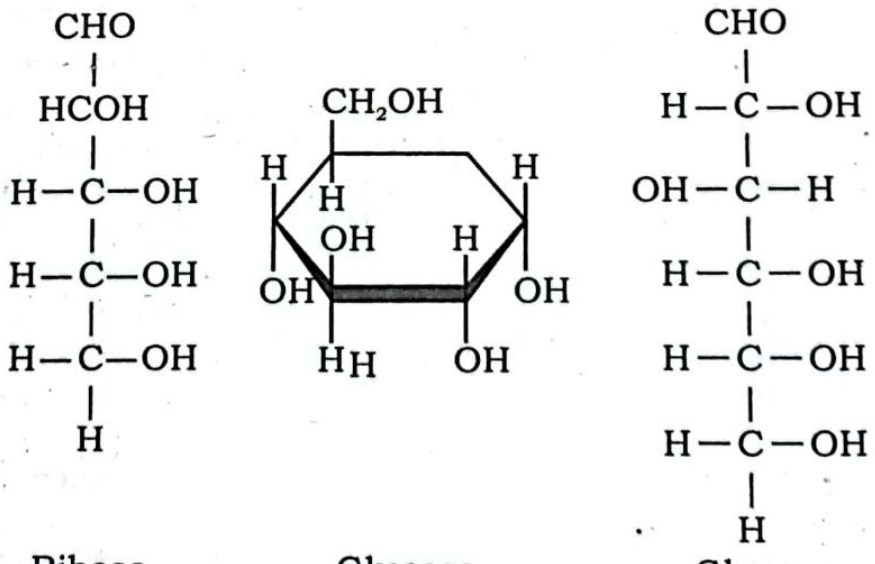
**(i) Monosaccharide: (Mono = one; Saccharide = Sugar)**

The group of carbohydrate molecules which contain only one sugar molecule. They cannot hydrolyses due to this reason. The empirical formula of their molecules is $C_nH_{2n}O_n$ e.g. Ribose ($C_5H_{10}O_5$). Fructose $C_6H_{12}O_6$, etc; all are found in white crystalline solid with sweet taste and soluble in water. Monosaccharide can further classified on the basis of C atoms present in them, the suffix 'Ose' use with no: of C atoms present in them as given in following table.

**Table 1.3 Classification of monosaccharides**

| Class | Formula | Example |
|---|---|---|
| Triose | $C_3H_6O_3$ | Glycerose (Glyceraldehyde) Dihydroxy acetone etc. |
| Tetrose | $C_4H_8O_4$ | Erythrose, Erythrulose etc. |
| Pentose | $C_5H_{10}O_5$ | Ribose, Ribulose etc |
| Hexose | $C_6H_{12}O_6$ | Glucose, Fructose, Galactose etc |
| Heptose | $C_7H_{14}O_7$ | Glucoheptose. |

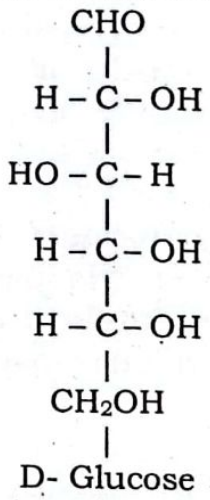
Glycerose and Dihydroxy acetone are important triose, produced during respiration. Tetrose are rare in nature, it occurs in some bacteria, pentose sugar form basic skeleton of nucleic acid. Hexose are most important sugars from biological point of view. Glucose found in ripe fruit, sweet corn and honey. It is also found in all known polysaccharide in combined state. Fructose another hexose present in fruit so called fruit sugar usually they are found in ring structures but we can also draw their structure in open chain form:



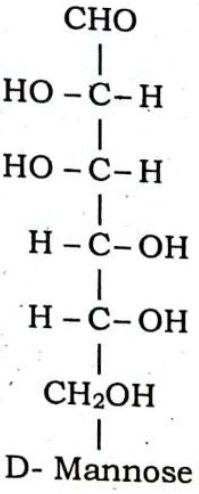

Ribose Glucose Glucose

The hexose are further divided into aldohexose isomers (having same molecular formula but different structural formula) like glucose, galactose,

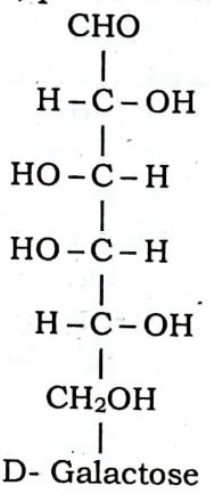
mannos etc and ketohexose isomers like fructose, sorbose, psicose etc.




D- Glucose



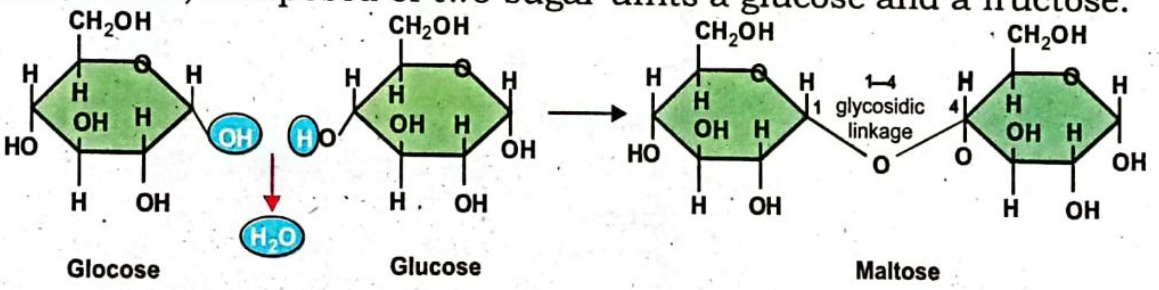

D- Mannose




D- Galactose

**(ii) Oligosaccharides:**

The type of carbohydrate which are made up to 2 to 10 monosaccharides. These are comparatively less sweet in taste and less soluble in water. They can hydrolyze. The most common type is disaccharide, on hydrolysis yield two monosaccharides. The covalent bond between these two monosaccharides is **Glycosidic bond** or linkage. A glycoside is simply a ring shaped sugar molecule that is attach to another molecule, the sugar ring may be either 5 membered ring or a six membered ring. For example sucrose is a disaccharide, composed of two sugar units a glucose and a fructose.




The disaccharide may be reducing or non-reducing sugar. The reducing sugar is any carbohydrate which is capable of being oxidized and causes the reduction of other substances without hydrolysis. It is due to the presence of free aldehyde or free ketone group. Examples are maltose, lactose etc. The non-reducing sugars are carbohydrate which are unable to be oxidized and do not reduce other substance. It is due to absence of free aldehyde or ketone groups, e.g. sucrose or refinose etc.

Living organisms especially plants transport their sugar from source (leaf) to sink (fruit) tissues in the form of non-reducing sugar where glycosidic bonds are formed between 'carbonyl' groups of both sugars. Sucrose is the sugar which is non-reducing. It contains more energy i.e, it is energy efficient in transport and storage. During transport it is not oxidized and react with other substance so no intermediate reaction with other molecules occur.

### (iii) Polysaccharide:

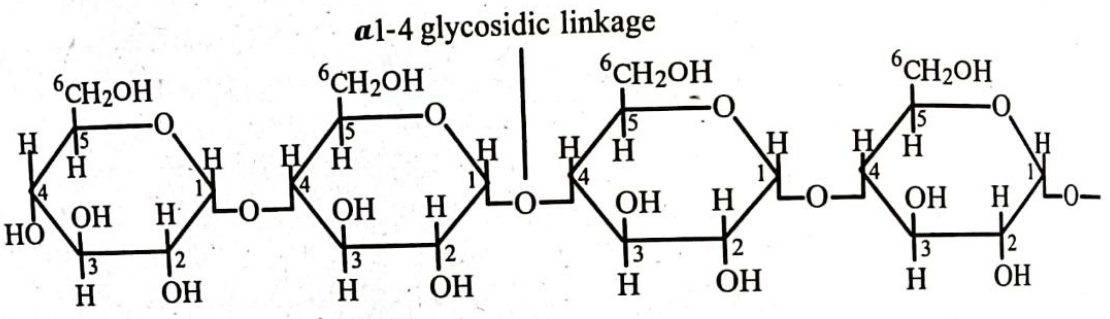
These are high molecular weight carbohydrates which on hydrolysi yield many monosaccharides. These are formed by the condensation hundreds or thousands of Monosaccharide units, e.g. starch, glycogen cellulose and chitin.

### 1.3.2 Starch:

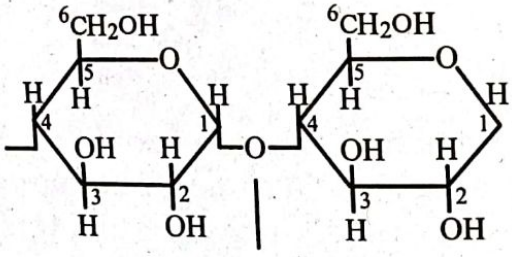
It is the most important and abundant reserve food material of highe plants, found in cereals, legumes, tubers and other vegetables. It is made u of many glucose molecules joined together in straight chain **amylose** whic is soluble in hot water and a branched chain **amylopectin**, which is insolubl in hot and cold water. It gives blue color to iodine.

### 1.3.3 Glycogen:

It is also a polymer of glucose. Its molecular structure is similar t starch but found in animal therefore it is commonly called animal starch. is mainly found in bacteria, fungi, in animals abundantly found in liver an muscles. It gives red color with Iodine.




Amylose




Amylopectin

### 1.3.4 Cellulose:

It is also a polymer of glucose, most abundant carbohydrate found in nature. It is highly insoluble in water. It is not digested in human body. In cellulose the glucose units are joined in straight chain and no branch chain present in it. This straight chain become spirally coiled and condensed to form tubes. These tubes of cellulose form cell-wall of plant cells. Cellulose give no colour to iodine.

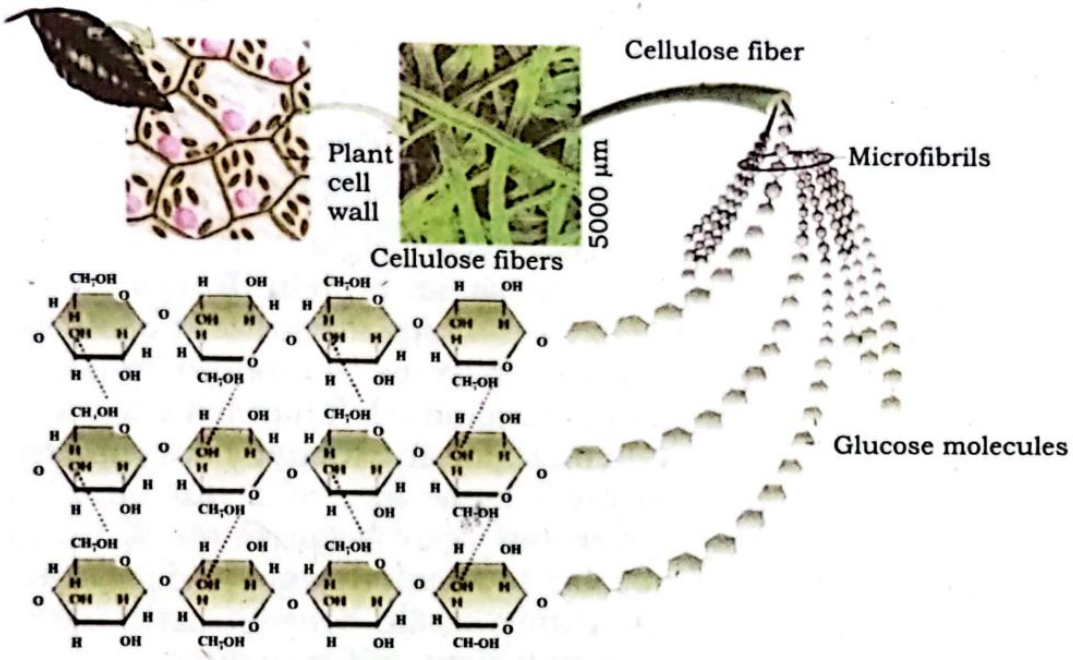



**Fig 1.7 Structure of cellulose**

### 1.3.5 Chitin $(C_8H_{13}O_5N)_n$:

It is a long chain polymer of N-acetyl glucosamine, an amide derivative of glucose. The structure of chitin is similar to cellulose, forming crystalline Nano fibrils. Functionally, it is comparable to Keratin protein. Chitin is modified polysaccharide contains Nitrogen which allows for increased hydrogen bonding between adjacent polymers, giving it more strength.

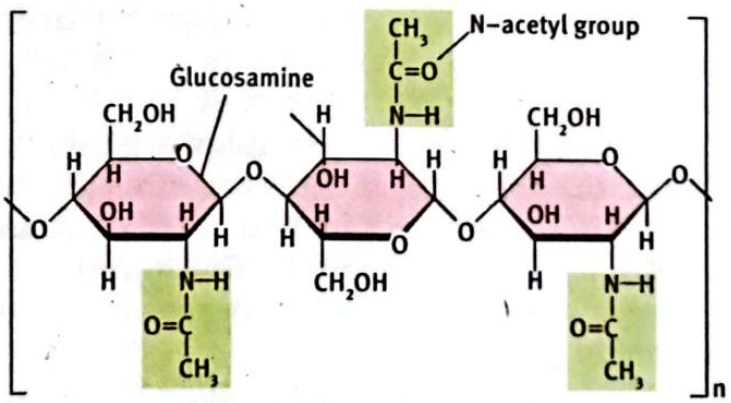


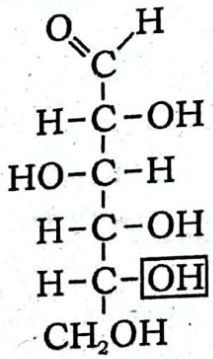

**Fig 1.8 Structure of chitin**

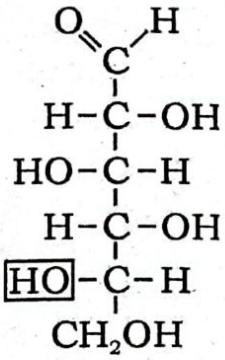
In its pure and unmodified form chitin is translucent, pliable, resilient and quite tough in most arthropods but it is mostly found in modified form such as proteineceous matrix form exoskeleton of insects, with $CaCO_3$ in the shells of mollusks and crustaceans, composite material is much harder and stiffer than pure chitin.

**Stereoisomers in Carbohydrates and its role in artificial sweetness:**

Many sugar molecules have stereoisomers i.e. the molecules are mirror images of each other.

D-Glucose
Right handed sugar





L- Glucose
Left handed sugar

Most of the sugars in our body are right handed. The taste of right handed and left handed sugars are same, protein (Enzymes) are also right handed and left handed. The enzymes which are present in our body are also right handed therefore right handed enzymes metabolize right handed sugars only. They are unable to digest or metabolize left handed sugars. The artificial sweetener which are used by diabetic patients usually are left handed sugars, these sugars have same mass and same sweetens but have zero calories. These sugars are not digested in our body because all of our enzymes are right handed and they are specific to break down the right handed sugars. The left handed won't fit into catalytic site consequently there will be no breakdown of these sugar, no metabolism and no calories.

## 1.4 PROTEIN: (GR: PROTEIOS MEANS 'FIRST RANK')

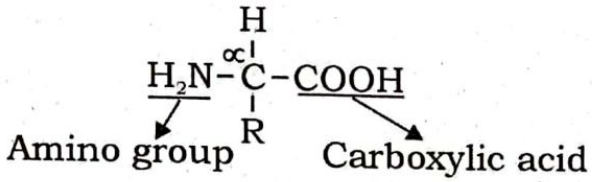
Proteins can be defined as the polymers of specific amino acid arrange in a particular manner which perform definite function. Proteins are the most important organic compounds of the cell which carry out virtually all of the cell's activities. They constitute major part of the dry weight of a cell.

Proteins are the complex organic compounds having C, H, O and N as elements, sometimes they contains S also. Due to presence of N in large proportion they are called **nitrogenous compounds**. Proteins are the building blocks of tissues. Many parts of the body such as hair, nails and feathers are also protein. Whereas meat, fish, milk and pulses are the major source of protein.

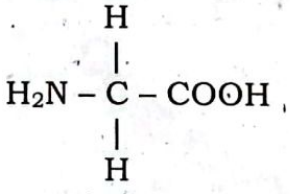
### 1.4.1 Amino acid as a building block of protein

Proteins are macromolecule or polymers of amino acids. These amino acids are monomers and linked with each other by a covalent bond called **peptide bond or peptide linkage**. As we have defined above that each protein has a unique sequence of amino acids that gives the unique properties to these molecules. There are twenty basic amino acids which constitute each type of protein, found in viruses to human beings.

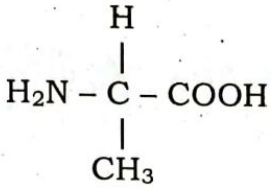
Amino acids are organic compounds which contain at least one amino group ($-NH_2$) which work as base and one carboxylic acid, work as acid, both are chemically bonded to an asymmetric carbon, this carbon is also called ∝ Carbon. The general structure (empirical formula) of amino acid is



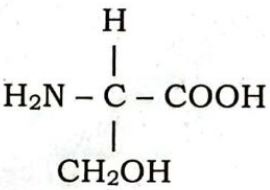

All 20 amino acids have same formula except R group i.e. Radical group, which is variable, the types of 20 amino acids based on the variability of R as shown in following simple amino acids.



Glycine



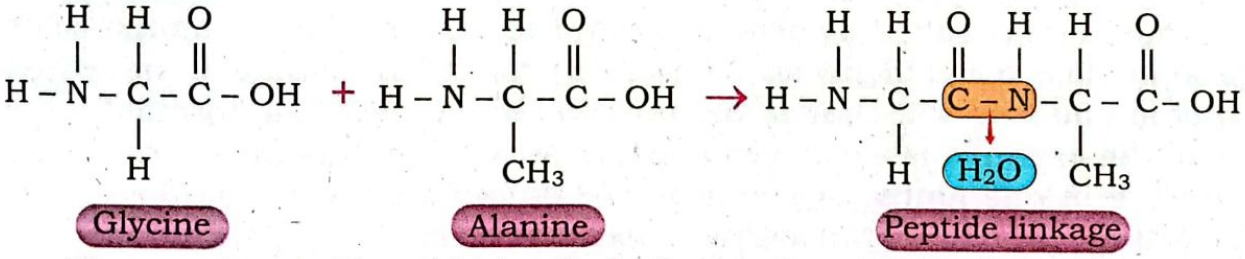
Alanine



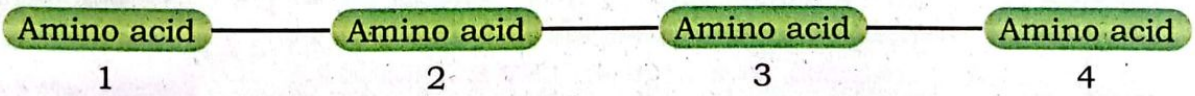
Serine

### 1.4.1.1 Formation and Breakdown of peptide linkage

The protein or polypeptide chain is formed by linking amino acids by peptide bond. The peptide bonds are formed by linking amino group of one amino acid with carboxylic acid of another amino acid by releasing one water molecule as given below




The resultant dipeptide is glyclyalanine has two amino acid subunit called **dipeptide**. A dipeptide has an amino group of one end and a carboxylic acid group at the other end of the molecule. In this way both reactive parts are again available for further peptide linkage to produce tri, tetra, penta peptide, leading to poly peptide chains.




The polypeptide chain can be broken by breaking peptide bonds by the process of hydrolysis with the help of hydrolytic enzymes. The protein chain can be broken into small chain of more than 10 amino acids called **peptone**, whereas peptone can be hydrolysis further into small units of few amino acid called **peptide** which are further hydrolysis into amino acids.

### 1.4.1.2 Significance of the sequence of amino acids

F. Sanger was the first scientist who determined the sequenc amino acids in a protein molecule. He found that Insulin is composed o amino acid in two chains. One had 21 amino acid and other had 30 am acids they held together by disulphide bonds. Same is found in Hemoglo which is composed of 4 chains, two alpha (α) and two Beta (β) chains. E alpha chain has 141 amino acids, while each beta chain contain 146 am acids.

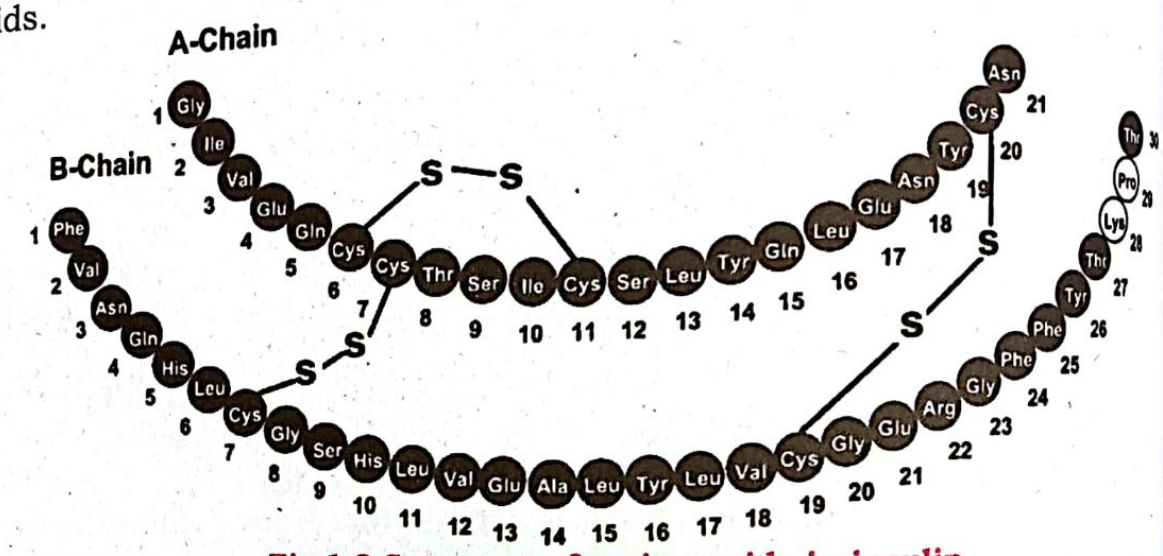



**Fig 1.9 Sequence of amino acids in insulin**

Human body has more than 10,000 protein. These protein composed of unique and specific arrangement of 20 amino acids. T sequence is determined by gene as DNA, the arrangement of amino acids a protein molecule is highly specific for its proper functioning. If the sequen of any amino acid will change the protein fails to carry its normal functio One of the example is sickle cell anemia i.e. abnormality in hemoglobin d to change in one amino acid out of 574 amino acid. Only glutamic acid replaced by valine at 6th position. Due to this little change the hemoglob fails to carry sufficient $O_2$ which leads to death of the person.

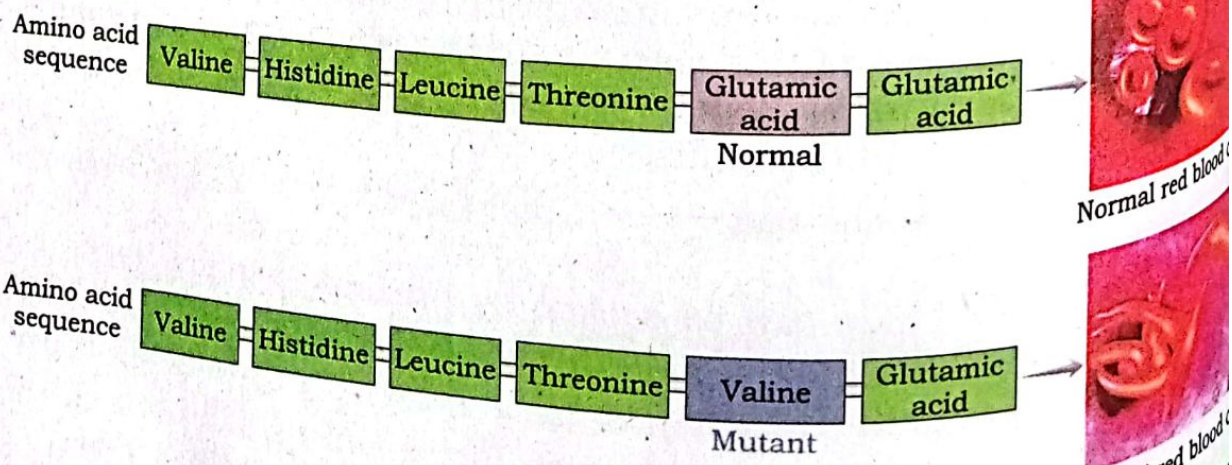



**Fig 1.10 Normal and abnormal sequence of amino acids**

### 1.4.2 Classification of Protein

Protein can be classified in many ways i.e. on the basis of structure or on the basis of function etc. Proteins can also be classified on the basis of shape in two following groups.

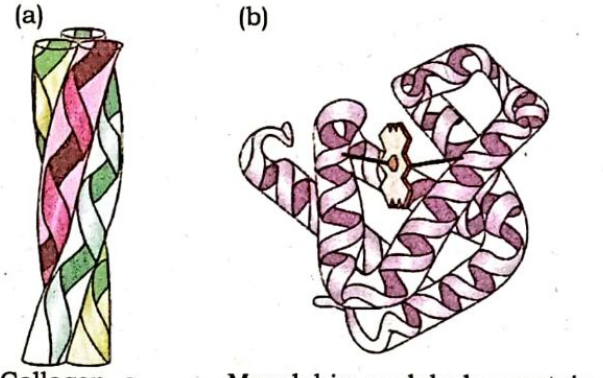
(i) Fibrous Protein (ii) Globular Proteins

**(i) Fibrous Protein:**

These are long fibers of proteins. The secondary protein (spiral) chains intertwine with each other's they are consist of more polypeptide chains in the form of fibrils these proteins are insoluble in water, non-crystalline and elastic in nature. They perform structural role in cells and organism e.g. silk, spider web, myosin in muscles, fibers and clothing, Keratin of nails and hairs etc.

**(ii) Globular Proteins:**

These are spherical or ellipsoidal due to three dimensional fold of secondary protein. These are either tertiary or quaternary in structure. They are soluble in salt, acid or base containing aqueous medium or alcohol. They can be crystalized. These proteins work as enzyme, antibodies, hormones and hemoglobin.




Collagen, a fibrous protein — Myoglobin, a globular protein

**Fig 1.11 Structure of Proteins**

**Table 1.4 List of structural proteins**

| | |
|---|---|
| Actin | Muscle forming protein |
| Amyloid | Work as cell surface protein |
| Caddisfly (Fibroin) | Used to bind debris like rocks sticks twigs and shells for net of prey. |
| Condrocalein | Form extra cellular matrix |
| Collagen | Give strength, turned elasticity to skin main component of cartilage, ligaments, tendon, bone and teeth. |
| Elastin | Provide resilience and elasticity to tissues and organs. |
| Fibrillin | Glycoprotein provide force bearing structural support in elastic and non-elastic connective tissues. |
| Gelatin | Nutritious protein derived from collagen of skin and bones. |
| Sclera protein | Include Keratin, collage, elastin and fibrin |
| Titin | Provide elastic stabilization of myosin and action filament |
| Tubulin | Microtubules farming protein |
| Keratin | Nails and hairs farming protein |

Table 1.5 List of Functional Proteins

| Type | Examples | Function |
|---|---|---|
| Digestive enzymes | Amylase, lipase, pepsin, trypsin | Help in digestion of food by hydrolysi into simple monomers. |
| Transport | Hemoglobin, albumin | Carry $O_2$ and $CO_2$ other substance the blood or lymph throughout th body. |
| Hormones | Insulin, thyroxin | Co-ordinate different functions of bod |
| Defenses | Immunoglobulin, interferon | Protect the body from foreign pathoge |
| Contractile | Actin, myosin | Muscle contraction |
| Storage | Legume storage protein, egg white (albumin) | Provide nourishment at the time development of embryo. |

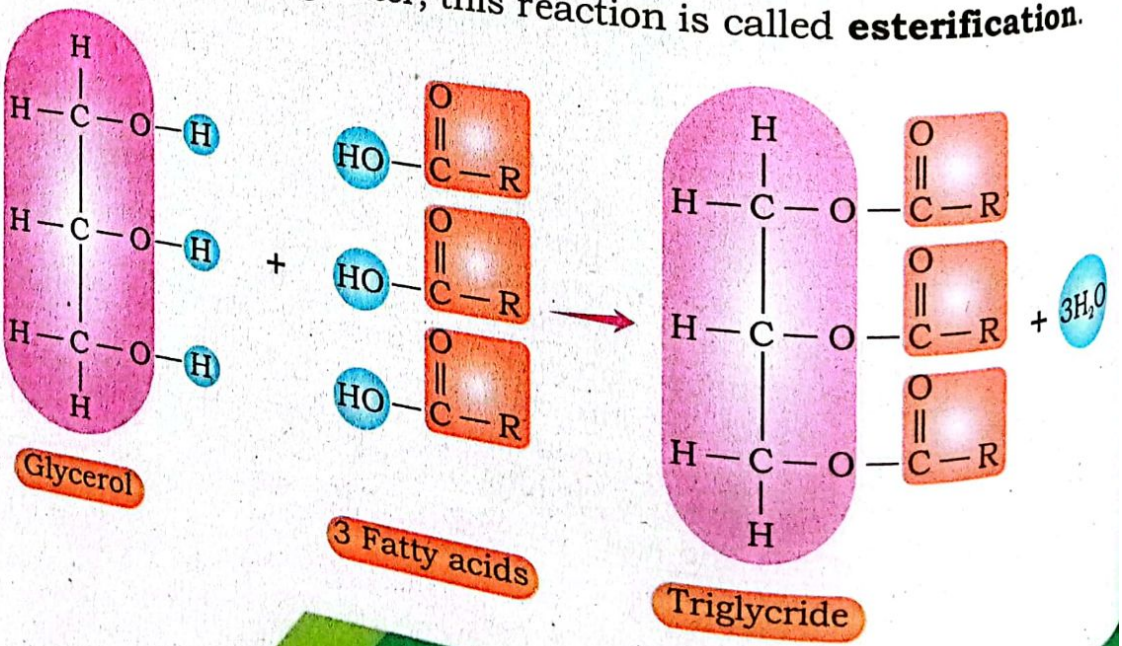
## 1.5 LIPIDS:

Lipids are the important diverse group of biological molecules, wid distributed among plants and animals. The term lipid is proposed by Blo in 1943, for those biomolecules which are insoluble in water and soluble organic solvents like ether and alcohol etc. These compounds are made of C, H, O like carbohydrates but contain much lesser ratio of oxygen tha carbohydrates e.g. stearin is a fat, has molecular formula ($C_{57}H_{110}O_6$). Due high quantity of carbon and hydrogen, they contain almost double amou of energy than carbohydrates.

Following are some common groups of lipids.

### 1.5.1 Acylglycerol (Fats and oil):

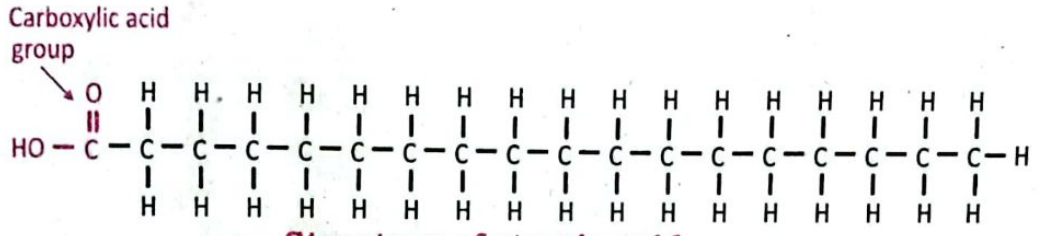
These are the condensation product of glycerol and three fatty aci commonly called **fats** and **oils**. They can be defined as the esters of glycer and fatty acid. Ester is the bond or linkage formed between alcohol a organic acid by removing water, this reaction is called **esterification**.



Glycerol is a trihydroxy alcohol, made of three carbon atom each contain on OH- group, while a fatty acid is a type of organic acid containing one carboxylic acid group with long hydrocarbon chain. When three fatty acid combine with glycerol each at one -OH, they form three ester bonds. A compound called **Triglycerol** (triglyceride) is formed. There triglycerol are neutral in nature because all three OH group of glycerol become bonded with fatty acids and no charge bearing OH is left. There are two types of acylglycerol.

### (a) Saturated acylglycerol (Fats):

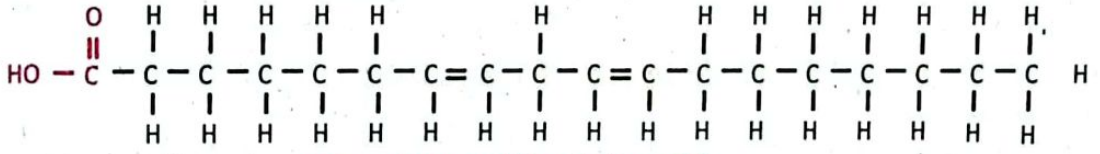
They contain saturated fatty acid i.e. do not contain any double bond between carbon atoms of hydrocarbon chain e.g. stearin.




**Structure of stearic acid**

### (b) Unsaturated acylglycerol (oils):

They contain unsaturated fatty acids i.e. contain one or more than one double bond between carbon atoms of hydrocarbon chain. They have stable physical state, usually found at liquid state at ordinary temperature, found in plants, also called oil e.g. linolin found in seed.



**Structure of linoleic acid**

Acylglycerol provide energy for different metabolic activities and are very rich in chemical energy, twice in amount of energy content than carbohydrate. It is estimated that a person of average size contains approx: 16 kg of fats which contain $144 \times 10^3$ KCal of energy.

### 1.5.2 Phospholipids:

Type of lipids which is condensation product of Glycerol, two fatty acids one choline and one phosphate.

Phospholipid is the most important group of lipids from biological point of view. A phospholipid is similar to acylglycerol, except that one fatty acid is replaced by phosphate which is attached with a nitrogenous compound **choline**. It contains two ends, one which is made up of fatty acid, which form non-polar part therefore behave as water repellant so called hydrophobic. The phosphate and choline form another end, which form polar part, therefore attract water molecule so behave as water loving i.e. hydrophilic. Phospholipids are present in all living cells and form membrane. They are related to vital functions such as regulation of cell permeability and

transport processes. Properties of cell membrane depend on it phospholipid component.

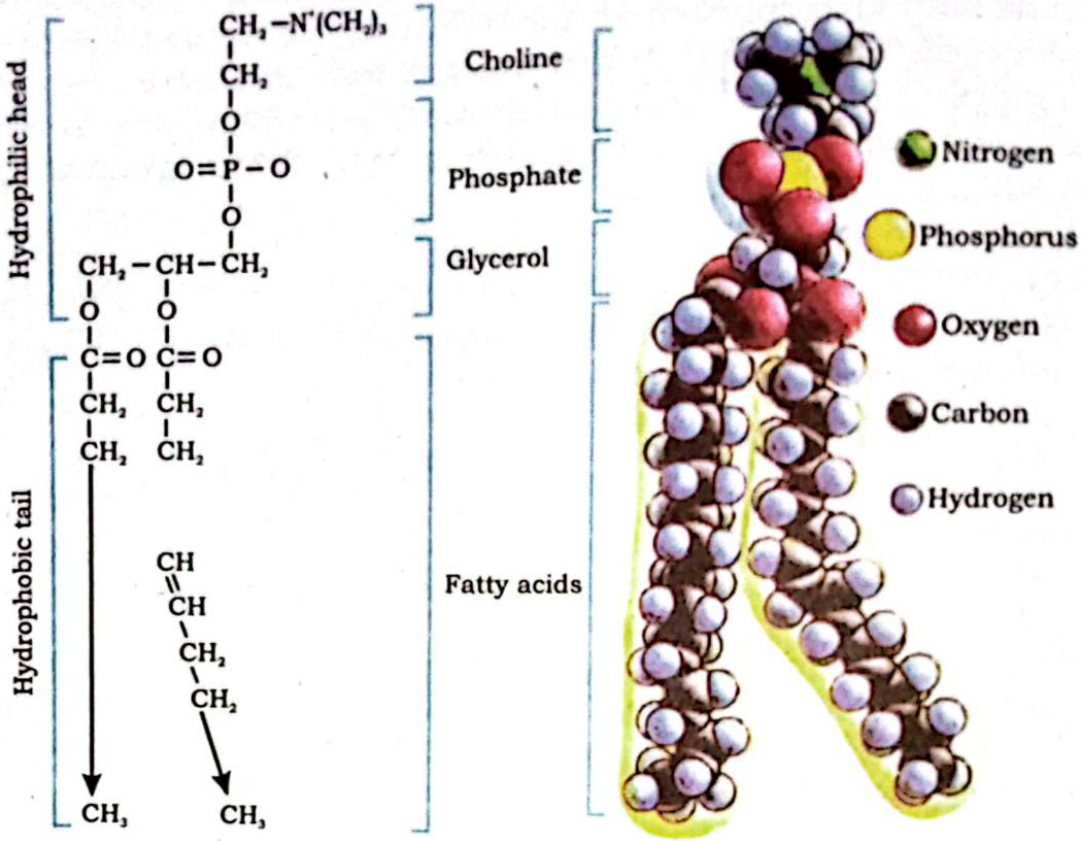
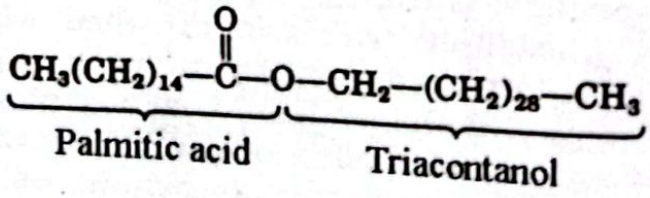



Fig 1.12 Phospholipid

### 1.5.3 Waxes:

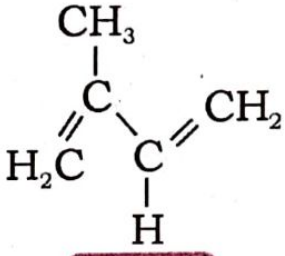
They are esters of long chain mono-alcohol and long chain fatty acids. These are simple lipid and found as protective coating on stem, stalks, leaves, petals, fruits skin, animal skin, fur and feathers etc, these are water repellant and non-reactive due to its non-polar nature i.e. hydrophobic compounds. These are chemically inert and resistant to atmospheric oxidation. There are two types of waxes i.e. Natural, like bee's wax and cutin form cuticle of leaves and synthetic waxes, generally derived from petroleum or polyethylene.

Waxes are of considerable commercial importance because they act as superior machine lubricants. Sperm whales were the principle source of these wax.



### 1.5.4 Terpenoids:

Terpenoid is a large and important class of lipids, made up of isoprenoid units ($C_5H_8$). Terpenes, steroids, carotenoids and prostaglandins are type of Terpenoids. These are found in cell membrane as cholesterol, as pigment like chlorophyll, fragrance as menthol etc.



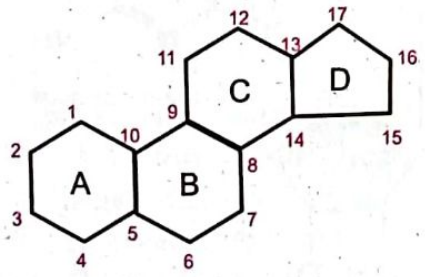
Isoprenoid

### 1.5.4.1 Terpenes:

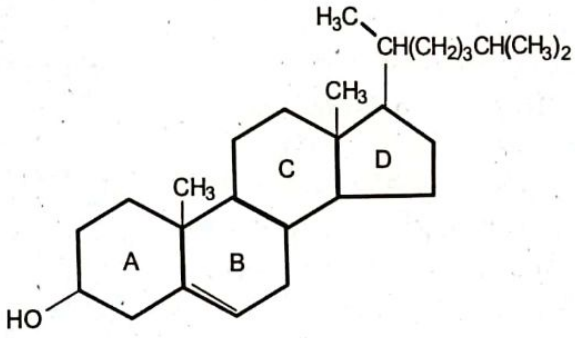
Terpens are the type of terpenoids which contain few isoprenoid units like diterpens, Triterpens. These small size terpens are volatile in nature and produce special fragrance. Some of these are used in perfume e.g. Myrcens from oil of bay, Geranoil from rose, Limonene from lemon oil, Menthol from peppermint oil. Some component of vitamin $A_1$, and $A_2$, chlorophyll molecules as well as some other molecules which utilized in the synthesis of rubber and latex.

### 1.5.4.2 Steroids:

Steroids is a type of Terpenoid which form steroid nucleus made up isoprenoid units contain 17 Carbon atoms arranged in four attached rings, three of them are hexagonal and one is pentagonal in shape. The radical attached with them as side chains distinguish them from one another cholesterol is one of the type of steroid. Cholesterol is the precursor for the synthesis of a number of steroids i.e. testosterone, progesterone and estrogens.



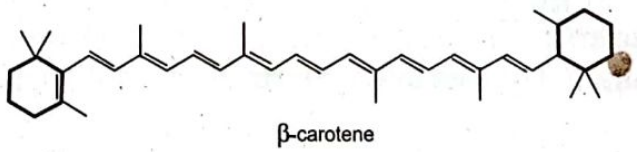
(a) Steroid skeleton



(b) Cholesterol

### 1.5.3 Carotenoids:

It is polyterpenes, consist of long chain of isoprenoid unit which contain isoprenoid rings at both or at one terminal. These compounds are pigments producing red, orange, yellow and brown color in plants. Some important carotenoids are plant pigments, like chlorophyll, cytochromes, phytochromes, latex, rubber etc.


β-carotene

### 1.5.4 Prostaglandins:

Prostaglandins is a group of lipids made by mammalian tissues at the sites of tissues damage or infection that are involved in dealing with injury and illness. They control different physiological process such as inflammation, intensity of sensation of pain, blood flow, and formation of blood clots, Immunity and the induction of labour. We use aspirin to reduce fever and decrease pain depend on the inhibition of prostaglandin synthesis.

## 1.6 NUCLEIC ACIDS:

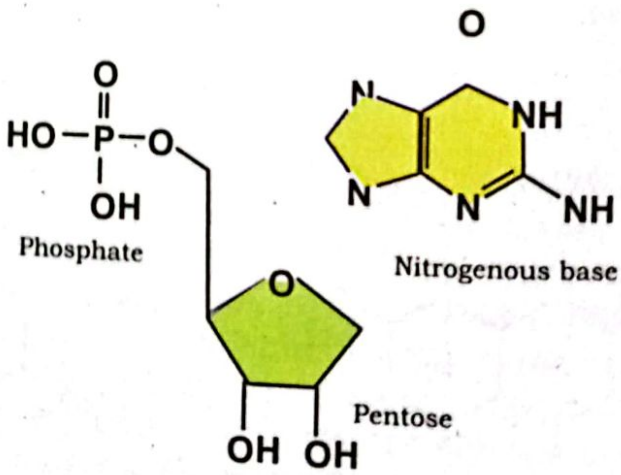
Friedrich Miescher a Swiss physician isolated a new compound from the nucleus of pus cells, which was quite different from other biomolecule therefore named "Nuclein" it was found that the nuclein had acidic properties and hence it was renamed **nucleic acid**.

The nucleic acids are polymers of five sugar based compound called **nucleotide**. These polymers have high molecular weight. These are present in all living things from virus to man.

There are two kinds of nucleic acids i.e. **Deoxyribonucleic Acid (DNA)** and **Ribonucleic Acid (RNA)**. Both nucleic acids are liner unbranched polymers. DNA is the polymer of Deoxyribonucleotide and RNA is the polymer of Ribonucleotide.

### 1.6.1 Composition of Nucleotide:

Nucleotide are the monomers of Nucleic acid, which is Pentose sugar based where a nitrogenous base molecule is attached at its first carbon and a phosphate is attached at 5th carbon of pentose sugar as shown below. The nucleotide without phosphate called Nucleoside.

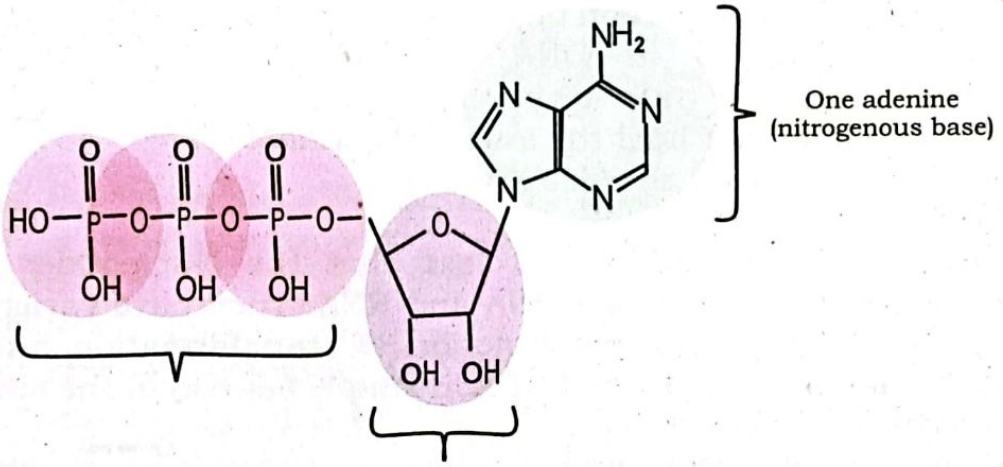


Structure of nucleotide

The DNA and RNA are made up four types of nucleotides, which are variable on the basis of nitrogenous basis. There are two groups of nitrogenous bases i.e. Purine and Pyrimidine. Purines are of two types i.e. Adenine (A) and Guanine (G) while Pyrimidine includes three nitrogenous bases Cytosine(C), thymine (T) and Uracil (U). The structures are given below.

### 1.6.2 Mononucleotide:

Generally, nucleotides are found in the nucleic acids as polynucleotide but sometime a single nucleotide also work independently as mono nucleotide, these mononucleotide have extra phosphate group as ADP (Adenosine phosphate) or ATP as (Adenosine Tri Phosphate). ATP work as energy storing, carrying and energy providing molecules to metabolic reactions. This energy is utilized to derive energy demanding reactions such as synthesis of proteins, lipids, carbohydrates, mechanical energy for cyclosis, contractility, cell-divisions, movement of flagella, active transport etc. During conversion of ATP into ADP, 7.3 Kcal/ mole or 31.81 kj/ mole energy is released.




Structure of ATP

### 1.6.3 Dinucleotide:

Sometimes two nucleotides are covalently bonded together to form a compound called **dinucleotide** one of the well-known dinucleotide is NAD **(Nicotineamide Adenosine Dinucleotide)**. A vitamin Nicotine is attached with these two nucleotides in NAD. It works as co-enzyme for Redox reaction. It carries $2e^-$ (electron), $2H^+$ (proton) and energy e.g. $NADH_2$, $FADH_2$ etc.

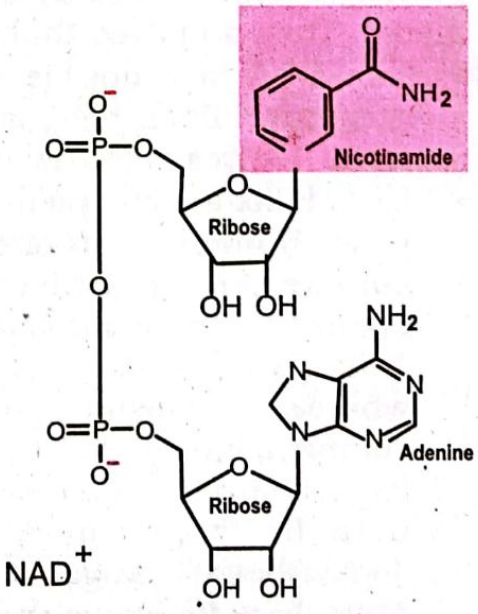



**Fig 1.13 Dinucleotide**

### Formation of phosphodiester bond

The two nucleotides are linked together by a bond in nucleic acid i.e. DNA or RNA, this linkage or bond is called phosphodiester bond. It is considered as the backbone of the nucleic acid strands. It is a bond which is formed as a result of the condensation reaction between phosphate group ($PO_4^{-3}$) group of pentose sugar. So it is defined as a chemical bond that forms when exactly two hydroxyl group in a phosphoric acid reacts with a hydroxyl another molecules of sugar forming ester bond. In this bond the 3'-carbon of pentose sugar is linked with 5' carbon in DNA or RNA via phosphoester bond and thus it acts as backbone. These are the bonds that hold the sugar phosphate components of the DNA molecule together.

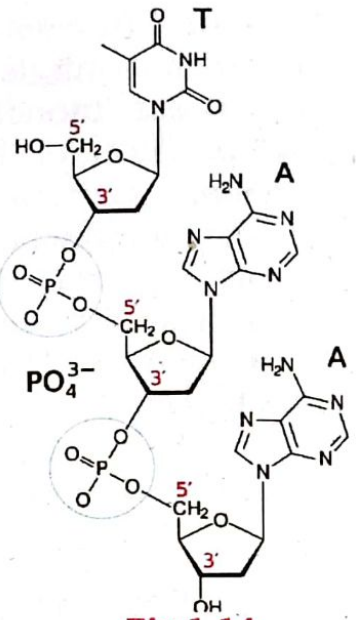



Fig 1.14
Formation of phosphodiester bond

### 1.6.4 Polynucleotide:

Earlier discussion made it clear that the Nucleotides are joined together and form polymers like DNA and RNA. They have variety of role in living organism. DNA performs function of transformation and heredity. Genetic information is encoded in DNA in simple fashion in the form of codes.

### 1.6.5 Structure of DNA:

Structure of DNA was explained by James Watson and Francis Crick in 1953 by making model. They proposed that.

- The DNA is a double helical structure. Each helix is made up of 4 types of Nucleotides.
- Both helix are complementary to each other i.e. if one helix contain A (Adenine) the opposite or complimentary helix will contain thymine whereas cytosine (C) is complementary to Guanine (G). Each helix is consist of 2 parts (i) Upright: made up of deoxyribose sugars and phosphate (ii) Rung: made up of Nitrogenous bases.

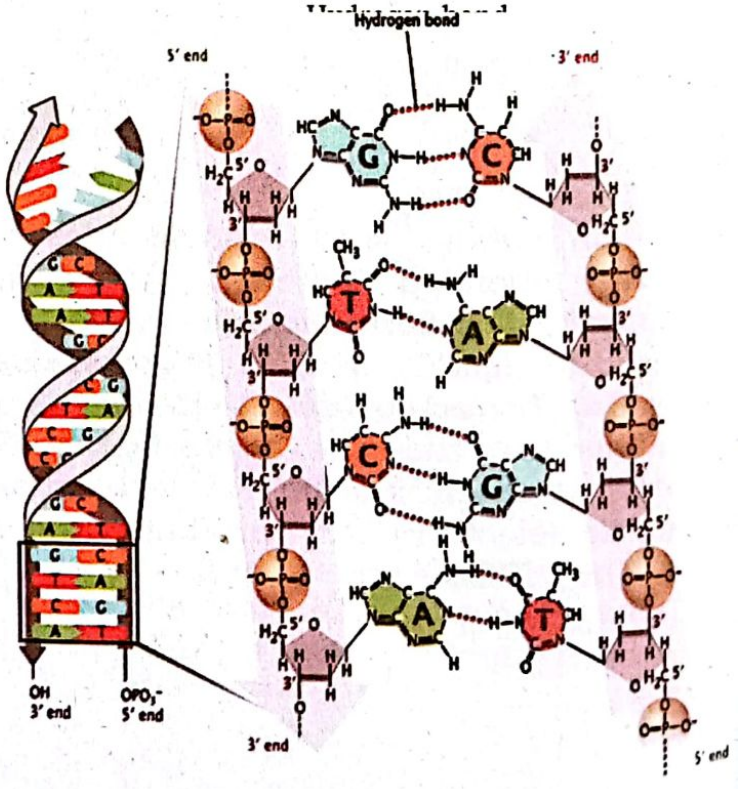



Fig 1.15 Structure of DNA

- Both helix are held together by H-bond due to which zipping and unzipping of both helix occur by making and breaking of there H bonds.
- Both helix are opposite in direction i.e. one chain run from 5' to 3' end (downward) whereas the other chain runs from 3' to 5' end (upward) direction.
- Distance between two helix remain same from one end to another end i.e. 20 $A^0$.
- Each turn of the duplex consist of 10 base pairs.

### 1.6.6 What is Gene?

We know now that DNA is a heredity material it carries genetic information from parent to offspring in the form of **Genes**. A gene is a part of DNA which has information to synthesis a protein, which will work as enzyme. It is a functional unit of heredity material. The gene gives instructions for developing characters like eye and hair color by producing enzymes.

Genetic information flow in a cell from DNA to *m* RNA than to cytoplasm in two steps for protein synthesis.

**1. Transcription** **2. Translation**

**1. Transcription:**

In this step the information of gene is copied into the form of RNA i.e. mRNA, which carries information from nucleus to the ribosome in the form of genetic code.

**2. Translation:**

In this step mRNA attach to ribosome. Two other types of RNAs i.e tRNA (transfer) and rRNA (ribosomal) translate the information of mRNA into specific sequence of amino acids which help to synthesize the protein.

### 1.6.7 Ribonucleic Acid (RNA):

RNA is also a polymer of nucleotides. We have already discussed it that it is a polymer of ribonucleotide i.e. the nucleotide contain ribose sugar and one of the nitrogenous bases i.e. A, G, C and U. It means instead of Thymine it contains the nucleotide of uracil.

DNA is a heredity material while RNA helps in protein synthesis. There are three types of RNA.

**(i) Messenger RNA (mRNA)**

It consists of single strand. Its length depends on the size of gene. It contains information in the form of Genetic codes, **CODON**. These codons are basically triplets of Nucleotides of mRNA which encode one amino acid. It is about 3 to 4 % of total RNA in the cell.

### (ii) Transfer RNA (tRNA)

The smallest sized RNA consists of only 70 to 90 nucleotides. Basically it is single stranded RNA but it shows duplex at some regions where complementary bases are present. It has anticodons of genetic codes as its complementary form. It transfers related amino acid from cytosol to ribosome, they are sixty in numbers, while human cell contains only 45 different types of tRNA. It is about 10 to 20% of total RNA.

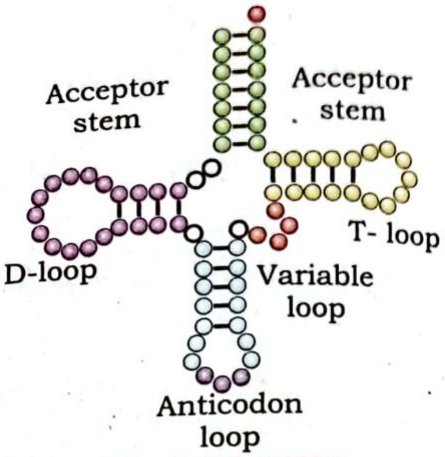


Fig 1.16 tRNA

### (iii) Ribosomal RNA (rRNA)

Ribosomal RNA is present in ribosome. It has largest size among all three RNA i.e. 80% of total of RNA in a cell is rRNA. It is involved in peptide linkages during protein synthesis.

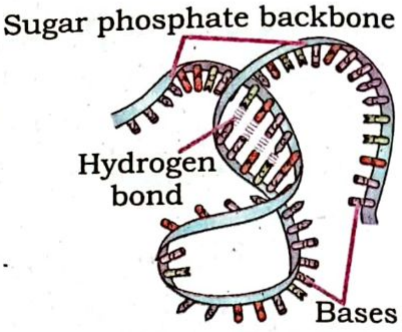


Fig 1.17 rRNA

## 1.7 CONJUGATED MOLECULES:

Conjugated molecules are formed when biomolecules of two different groups combine chemically with each other, acting as one unit. These are glycolipids, glycoproteins, lipoproteins and Nucleoproteins.

### (i) Glycolipids or Cerebrosides:

These are conjugates of lipids and carbohydrates. They are also called cerebrosides because they are present in white matter of brain and myelin sheath of nerve fiber. They are also found in the inner membrane of chloroplast.

### (ii) Glycoproteins or Mucoids:

Glycoproteins are formed by combining a molecule of carbohydrate with a protein molecule. Most of the oligo and polysaccharide in animal and plant cells are linked covalently to protein molecules. They perform function as, transport proteins, receptors, antigens of blood group etc. It is one of the part of egg albumin and gonadotropins.

### (iii) Lipoprotein:

They are conjugate of lipids and proteins. They help in the transportation of lipids in blood plasma. They also occur as component of membrane of mitochondria, endoplasmic reticulum, nucleus, egg yolk and chloroplast membrane.

### (iv) Nucleoprotein:

Nucleoprotein are formed by simple basic protein and nucleic acid. They are the main component of chromatin material, chromosomes and ribosomes.

# SUMMARY

- The branch of biology which explains the biochemical basis of life is called biochemistry.
- Molecules which form the structure and carry out activities of the cells are large in size and highly organized molecules called macromolecules.
- Macromolecules are broken down into their subunits by addition of $H_2O$ molecule is called hydrolysis
- Water is most abundant component in living cell.
- The attractive force between similar molecules is called cohesive force of attraction.
- Due to ionization property water may behave as acid and base.
- Carbohydrates are polyhydroxy aldehyde or polyhydroxy ketones.
- Carbohydrates which are made up to 2 to 10 monosaccharides are called oligosaccharides.
- Cellulose is polymer of glucose, most abundant carbohydrate found in nature.
- Amino acids are organic compounds which contain at least one amino group and one carboxylic acid both are chemically bonded to an asymmetric carbon.
- The protein and polypeptide chain is formed by linking amino acids by peptide bond.
- Human body has more than 10,000 proteins.
- Lipids are the important diverse group of biological molecules, widely distributed among plants and animals.
- A phospholipid is similar to acylglycerol except that one of fatty acid is replaced with phosphate and choline.
- Terpenoid is a large and important class of lipids, made up of isoprenoid units ($C_5H_8$).
- Prostaglandins is a group of lipids made by mammalian tissues at the sites of tissue damage or infection.
- The nucleic acids are polymers of five carbon sugar based compound called nucleotide.
- The DNA is a double helical structure. Each helix is made up of 4 types of nucleotides.
- DNA is a heredity material while RNA helps in protein synthesis.
- Conjugated molecules are formed when biomolecules of two different groups combine chemically with each other acting as one unit.

# EXERCISE

**1. Encircle the correct choice**

(i) The slight negative charge at one end of one water molecule is attracted to the slight positive charge of another water molecule. What is this attraction called?
(a) Covalent bond (b) Hydrogen bond
(c) Ionic bond (d) Hydrophilic bond

(ii) Tendency of water to coalesce oil drop into large droplet called
(a) Hydrophilic force (b) Hydrophobic exclusion
(c) Hydrophilic exclusion (d) Hydrogen bonding

(iii) The covalent bond between two monosaccharides is called
(a) Peptide bond (b) Ester bond
(c) Phosphodiester bond (d) Glycosidic bond

(iv) Most abundant carbohydrate found in nature?
(a) Glucose (b) Maltose
(c) Cellulose (d) Glycogen

(v) Most important organic compound of the cell which carry out virtually all of the cell's activities.
(a) Protein (b) Carbohydrates
(c) Nucleic acid (d) Lipids

(vi) All amino acids have same formula except
(a) Alpha carbon (b) Hydroxyl group
(c) Radical group (d) Amino group

(vii) A trihydroxy alcohol, made of three carbon atoms called
(a) Glucose (b) Glycerol
(c) Maltose (d) Ribose

(viii) Large and important class of lipid made up of isoprenoid unit called
(a) Phospholipid (b) Terpenoids
(c) Waxes (d) Acylglycerol

(ix) How many molecules of water are needed to completely hydrolyze a polymer that is 21 monomers long?
(a) 10 (b) 20
(c) 21 (d) 2

(x) Which of the following is true of both starch and cellulose?
(a) They are both polymers of glucose
(b) They are geometric isomers of each other.
(c) They can both be digested by humans
(d) They are both used for energy storage in plants.

2. **Write short answers of the following questions:**

1. Why water molecules are called amphoteric in nature?
2. Why amino acids are named so?
3. How monosaccharides are classified?
4. Enlist bio-elements make 98 % of living system?
5. Why fats provide more energy than carbohydrates?
6. How many steps involve in nucleotide formation?
7. Distinguish between saturated acylglycerol and unsaturated acylglycerols.

3. **Write detailed answers of the following questions:**

1. Describe the properties and roles of starch, glycogen, cellulose and chitin.
2. What is nucleic acid? Describe structure of a mononucleotide (ATP) and a dinucleotide (NAD).
3. What is amino acid? Explain peptide linkage formation.
4. Explain classification of protein and list structural and functional protein.
5. What are lipids? Explain acylglycerol and waxes
6. Explain terpenoids and its types.
7. What are conjugated molecules? Explain types of conjugated molecules.

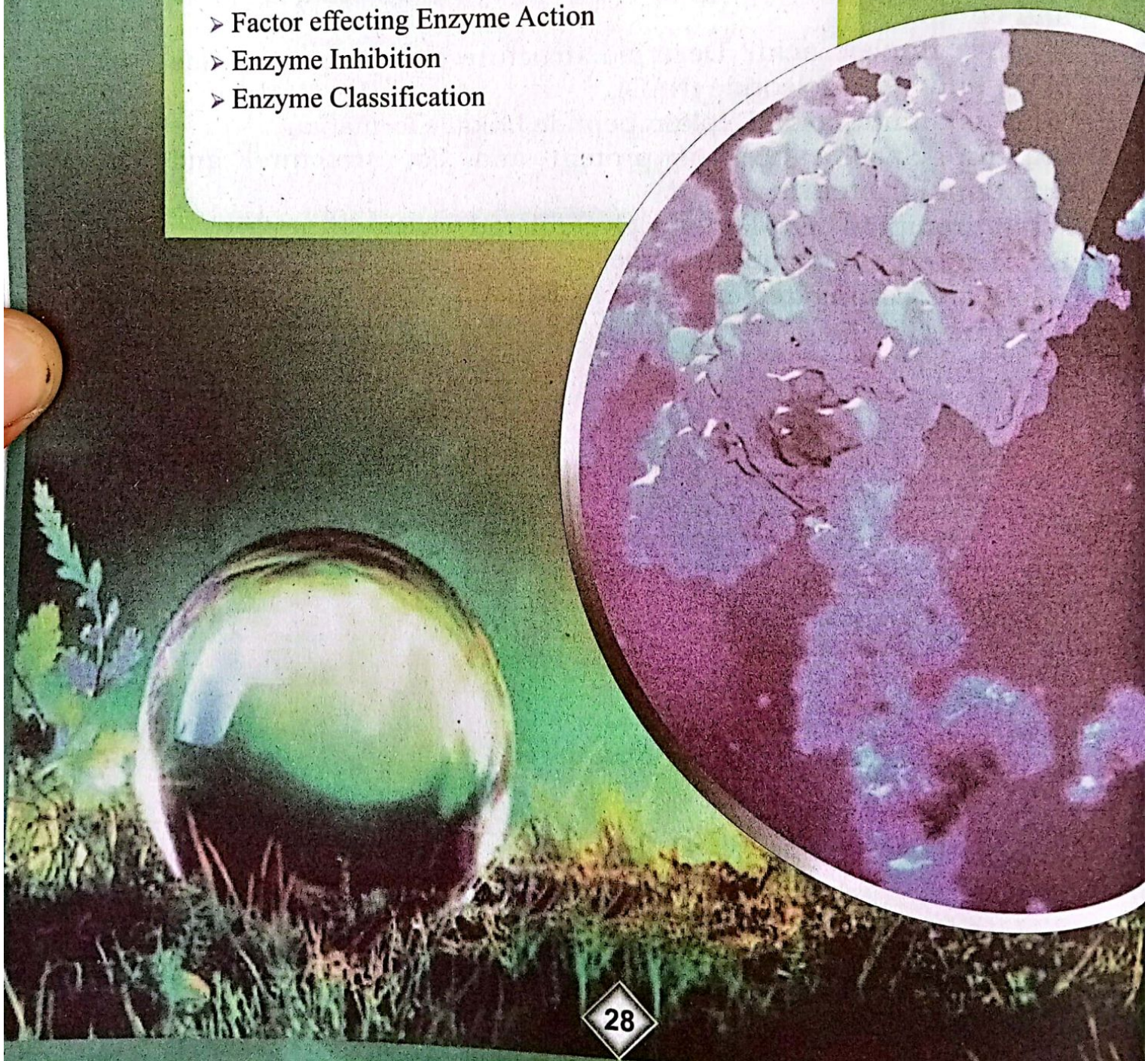
# ENZYMES

Chapter 2

## Major Concept

### In this Unit you will learn:

- Enzyme Structure
- Mechanism of Enzyme Action
- Factor effecting Enzyme Action
- Enzyme Inhibition
- Enzyme Classification



## Introduction:

Life would not be possible without metabolic activities of the cell. This in turn is dependent upon the catalytic molecules called the enzymes. Without enzymes, the dynamic, steady state of the cell would cease to exist.

Life is a mesh work involving a perfect co-ordination of a vast majority of chemical relations. Some of these reactions result in synthesizing large molecule others in cleaving large molecules and still others either utilize energy or liberate energy. All these reactions would occur very slowly at low temperature and atmospheric pressure. The conditions under which living cells carry on their life processes. In the living system these reactions proceed at extremely high rates. This is due to the presence of some specialized substances or biocatalysts which are synthesized inside the living cells. The biocatalysts are called enzymes (Gr: En; inside, zyme=yeast) the term enzyme was coined by Friedrich Wilhelm Kuhn (1878). Enzymes may be defined as organic substances capable of catalyzing specific chemical reactions in the living system.

Just few years ago, it was considered that all enzyme were proteins. During the 1980s Thomas Cech and Sidney Altman discovered that certain molecules of ribonucleic acid also function as enzymes. These molecules are called Ribozymes which catalyze reactions involved in processing genetic information to be used by a cell but generally enzymes are proteineceous in nature. Following are some characters of enzymes.

- Enzymes are biocatalyst produced in the protoplasm, synthesized in the cell.
- Most of the enzyme are proteinaceous in nature, macromolecules of globular proteins with high molecular weight.
- They are either consist of protein e.g. amylase or pepsin or may contains, along with protein, a non-protein part e.g. Acetyl CoA.
- Enzyme act with in the cell where they have produced called endo-enzyme and the enzyme which acts outside the cell called exo-enzymes.
- They are specific in nature and function.
- They are much greater is size than the substrate.
- They have particular sites to react with substrate, these sites are called **Active site.**
- Enzyme activity can be accelerated by certain ions or salts called activators e.g. Mn, Mg, $Cl^-$ etc.
- Enzyme can be inhibited by certain factor called inhibiters. e.g. substrate concentration, enzyme concentration, pH and temperature.
- They are sensitive i.e. they work at specific pH.
- They remain chemically unchanged during and after the chemical reactions.

## 2.1 STRUCTURE OF ENZYME:

As we have discussed that the enzyme are three dimensional globular protein. Every enzyme specifically reacts with special substance called **substrate.**

**Active Site:**

Each enzyme has a special charged place to fit the substrate called Active Site which is complementary is shape to the shape of substrate. The charge and shape of the active site is formed by some amino acids present in the polypeptide chain of the active site of the enzyme. The amino acids which from active site come closed to arrange in specific way to coil and fold within a globular symmetry.

The active site of enzyme has two regions

(i) Binding site.

(ii) Catalytic site.

Binding site is the region of active site whose amino acids make temporary bonds with substrate. On the other hand some amino acids are responsible for catalytic activity therefore it is called catalytic site.

**Structural Part:**

Beside active site some enzymes are completely made of protein only while the other enzymes are made up of protein and non-protein part. These enzymes are called conjugated enzyme. The non protein part of enzyme is called **co-factor**, it is responsible for attachment of substrate at active site and perform catalytic activity. The co-factors may be organic or inorganic molecules. Inorganic co-factors may be metallic ions. These are detachable co-factors called activators because they get attached at the time of substrate binding. Other co-factors are organic molecules which may divide into two groups i.e. co-enzymes and prosthetic group. **Co-enzymes** are the derivative of vitamin like Nicotine or Flavin in NAD and FAD respectively. They behave like inorganic co-factor i.e. attach at the time of substrate binding and detachable.

The others type of organic co-factor is **prosthetic group**. It is bonded covalently and permanent part of enzyme i.e. do not detached e.g. Mg containing porphyrin of chlorophyll.

The conjugated enzyme without co-factor called **Apo-enzyme**. It does not work separately. In activated enzyme consists of polypeptide chain and co-factor is collectively called **Holoenzymes.**

Pepsin is an enzyme secreted by gastric gland of stomach in inactive form pepsinogen. Pepsinogen is inactive due to presence of polypeptide chain at its active site to block. When pepsinogen acts with HCl the additional polypeptide removed and become active form pepsin.

## 2.2 MECHANISM OF ENZYME ACTION:

As we have discussed that all metabolic reactions are catalyzed by enzymes. During these reactions the substrate bind to active site of the enzyme and form enzyme substrate complex (ES) that substrate convert into product but remain attached with enzyme and form enzyme-product complex (EP) and then product release from active site of enzyme. The quantity and shape of enzyme remain same before and after chemical reaction.

| E | + | S | | ES | | EP | | E | + | P |
|---|---|---|---|---|---|---|---|---|---|---|
| Enzyme | → | substrate | → | Enzyme Substrate complex | → | Enzyme Product complex | → | Enzyme | → | Product |

In order to explain the mode of action of enzyme two models were presented.

### (i) Lock and key model

Emil Fischer 1898 proposed this model, according to this model a particular enzyme acts on a particular substrate like particular lock can be unlocked by a particular key. This theory depend upon physical contact between substrate and enzyme molecule.

The active site of each enzyme has a distinct shape (Rigid) and distribution of charge which is complementary to its substrate like lock and key, where a lock allows very few keys to fit in. Similarly enzymes allow a few complementary molecules to fit in and react while rejecting even fairly similar molecules. These enzymes work in absolute specefity i.e. catalyze only one substrate.

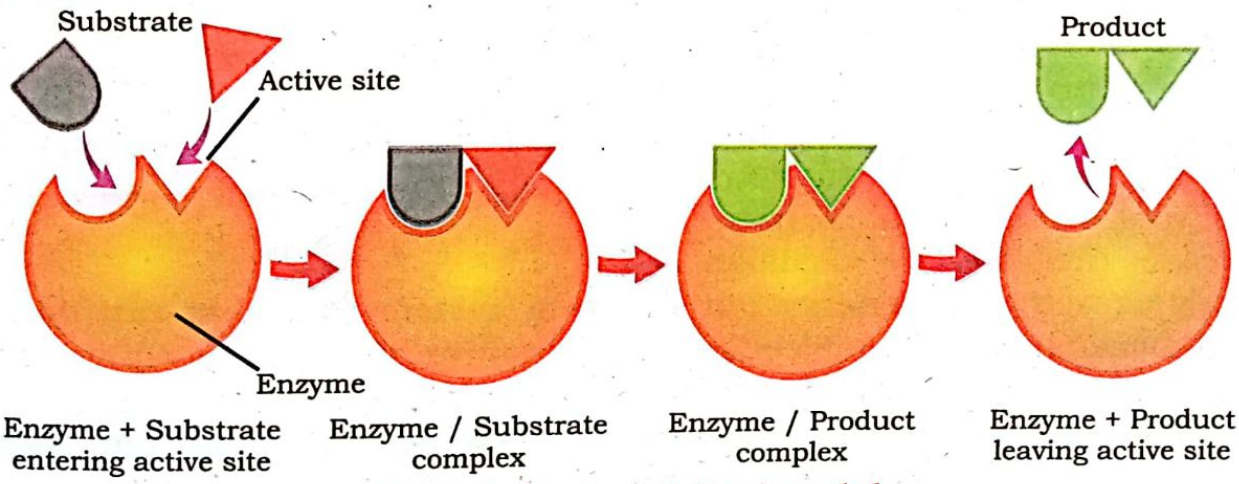



**Fig: 2.1 Lock and key model**

### (ii) Induced fit model

Koshland in 1959 proposed another model with the name of induced fit model. He stated that when a substrate combine with an enzyme. It induces change in the enzyme structure, this change enables the enzyme to perform the catalytic activity more efficiently. It means according to his model

## 2.2 MECHANISM OF ENZYME ACTION:

As we have discussed that all metabolic reactions are catalyzed by enzymes. During these reactions the substrate bind to active site of the enzyme and form enzyme substrate complex (ES) that substrate convert into product but remain attached with enzyme and form enzyme-product complex (EP) and then product release from active site of enzyme. The quantity and shape of enzyme remain same before and after chemical reaction.

$$\underset{\text{Enzyme}}{E} + \underset{\text{substrate}}{S} \rightarrow \underset{\substack{\text{Enzyme}\\\text{Substrate}\\\text{complex}}}{ES} \rightarrow \underset{\substack{\text{Enzyme}\\\text{Product}\\\text{complex}}}{EP} \rightarrow \underset{\text{Enzyme}}{E} + \underset{\text{Product}}{P}$$

In order to explain the mode of action of enzyme two models were presented.

### (i) Lock and key model

Emil Fischer 1898 proposed this model, according to this model a particular enzyme acts on a particular substrate like particular lock can be unlocked by a particular key. This theory depend upon physical contact between substrate and enzyme molecule.

The active site of each enzyme has a distinct shape (Rigid) and distribution of charge which is complementary to its substrate like lock and key, where a lock allows very few keys to fit in. Similarly enzymes allow a few complementary molecules to fit in and react while rejecting even fairly similar molecules. These enzymes work in absolute specefity i.e. catalyze only one substrate.

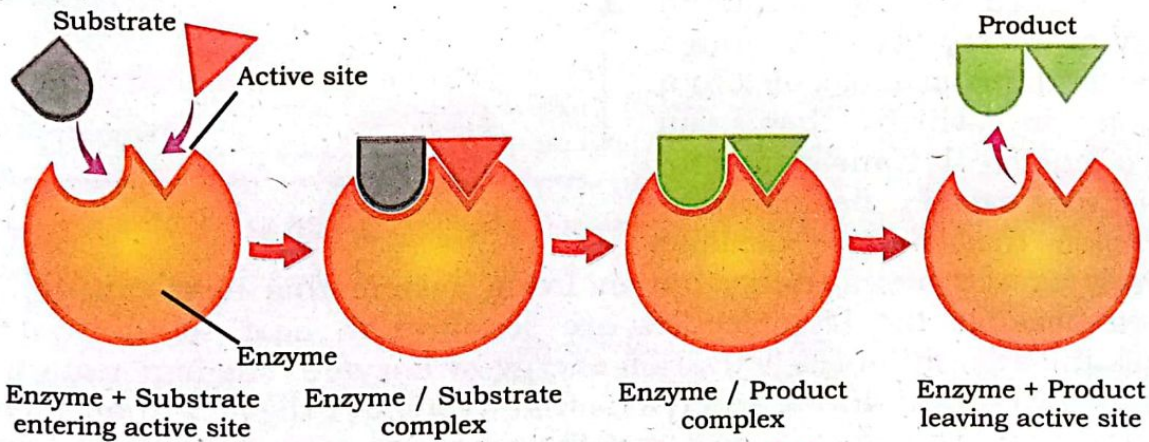



**Fig: 2.1 Lock and key model**

### (ii) Induced fit model

Koshland in 1959 proposed another model with the name of induced fit model. He stated that when a substrate combine with an enzyme. It induces change in the enzyme structure, this change enables the enzyme to perform the catalytic activity more efficiently. It means according to his model

the active site is flexable. Therefore, the change in active site occur during catalytic reaction is responsible for the conversion of substrate into product.

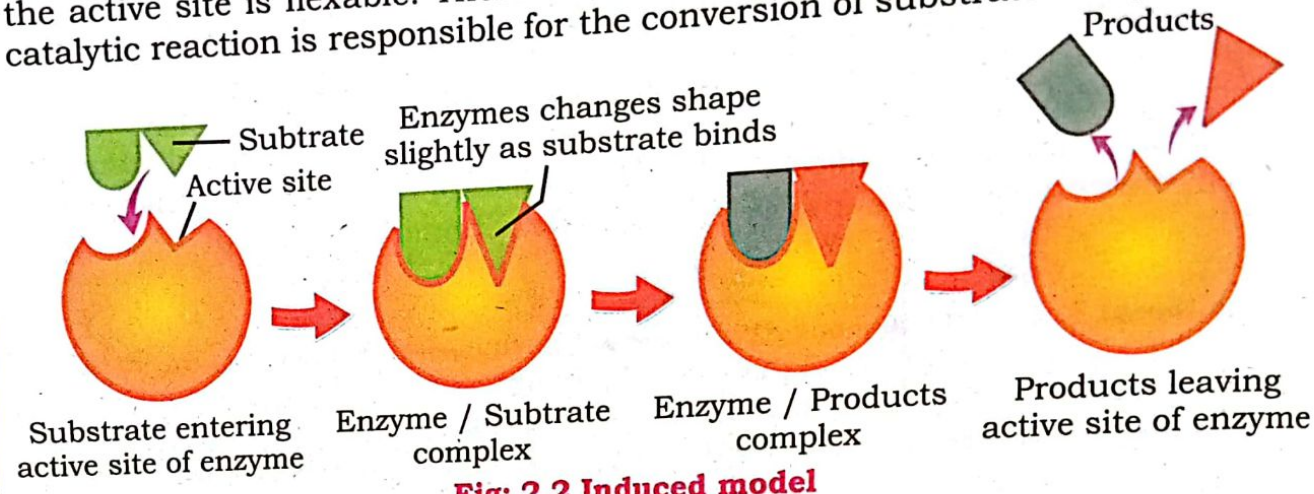



**Fig: 2.2 Induced model**

### 2.2.1 Energy of Activation.

The question arises here, how enzyme are able to accomplish such effective catalysis and why thermodynamically favourable reaction do not proceed on their own at relatively rapid rates in the absence of enzyme?

Chemical transformation requires the breakdown of certain covalent bond of substrate. For this, reactants must contain sufficient energy to overcome a barrier, this barrier is energy of activation or **activation energy**. It can be defined as the minimum quantity of energy that is required to activate atoms or molecules to a condition in which they can undergo chemical transformation. In non-living system, heat is used to increase the effective collision and work as activation energy but in living system this heat can not be provided because the biomolecules are sensitive to heat so the system decrease the amount of his activation energy by enzyme. The important role played by the enzyme during reaction is that they lower the activation energy of the reaction. The enzyme reacts with the energy rich and energy poor molecules to from an intermediate complex. This complex again breaks into product and enzyme. If activation of this complex is low many molecules can participate in reaction. In this way activation energy is lowered by the enzyme but in this action equilibrium i.e. ratio of reactant and product concentration is never altered.

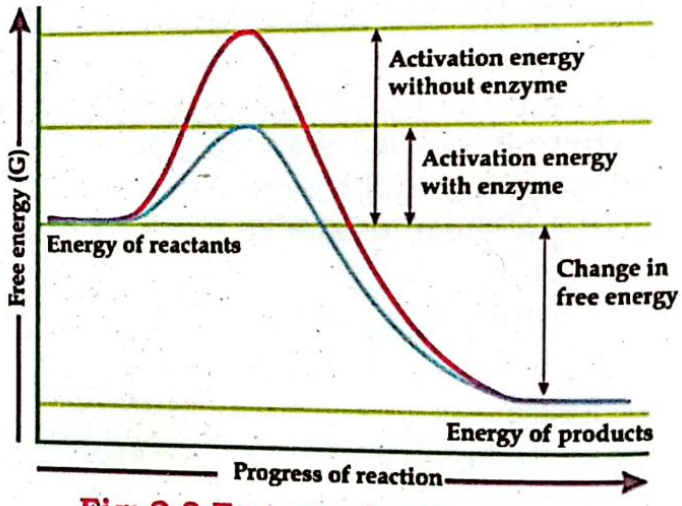



**Fig: 2.3 Energy of activation**

## 2.3 FACTORS AFFECTING ENZYME ACTIVITY

The rate of enzyme activity means the quantity of substrate transform into product in a unit time (1 second). Greater the amount of product formed per second greater will be the enzyme activity or vice versa. Some of the factors which affect the rate of enzyme activity are temperature, pH concentration of enzyme and concentration of substrate etc.

When an inhibitor bind to an enzymes away from active site the shape of enzyme become alter due to these allosteric inhibitor. As a result of this change all active sites of the enzymes are changed slightly so that they become unable to receive substrate. Some molecules also work as activator when bind to the enzyme away from the active site these molecules are called allosteric activators, these allosteric activators an increase in the function of active site. These molecules do not bound covalently to the enzymes so their interactions are reversible. These activators may influenced by thermal factor and concentration of substrates.

### 2.3.1 Temperature

The chemical reactions depend on the molecular motion, i.e. higher the number of substrate molecules reach to enzyme higher will be the chances of reaction or vice versa. It is estimated that increase in 10°C of temperature double this rate of reaction. Enzymes are also sensitive to temperature due to its proteinecous composition. The temperature where enzyme work maximumly or rate of enzyme activity is maximum called optimum temperature, below and above this temperature the enzyme activity decreases. The human enzyme are highly active at about 37°C and all are completely denatured at 100°C, where at minimums i.e. 0°C, activity is reduced to minimum but enzymes are not destroyed. Most of the enzymes in higher organism have optimum temperature between 25°C to 42°C.

Some bacteria which survive in hot spring are called thermophilic because they have optimum temperature of 70°C or higher. Such enzymes are also used in biological washing powder at high temperature washing.

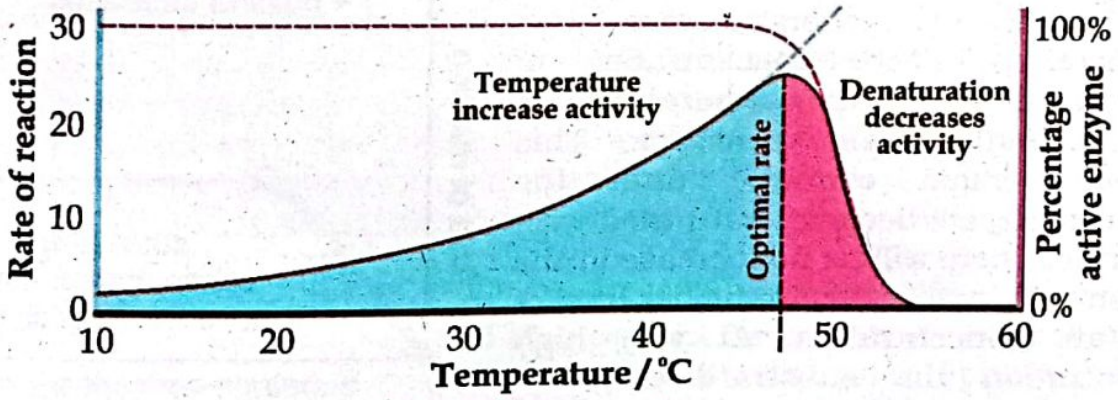



**Fig: 2.4 Effect of temperature on enzymes**

### 2.3.2 Effect of pH:

The activity of enzyme varies considerably with pH and there is generally a marked optimum pH for each enzyme. Each enzyme has very narrow range or it works as optimum pH. The pH has marked effect on the charges of an amino acid side chains which form tertiary and quaternary structure of protein (enzyme). Little change in pH causes ionization of amino acids of enzyme and they becomes ina

Majority of the human digestive enzyme works in the range of 7 to 8. With few exception like gastric enzyme secreted by some cells of stomach i.e. pepsin. The pepsin works at highly acidic condition i.e. its optimum pH is 1.4 but works in the range of 1.5 to 2.5. On the other side amylase is the enzyme released from pancreas work at highly alkaline i.e. 8.5 pH.

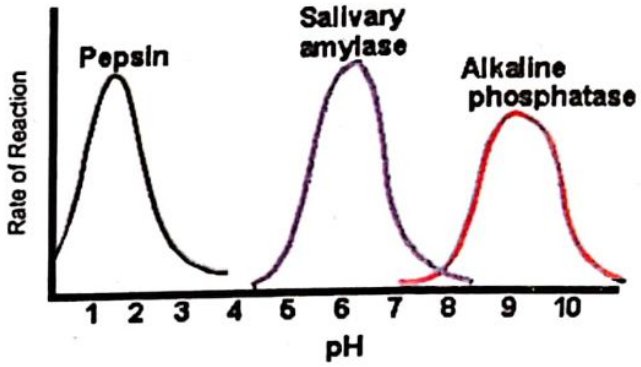



Fig: 2.5 Effect of pH

### 2.3.3 Enzyme Concentration:

The enzyme activity depends upon the availability of substrate and enzyme molecules. If the substrate to concentration is very high the enzyme concentration is directly proportional to the concentration of enzyme but in real condition the concentration of substrate is always limited so the enzyme activity increase with the increase in the enzyme concentration initially but after some time it remains constant.

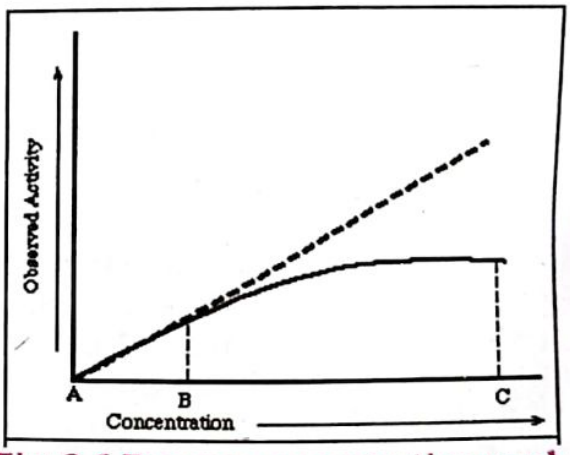



Fig: 2.6 Enzyme concentration graph

### 2.3.4 Substrate Concentration:

The rate of reaction increases with an increase in the concentration of substrate in a condition where enzyme concentration remain constant. This increase remain continue until the available enzyme becomes saturated with substrate. There will be no increase in the enzyme activity to a certain higher level of substrate concentration. At very high concentration the substrate exerts a retarding effects upon enzyme action.

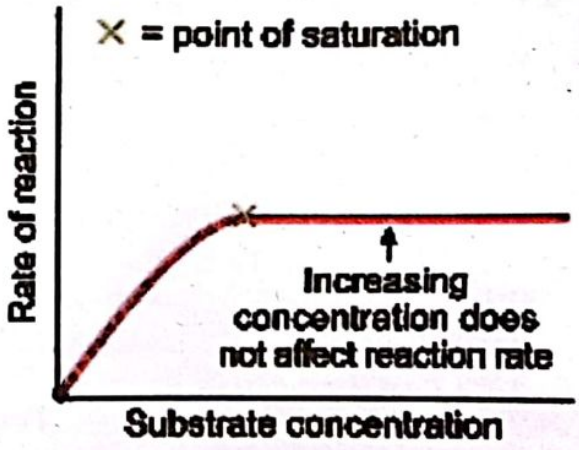
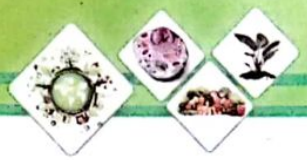



Fig: 2.7 Substrate concentration graph



This may be due to two reasons:

(a) Higher quantity of substrate than enzyme.

(b) Accumulation of end product.

It means the substrate and enzyme concentration are directly proportional up to a certain maximum velocity after which further increase in substrate concentration has no effect on the rate of reaction.

## 2.4 ENZYME INHIBITION:

Sometimes enzyme does not work properly or system wants to decrease this enzyme activity because the products are no more required this condition of decrease in enzymatic related processes, enzyme production or enzyme activity is called **enzyme inhibition**.

### 2.4.1 Types of Enzymes Inhibition:

There are three types of enzyme inhibition

i) Competitive inhibition ii) Non-competitive inhibition

iii) Un competitive inhibition

Substances which decrease the activity of an enzyme are called inhibitors. The inhibitor may act by combining directly with the enzymes or they may react with the activators therefore, activator does not remain available to enzyme for activation.

#### (i) Competitive Inhibition:

The type of inhibition occurs by the molecules which are very similar to the substrate and bind to active site instead of original substrate. These molecules block active site for actual substrate e.g. Penicillin is a competitive inhibitor which block the enzyme which is responsible to construct bacterial cell-wall. If this, inhibition is reversible it can overcomes by increasing concentration of substrate so that as active site become available more substrate molecule than inhibitor molecules are around to gain entry to these sites.

#### (ii) Non-Competitive Inhibition:

The non-competitive inhibition is the type of inhibition when a molecule binds with enzyme at any site except the active site. These molecules are called non-competitive inhibitors. These binding sites which are away from active sites are called **allosteric site** (Allos=away). This interaction causes the enzyme molecule to change its shape, reading the active site unrespective to the substrate or leaving the enzyme less effective at catalyzing for the conversion of substrate to product. Feedback inhibition is the example of reversible non-competitive enzyme inhibition.

#### (iii) Un-Competitive Inhibition:

It is also known as anticompetitive inhibition It takes place when an enzymes inhibitor bind only to the complex format between the enzyme and the substrate (E-S-Complex) this type of inhibition typically occurs in reactions with two or more substrate or product.

### 2.4.2 Significance of Enzyme Inhibition:

It serves as a major control mechanism of biological systems especially when inhibition occurs by small molecules. It is also used as strategy for drug discovery. It also gives knowledge into the metabolic path way e.g. identify substrate and condition critical for catalysis. Enzyme inhibitors are used to screen various levels of diseases which propel the growth of inhibitors.

### 2.4.3 Feed Back Inhibition:

The activity of almost every enzyme in a cell is regulated by feedback inhibition. It is a type of biological control mechanism where the activity of an enzyme is inhibited by its own product. It is called feedback inhibition. It is reversible non-competitive inhibition and takes place during metabolic path way. It usually occurs, when the product is in high quantity, it binds competatively with its enzymes active site or come in between. Substrate and enzyme once the product is consumed the inhibition also reduced and form more product.

Most enzymatic path ways are also regulated by feedback inhibition, but in these cases the end product of path way binds at an allosteric site on the first enzyme of the path way. This binding shutdown the path way and no more product is produced.

## 2.5 CLASSIFICATION OF ENZYMES:

Enzyme can be classified on different basis either on the basis of the types of reactions they performed or on the basis of substrate at which they act.

**Classification on the basis of types of reaction:**

They can be classified in following group

1) **Oxido Reductase:**
   Enzymes require to perform oxidation and reduction reaction by removal and addition of $H^+$ respectively e.g. Ferredoxin reducing substance.
2) **Transferase:**
   Enzymes responsible to transfer a group from one substance to other i.e. transfer of phosphate from ATP to hexose.
3) **Hydrolase:**
   These are digestive enzyme responsible to break the bond by $H_2O$ and convert oligomers into monomers.
4) **Lyase:**
   These enzymes catalyze the breakdown of specific covalent bonds and removal of group without hydrolysis.
5) **Isomerase:**
   Enzyme catalyse intra molecular re-arrangement of atoms in the molecules to form another isomer e.g. glucose – 6 – phosphate converted into fructose –6-phosphate during glycolysis by enzyme phosphohexose.

**6) Ligase (Synthetase)**

Enzyme Catalyse the condensation reaction like DNA and RNA polymerase.

### 2.5.1 Classification based upon substrate:

i) Protease – act on protein e.g. trypsin, pepsin e.t.c.

ii) Lipase – perform hydrolysis of fats into glycerol and fatty acids.

iii) Glycosidase – act on carbohydrate molecules like
Amylase – act on amylose to convert into maltose.
Cellulase – act on cellulose
Maltase – act on maltose.
Sucrase – act on sucrose.
Lactase – act on lactose.

iv) Nuclease – act on different nucleic acids.
e.g. RNAase, DNAase, ATPase etc.

## SUMMARY

- Organic substance capable of catalyzing specific chemical reactions in the living system called enzyme.
- Most of the enzymes are made up of protein and very few are of RNA. They are globular in nature.
- The enzyme which act within a cell called endo enzyme and those which act outside the cell called exo enzyme.
- Enzyme are specific in nature and function.
- Each enzyme has a particular site where substrate attach with it called active site.
- The active site has two sites (a) Binding site (b) Catalytic site.
- The enzyme which are made up of protein and non-protein part called conjugated enzymes. This non-protein part is called co-factor.
- For enzyme action two models are presented.
- (a) Key lock model (b) Induced fit model.
- Activation Energy is the minimum amount of energy that is require to activate atoms or molecule for a reaction.
- Enzyme activity is affected by temperature, pH, Enzyme, concentration, substrate concentration etc.
- Decrease in enzyme activity or inactivation of enzyme is called enzyme inhibition.
- Three types of enzyme inhibition are there (i) competitive (ii) non-competitive (iii) uncompetitive inhabitation.
- The type of biological control where enzyme activity is inhibited by its own product called feedback inhibition.

- Oxido-reductase, Transferase, Hydrolase, Lysase, Isomerase, Ligase are the type of enzyme on the basis of reactions.
- Protease, Lipase, Glycosidase, Nuclease are the types of enzyme on the basis of substrate on which enzyme act.

## EXERCISE

**1. Encircle the correct choice**

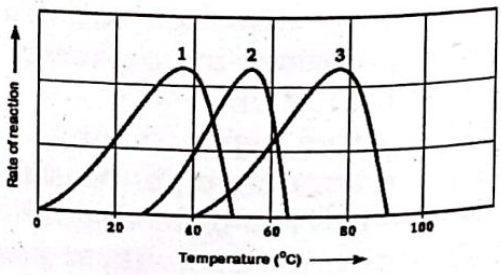
(i) Which of the following statements is (are) true about enzyme catalyzed reactions?
- (a) The reaction is faster than the same reaction in the absence of the enzyme.
- (b) The free energy change of the reaction is opposite from the reaction in the absence of the enzyme.
- (c) The reaction always goes in the direction toward chemical equilibrium.
- (d) Both a and b.

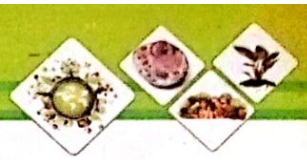
(ii) The active site of an enzyme is the region that
- (a) Binds allosteric regulators of the enzyme
- (b) Is involved in the catalytic reaction of the enzyme
- (c) Binds the products of the catalytic reaction
- (d) Is inhibited by the presence of a coenzyme or a cofactor.

(iii) According to the induced fit hypothesis of enzyme catalysis, which of the following is correct?
- (a) The binding of the substrate depends on the shape of the active site.
- (b) Some enzymes change their structure when activators bind to the enzyme.
- (c) A competitive inhibitor can outcomepete the substrate for the active site.
- (d) The binding of the substrate changes the shape of the enzyme's active site.

(iv) Which curve represents the behavior of an enzyme taken from a bacterium that lives in hot-springs.

I. Curve 1 II. Curve 2 III. Curve 3
- (a) I only
- (b) II only
- (c) III only
- (d) I and II
- (e) II and III





(v) Increasing the substrate concentration in an enzymatic reaction could overcome which of the following?
(a) Denaturization of the enzyme
(b) Allosteric inhibition
(c) Competitive inhibition
(d) Saturation of the enzyme activity

(vi) Competitive inhibitors block the entry of substrate into the active site of an enzyme. On which of the following properties of an active site does this primarily depend?
(a) The ability of an enzyme to form a template for holding and joining molecules
(b) The enzyme's ability to stretch reactants and move them toward a transition state
(c) The enzyme providing an appropriate microenvironment conducive to a reaction's occurrence
(d) The enzyme forming covalent bonds with the reactants

(vii) A series of enzymes catalyze the reaction $X \rightarrow Y \rightarrow Z \rightarrow A$. Product A binds to the enzyme that converts X to Y at a position remote from its active site. This binding decreases the activity of the enzyme.What is substance X?
(a) A coenzyme
(b) An allosteric inhibitor
(c) A substrate
(d) An intermediate

(viii) If an enzyme is added to a solution where its substrate and product are in equilibrium, what would occur?
(a) Additional product would be formed.
(b) Additional substrate would be formed.
(c) The free energy of the system would change.
(d) Nothing; the reaction would stay at equilibrium.

(ix) Which one of the following is the mechanism of action of enzymes?
(a) They act upon substrate molecules to release new substrate molecules.
(b) They actually increase the amount of energy of activation.
(c) Enzymes dramatically decrease the amount of energy of activation.
(d) Enzymes break product molecules to release new product molecules.

(x) How does a noncompetitive inhibitor decrease the rate of an enzyme reaction?

(a) By binding at the active site of the enzyme
(b) By changing the shape of a reactant
(c) By changing the free energy change of the reaction
(d) By acting as a coenzyme for the reaction

## 2. Write short answers of the following questions:

1. Why enzymes are specific in nature?
2. Why enzyme activity is directly proportional to enzyme concentration?
3. Why enzymes are called temperature sensitive?
4. How enzyme reduces the energy of activation?
5. How enzymes activity effect on substrate concentration?
6. What do you mean by prosthetic group?
7. Differentiate between the activator and inhibitors.

## 3. Write detailed answers of the following questions:

1. What is enzyme? explain characteristics of enzyme.
2. Describe the effect if temperature on the rate of enzyme action.
3. Describe mechanism of enzyme action.
4. Describe the classification of enzymes.
5. Describe enzymatic inhibition, its types and its significance.
6. Describe structure of enzyme.
7. Explain the effect of substrate and concentration on the rate of enzyme action.

# CELL STRUCTURE AND FUNCTION

Chapter 3

**Major Concept**

**In this Unit you will learn:**

- Techniques used in Cell-Biology
- Cell-Wall and Plasma membrane as boundary wall
- Cytoplasm and Organelles
- Prokaryotic and Eukaryotic Cells

**Introduction:**

We are studying cell from our early classes and know that it is the basic structural and functional unit of all living organisms. As a student of biology we must study cell in detail. For this study we must know about the techniques of its studies because it is a microscopic structure. The isolation, magnification and other basic needs should understand clearly before this study.

## 3.1 TECHNIQUES USED IN CELL BIOLOGY

To study cell, its organelles and functions following procedure are required.

(i) Cell fractionation – Centrifugation and sedimentation.
(ii) Differential staining
(iii) Microdissection
(iv) Chromatography
(v) Electrophoresis
(vi) Spectrophotometry
(vii) Tissue culture
(viii) Microscopy
(ix) Measurement of cell and their organelles size.

### i) Cell fractionation

Isolation of cellular components to determine their structure and chemical composition is called cell fractionation. It is a combination of various procedures to separate cell organelles on the basis of size and density. It consists of two steps:

(a) Homogenization
(b) Sedimentation

### (a) Homogenization:

It is the first step of cell fractionation, where large number of similar type of cells breaks in an ice cold suitable medium with proper pH and ionic composition. These cells are placed in homogenizer or mortar and pestle. For plant cells an enzyme pectinase is also used in medium to separate cells by digesting middle lamella.

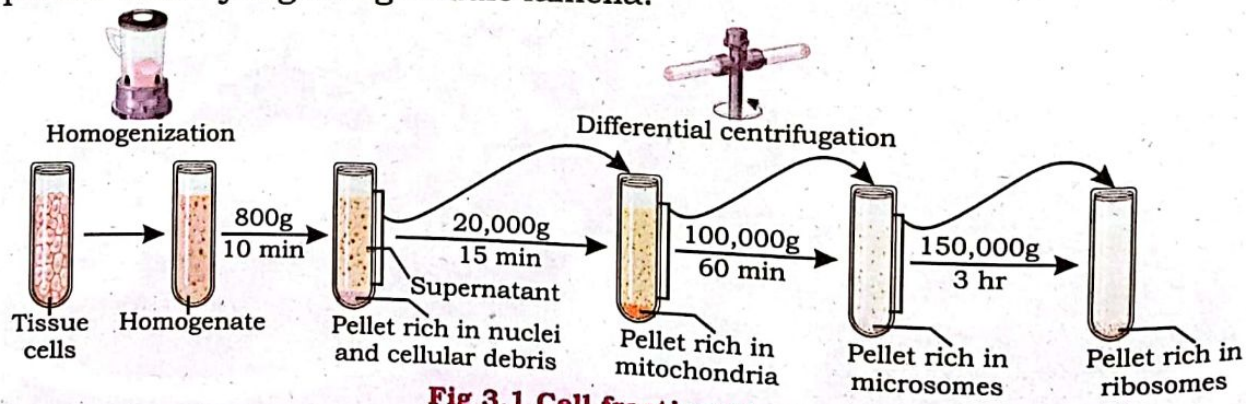



**Fig 3.1 Cell fractionation**

**(b) Sedimentation:**

The process of setting down cell organelles on the basis of density and mass by the process of centrifugation is called sedimentation. Smaller the particle (organelles or molecules) the higher will be the gravitational force required for the separation. It requires ultra centrifuge instrument (its rotation can be up to 60,000 cycles per minutes). Centrifugation method is used for the isolation of cell organelles and components. It is very common method in cell biology where separation is based on sedimentation rate. It is stepwise process by increasing in the centrifugation speed. In the beginning lower speed of centrifuge is used to separate the heavier and bigger organelle from sample and then gradually the speed and size of rotator increases stepwise until the target achieve. At low speed large particles like cell nuclei, settle down as sediment. Smaller particle are still in the supernatant (fluid) which can be poured into a fresh tube and subjected to centrifugation at higher speed until the smallest particles have been separated out. The various cell fractions are now available for cytological and biochemical analysis.

**ii) Differential Staining**

In cell or tissues some structures are transparent. To study the differences between these structures some dyes are used which are absorbed differentially due to their chemical composition for example, for different types of WBCs we use different dyes. This technique is called staining, and the process where different dyes are used at the same time to distinguish them from one another called differential staining.

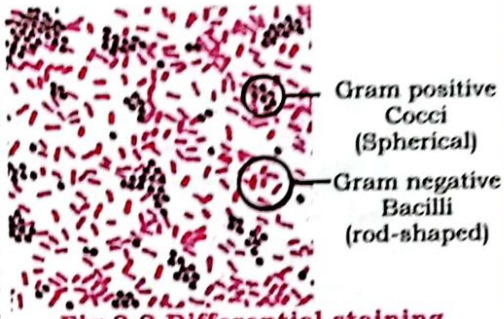



Fig 3.2 Differential staining

**iii) Microdissections**

Microdissection is a technique to isolate specific cells with the help of microscope. It is used in biological research to find out the role of embryonic cells in development, role of different chemicals on cell development and treatment of different diseases. So it is a collection of different techniques where a microscope is used during studies.

**iv) Tissue Culture**

It is a technique of cloning where cell or tissues or an organ grow on artificial medium in a test tube or Petri dish. It was first started from plant cell because plant cells are totipotent (totally potential) i.e. each cell has complete genetic potential to grow in a plant. In 1958 F.C Steward grew a complete carrot plant from a tiny piece of phloem on a medium containing sugar, minerals and vitamins. With these he also added coconut milk (containing plant hormone) these cells began dividing, they produced a

callus (an undifferentiated group of cells). That callus differentiated later on into shoot and root and developed into a new plant. Now a day this technique is also used to grow some tissues for transplantation to find abnormality in cells like cancer cells.

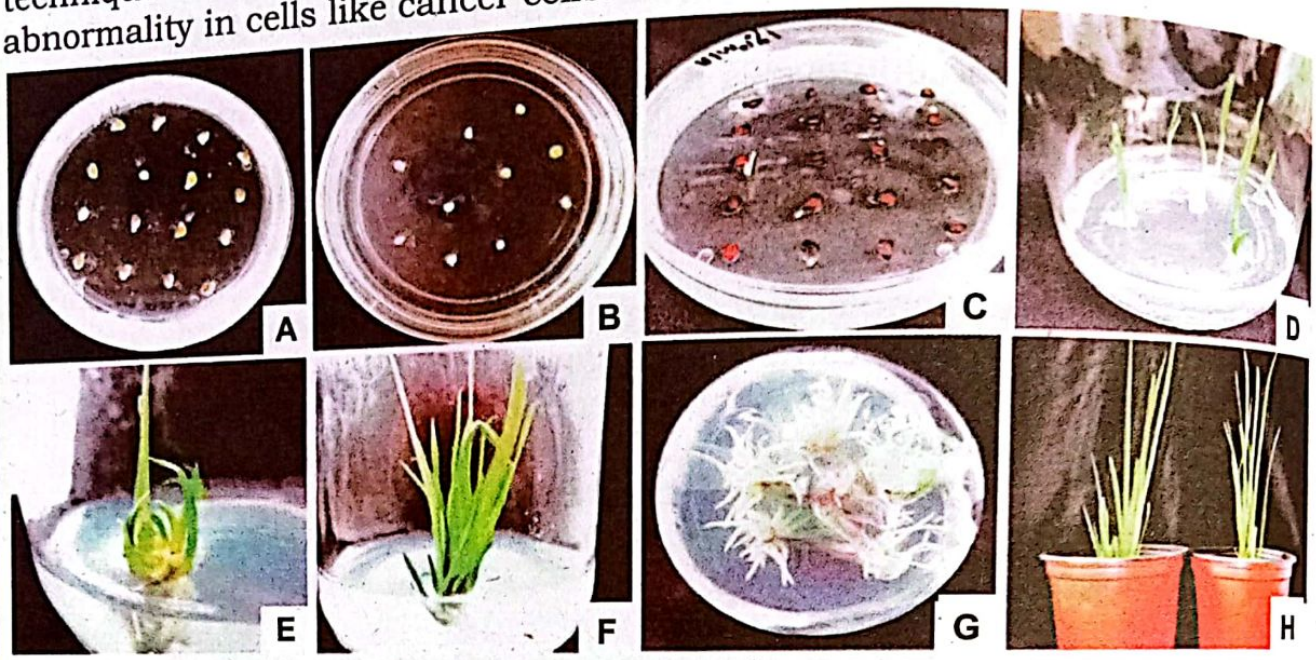



**Fig 3.3 Tissue culture from seed to plant**

### v) Chromatography (Chroma = colour, graphic = lines or pictures)

It is a technique used for separating different components of mixture. The speed of molecular movement is also depend on its molecular size, so different components of mixture travel through the stationary phase at different speed. There are four different types of chromatography techniques used for qualitative analysis.

a) Paper chromatography
b) Thin-layer chromatography
c) Gas chromatography
d) High performance liquid chromatography.

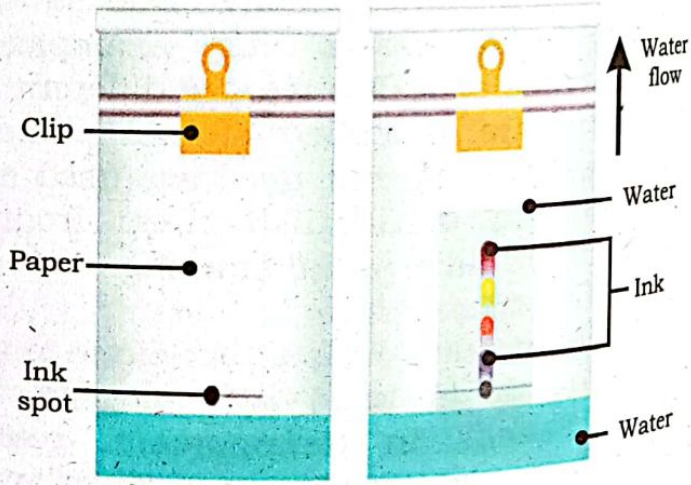



**Fig 3.4 Paper chromatography**

Paper chromatography is a simple and mostly used in analytical chemistry. In this method there are two phases. One is stationary phase and other is mobile phase. The cellulose sheet i.e. filter paper works as stationary phase while sample mixture within a solvent work as mobile phase. The component of sample (mixture) starts separating on paper according to their rate of movement.

### vi) Electrophoresis:

A technique used to separate charged molecule based on their size and electrical charge in an electrolytic cell is called electrophoresis. It is mainly used to separate DNA, RNA or protein molecules.

This technique is familiar with the name of Gel electrophoresis because the charged molecules of different size move through a gel made up of a compound i.e. Acrylamide, this movement of charged molecule occur when an electric current is passed across it. The Gel consists of a permeable matrix, like sieve, through which molecules can travel when an electric current is passed across it. The Gel is suspended in an electrolytic solution and it is placed between two electrodes. At one end the gel has positive electrode i.e. positively charged and the other end has a negative electrode i.e. negatively charged.

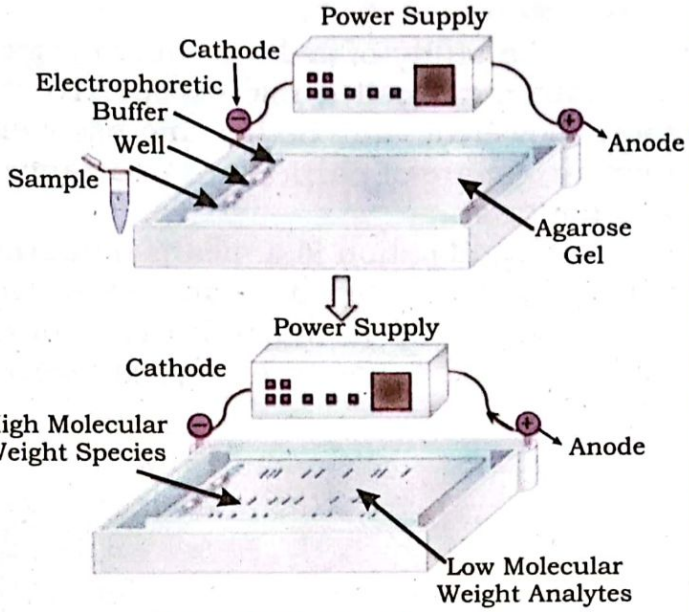



Fig 3.5 Electrophoresis

The movement of charged molecules is called migration molecules. They migrate towards opposite charge. A molecule of negative (-) charge will migrate towards positive (+) end. Smaller molecule migrates more quickly through the pores of gel and travel faster than large molecules. As a result different molecules are separated.

### vii) Spectrophotometry

Each compound absorbs visible light of a certain range and wave length. We can recognize the compound from this range of absorption septrum. This method of measuring light absorption by a particular substance is called spectrophotometry. The instrument used is called **spectrophotometer**. This instrument uses a light beam which passes through the sample where each compound of sample solution absorbs or transmits light of a certain wavelength. This emitted or absorbed wave length is measured by spectrophotometer. It is used to determine growth of bacteria, rate of photosynthesis and minute quantity of (DNA) etc.

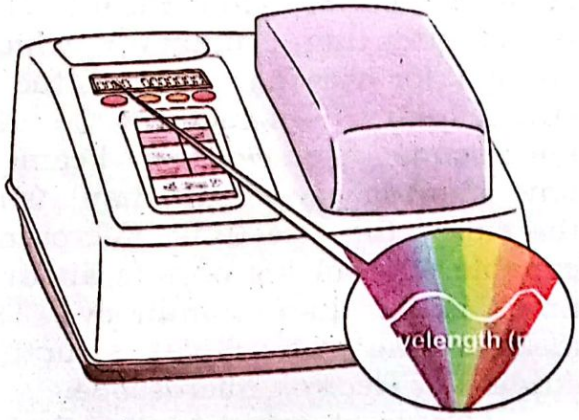


Fig 3.6 Spectrophotometer

### viii) Microscopy

The study of cell and micro-organisms is dependent upon the use of an instrument called microscope. To study cell and its organelles properly more powerful and better microscopes are required. Three attributes of microscope are of particular importance, these are magnification, resolution and contrast.

Magnification is a means of increasing the apparent size of an object, with a light microscope a specimen could quite easily be magnified by as much as 10,000 x. Magnification power of a microscope is calculated by multiplying the power of its eye piece with its magnifying power of its objective.

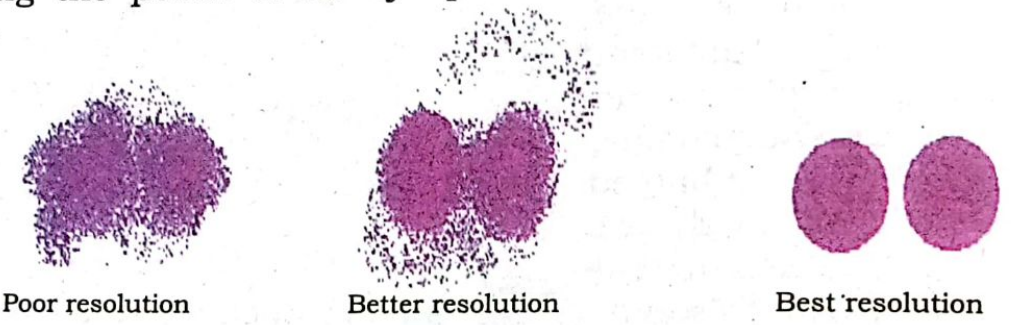



**Fig 3.7 Microscopy**

When we magnify the object beyond a limit its image become blurred i.e. loose its clarity. This clarity of image is generally known as **resolution,** we can say that it is the capacity of an instrument to separate adjacent form or object i.e. minimum distance at which two distinct point of a specimen can still be seen by observer.

A very high magnification can be obtained by light microscope, but their resolution power is limited. It is about 500 times better than human eye, which is not enough for viewing some of the smaller sub-cellular structures. Electron microscope use electron beams which have shorter wavelength than visible light therefore the electron microscope are capable of resolving objects about 10,000 times better than human eye. Therefore most of the sub-cellular structures are studied by electron microscope.

Contrast refers to the darkness of the background relative to the specimen. In order to see colorless or transparent specimen, a special type of microscope is

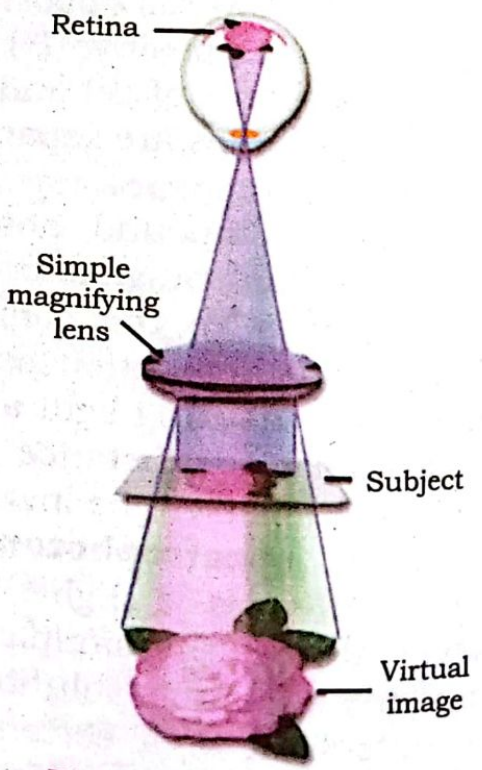



**Fig 3.8 Magnification with a simple thin lens**

required called phase contrast microscope. It is important to distinguish one part of cell from another. In light microscope contrast is often obtained by fixing and staining the material.

### 3.1.2 Micrometry

It is the science related to measurement of dimensions and size of an object observing under microscope. It requires special device of measurement called micrometer, this instrument is attached or put into the microscope. There are two types of micrometer i.e. an ocular micrometer and stage micrometer. The ocular micrometer is a disc, made up of glass. It has 100 equal divisions with no absolute value. It is placed in the eye piece of microscope. A stage micrometer is a calibrating device. It is a glass slide with proper scale like ruler. To calibrate and estimate the size of a given object, the image of ocular micrometer is super imposed on stage micrometer.

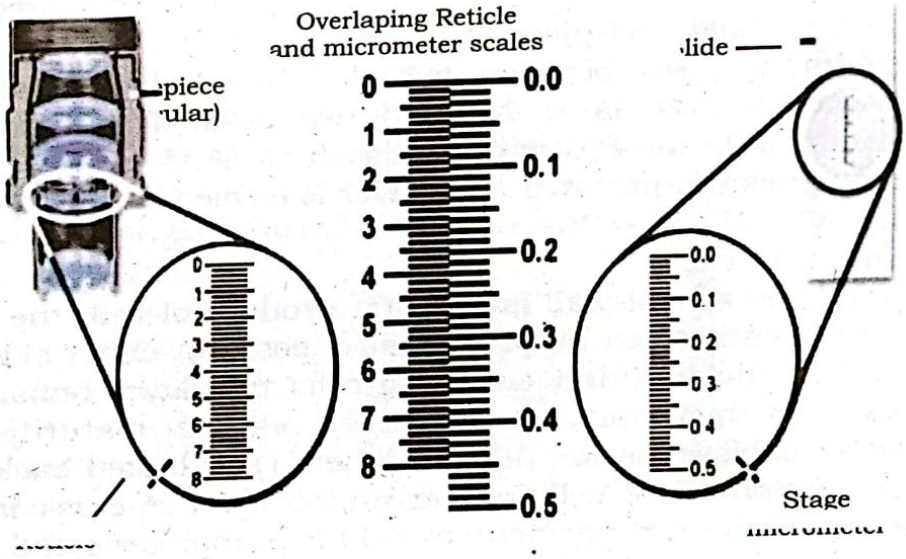



**Fig 3.9 Eyepiece reticles and stage micrometers**

Micrometer is a also called micron, so the unit of micrometer is micron for length i.e.0.001 mm or about 0.000039 inches. It is symbolized by μm.

## 3.2 CELL WALL AND PLASMA MEMBRANE

### Cell Wall

The outer surface of some cells is covered with non-living, stiff layer called cell-wall. This cell wall is present at bacterial, fungal, algal and plant cells. Bacterial cell-wall is made up of peptidoglycan, and fungal cell wall is made up of modified polysaccharide chitin, while plant and algal cell wall is made up of (cellulose) already discussed in chapter of Biomolecules.

Cell wall is composed of mainly cellulose, pectin and other polysaccharides. These materials of cell-wall are always synthesized by protoplasm, secreted out of the cell and deposited around outer surface of plasma membrane. We will discuss only plant cell wall here.

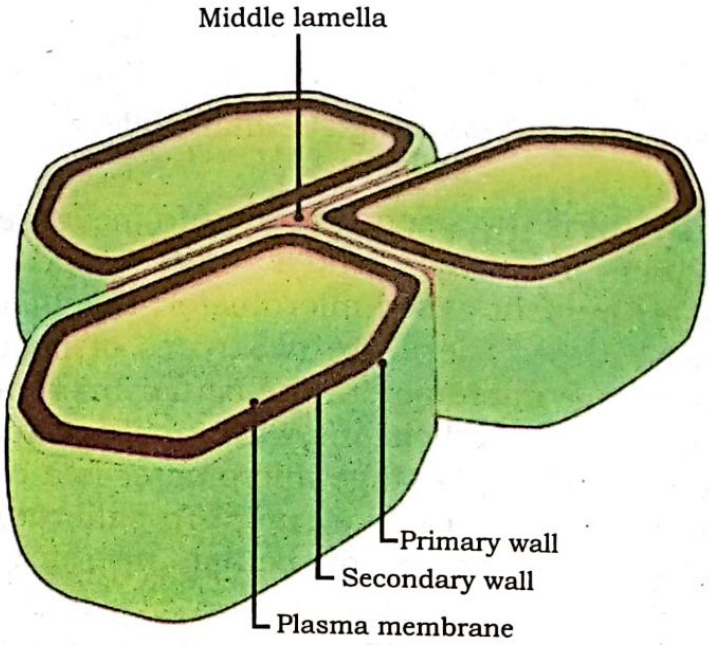


Fig 3.10 Cell wall

A plant cell-wall is mainly differentiated into three layers,

i) Middle lamella,
ii) Primary wall,
iii) Secondary wall.

**i) Middle lamella**

The first formed cell-plate work as cementing layer between two daughter cells is called middle lamella. It is a common layer between two cells. These two cells will separate when middle lamella will be dissolved. It is mainly made up of calcium and magnesium pectates. This layer is formed during cytokinesis of cell-division.

**ii) Primary cell wall**

Primary layer of cell-wall is the first product of cell, the material of primary layer is synthesized by protoplast deposit on either side of middle lamella. In young dividing and enlarging cells this layer remain thin and elastic. It becomes thick and rigid when cell reach at maturity. It contain hemicellulose (a polysaccharide that have beta (1-4) linked backbones with cross linked) microfibril of cellulose arranged in criss-cross manner and pectin. The crisscross arrangement of cellulose increases the strength of cell-wall. At some places in the cell-wall, the deposition of wall material does not take place. These places known as **plasmodesmeta** (singular, plasmodesma) through which cellular content of neighbor cells remain in communication with each other.

**iii) Secondary cell wall**

The layer of wall developed in between plasma membrane and primary cell-wall. It does not deposit in every plant cell, only deposited in hard tissues i.e. sclerenchyma. The cells become dead at their maturity.

Secondary wall deposits after complete maturation of primary cell-wall. It is very thick and rigid due to deposition of lignin, inorganic salts and some waxes. It plays important role in support of plant i.e. sclerenchyma fiber, scleroids, xylem vessels, tracheids, which contain secondary cell-wall.

### Function of cell-wall

It performs two important functions. Firstly it provides mechanical support, gives definite shape and protection to cell. It acts like a skeletal frame work of plants particularly in vascular plants. Secondly, being hydrophilic in nature it is capable of imbibing water and thus helps in the movement of water and solutes toward protoplast i.e. cell-wall acts as permeable structure.

### 3.2.2 Plasma membrane or cell membrane

All cells either prokaryotic or eukaryotic cells are enclosed in a membrane which serves as their outer most living boundary, called plasma membrane. It separates the cytoplasm from the external environment.

#### (i) Chemical composition of cell membrane

All biological membranes have the same basic molecular organization. They are made up of double layer (Bilayer) of phospholipids interspersed with proteins.

The phospholipids molecules in the plasma membrane are arranged in two parallel layers. Their non-polar hydrophobic ends face each other whereas their polar hydrophilic ends are associated with carbohydrates protein etc. Plasma membrane also contains several types of lipids like cholesterol sterol etc. In some animal cells cholesterol may contain 50% of lipid molecules in plasma membrane. It is absent in the cell membrane of most plant cells.

Most of the plasma membrane consists of approx 50% lipids and 50% protein by weight, while the carbohydrates portion of glycolipids and glycoprotein constituting 5 to 10% of the membrane mass.

#### (ii) Structure of Plasma membrane

Number of biologists presented different models of cell-membrane. One of the models is sandwich model. According to this model the cell-membrane is composed of lipids bilayer sandwiched between inner and outer layer of protein. This basic structure is called the unit membrane and is present in all the cellular organelles. The modern technology has revealed that lipid bilayered is not sandwiched between two protein layers.

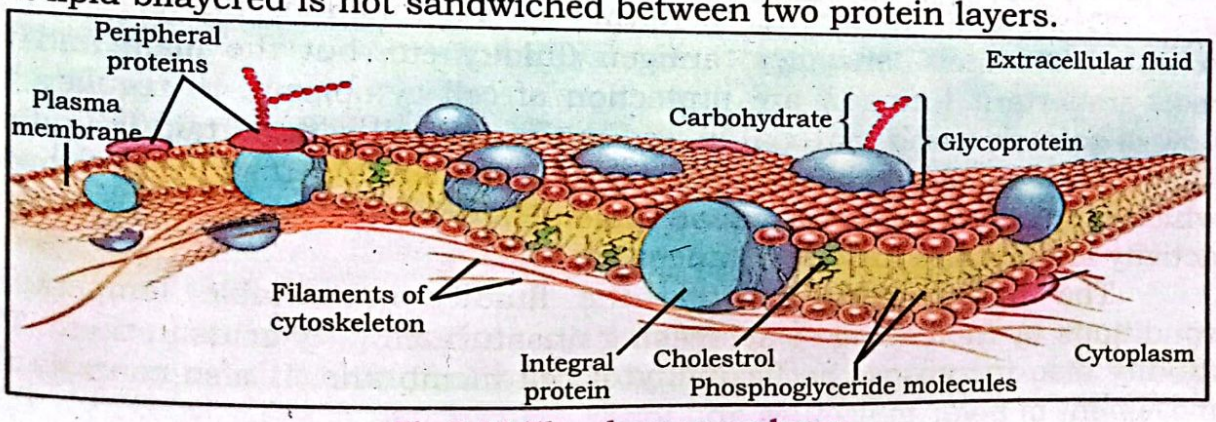



**Fig 3.11 The plasma membrane**

### Fluid Mosaic Model

In 1972 Singer and Nicolson proposed a working model of plasma membrane known as fluid mosaic model. In the fluid mosaic model the lipid bilayer is retained as the core of the membrane. These lipid molecules are present in a fluid state able to rotate, translate and vibrate these molecules moving laterally within their layers of membrane. Proteins are also present in bilayer of phospholipids.

The structure and arrangement of membrane protein in the fluid mosaic model are like ice bergs in the sea. The protein occurs as a "mosaic" of discontinuous particles that penetrate deeply into and even completely through the lipid sheet. The components of plasma membrane are mobile and capable of coming together to engage in various type of transient or semipermanent interaction.

The proteins associated with the lipid bilayer can be divided into two groups.

a) Integral proteins
b) Peripheral proteins

**(a) Integral proteins (Intrinsic proteins):**

A class of proteins that are directly incorporated within the lipid bilayer. Some of these proteins are believed to provide a channel through which water-soluble substances, such as ions, can pass back and forth between the extracellular and intracellular compartment.

**(b) Peripheral proteins (Extrinsic proteins):**

A class of proteins located entirely outside the lipid bilayer on either the extracellular or cytoplasmic surface, exhibit a loose association with membrane surface.

These proteins which may possess lipid (lipoprotein) or carbohydrates (glycoprotein) side chains are arranged as mosaic within the cell-membrane.

### Function of Plasma membrane

The plasma membrane performs several functions like platform for receptor, channels, enzymes, antigen fluidity etc, but the main and the most important function are protection of cell cytoplasm, to regulate the flow of solutions and material in and out of the cell with certain limitation. These limitations are checked by in flow of materials across the membrane which is necessary to maintain suitable pH, ionic concentration for enzyme activity and excrete toxic substances etc.

The lipid bilayer controls the fluidity in variable temperature conditions by increasing or decreasing unsaturated fatty acids in them. The fluidity also increases the flexibility of cell-membrane. It also controls the movement of polar molecules and ions.

The differentially or selective permeability is due to presence of specific channel proteins which permit only specific molecule to pass through them. The protein is carrier protein embedded in phospholipid layer. Some extrinsic proteins also work as enzymes e.g. ATPase complex to synthesize ATP.

Some proteins are conjugated proteins work as receptor for different hormones and other molecules. While other proteins work as antigen like $R^H$ protein of RBCs.

**Role of plasma membrane in regulating cells interaction with its environment**

For entry and exit there are two main process of transport. i). Passive transport. ii). Active transport. They are discussed as follows.

**(i) Passive transport:**

It is a transport of molecules by diffusion and osmosis without consumption of ATP.

**(ii) Active Transport:**

Movement of molecules against concentration gradient by using energy of ATP.

There are two other phenomena i.e. endocytosis and exocytosis. Endocytosis is the process of intake of material in bulk by infolding cell membrane. It may be intake of solid material i.e. phagocytosis or intake of fluid or liquid i.e. pinocytosis, whereas exocytosis is the process of membrane fusion and exfolding to exit the material from the cell.

Cholestrol helps to regulate membrane fluidity over the range of temperature. It also prevents the passage of proton and sodium ions across the plasma membrane.

**Role of Glycolipids and Glycoproteins as cell surface markers**

The Glycolipids formed on the outer side of phospholipids bilayer of plasma membrane in eukaryotic cells. Its main function is to maintain stability of the membrane and facilitate cell-cell interaction i.e. cell adhesion to form a tissue. They also help cellular identification during immune responses. It also acts as receptor for viruses and other pathogens.

Specific glycoproteins present on the surface of red blood cells determine blood group type A,B, AB, and absence in O.

> The Glycolipids on the plasma membrane of R.B.C are of particular importance, it plays important role in blood transfusion. These glycolipids form AB antigen.

## 3.3 CYTOPLASM

The term cytoplasm was introduced by Rudolf Von Kolliker in 1868 for the material which is filled in between cell-membrane and nuclear membrane of eukaryotic cell and whole material inside cell-membrane in

prokaryotic cell. In some cells the cytoplasm is distinguish into two regions, the outer clear part near plasma-membrane is viscous called **cytogel** (previously called ectoplasm) and the inner part near nucleus is less viscous like solution called cytosol (previously called endoplasm).

### 3.3.1 Chemical nature and metabolic role of cytoplasm

Cytoplasm is a translucent granular liquid. It consists of an aqueous ground substance called cytosol. Chemically it contains about 90% water. It forms a solution containing all the fundamental molecules of life i.e. salts, sugar, amino acids, fatty acids, nucleotides, vitamins, hormones, inorganic ions. The large molecule like proteins and lipids are also present in the form of colloidal semi-fluid.

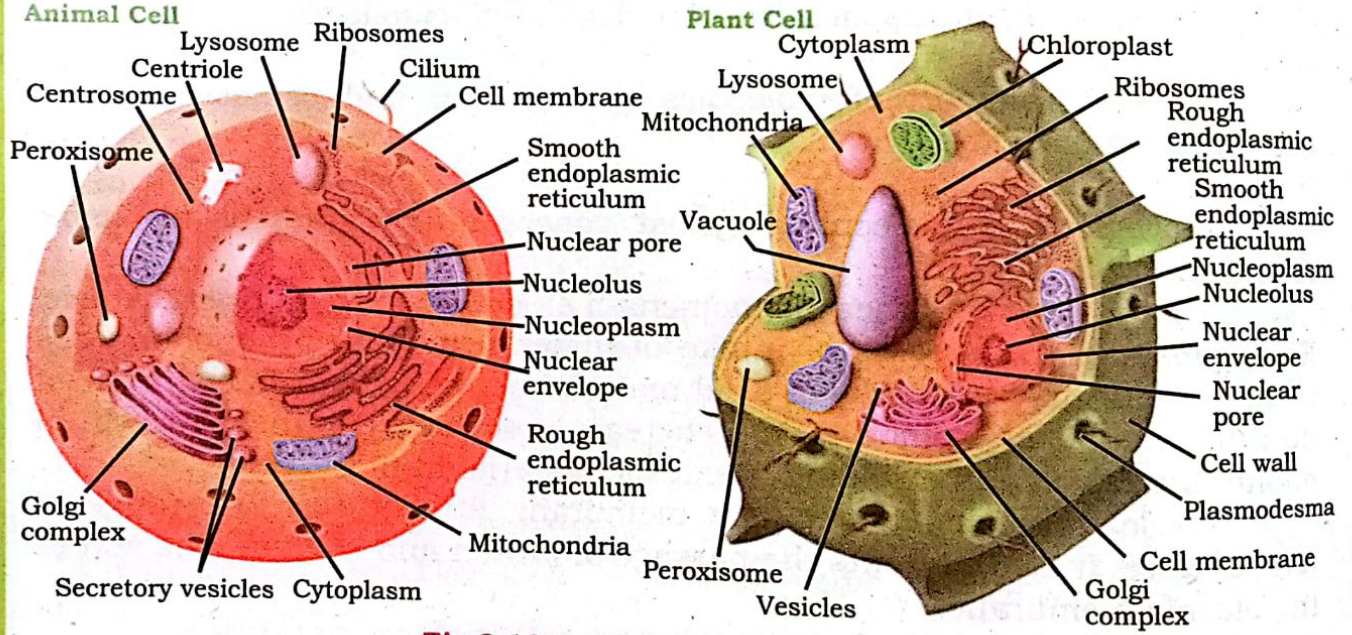



**Fig 3.12 Animal cell and Plant cell**

Observation under electron microscope revealed that the cytoplasm is not consists of liquid part only, it also contains granular part called cytoplasmic organelles, with this granular part a mesh of tiny filaments, the microfibrils which form a type of skeleton, giving rigidity to cell and help unicellular organism in movement. Most of the cytoplasmic organelles are tough to be attached with this cytoskeleton.

The cytoplasm exhibits active streaming movement around the inner surface of the cell called **cyclosis**. This movement is responsible for even distribution of cell content in cytoplasm. It is considered the seat of all metabolic activities from gene expression to energy production processes like glycolysis and Kreb's cycle. The energy is captured and conveted here in chloroplast. It also performs the function of molecular modification to detoxification, storage in vacuole and other organelles.

### 3.3.2 Cytplasmic organelles

In living eukaryotic cell, variety of organelles are present in cytoplasm such as endoplasmic reticulum, mitochondria, nucleus, plastids, ribosomes, lysosomes, centriole and vacuole. They perform their own functions. On the basis of these organelles and their functions the cell is considered as basic unit of life.

### 3.3.3 Endoplasmic reticulum (Endo = inside, plasma = formed substance, reticulum = network).

The elaborated, tube like system of lipoprotein form a complex network of channels, extended from plasma membrane to nuclear membrane called **endoplasmic reticulum**. This network is present throughout the cytoplasm like network of roads of a country. There are two types of endoplasmic reticulum.

a) Agranulated or smooth endoplasmic reticulum (SER)
b) Granulated or rough endoplasmic reticulum (RER)

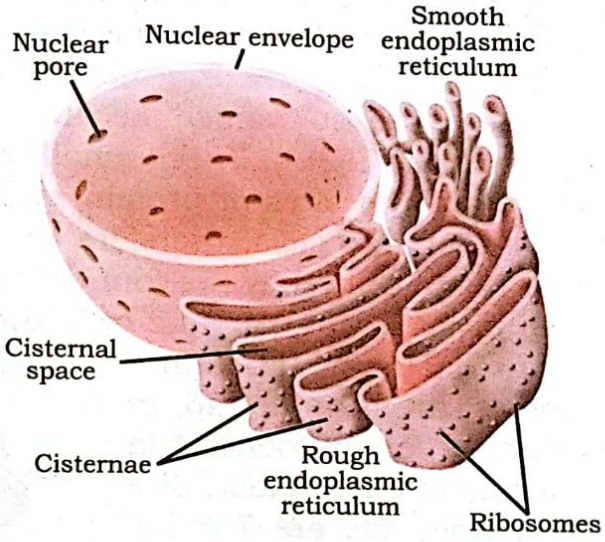



Fig 3.13 Endoplasmic reticulum

Usually cell contains both the type of endoplasmic reticulum in different ratios according their function. Although, some cells have only one type like fibrous cells of skeletal muscles, which have only smooth type of endoplasmic reticulum with the name of sarcoplasmic reticulum.

#### Rough Endoplasmic Reticulum (RER)

It is a type of endoplasmic reticulum which is heavily coated with ribosomes on its outer surface towards cytoplasmic face. It occurs mostly in protein synthesizing cells in high proportion. The process of translation during protein synthesis takes place here. After synthesis, the protein is either stored in the cytoplasm or exported out of the cell through these channels.

#### Smooth Endoplasmic Reticulum (SER)

The smooth endoplasmic reticulum named due to smooth surface i.e. ribosomes are not present on it. It is found in steroid producing cells like adipose cells, interstial cells, glycogen storing cells of liver and muscles. It is involved in the synthesis of oil, phospholipids and different types of steroids. The smooth E.R also provides mechanical support to cell.

### Function of Endoplasmic Reticulum

The endoplasmic reticulum performs many important functions in the cell. It serves as supporting platform for the ribosome (RER). It forms a structural framework of the cell with increased surface of the various metabolic reactions (especially SER). It also provides conducting pathways for import, export and intercellular circulation of various substances. it provides passage for RNA to pass from nucleus to various organelles of cytoplasm.

It helps in detoxification of harmful drugs, storage, and release of $Ca^{++}$, manufacture of lipids and formation of Golgi apparatus (SER). The S.E.R transport protein from R.E.R to Golgi bodies through themselves.

### 3.3.4 Ribosome (RNA containing bodies)

These are so named because they contain high concentration of ribonucleic acid (RNA). These small spherical, granular, non-membranous structure are the sites of protein synthesis in cell type i.e. prokaryotic as well as eukaryotic cells, therefore they are regarded as "Protein factories". In prokaryotic cells they are found freely dispersed in the cytoplasm due to absence of E.R. In eukaryotic cells they are found free as well as attached to endoplasmic reticulum. Ribosomes are also found in the matrix of mitochondria and stroma of chloroplast. Size of these ribosome are 70S i.e. prokaryotic. It is good evidence that eukaryotic cells evolved from prokaryotic cells. The size of ribosome of eukaryotic cell is little larger than prokaryotic cells i.e. 80S while the prokaryotic ribosome is 70S. (S=Svedberg unit)

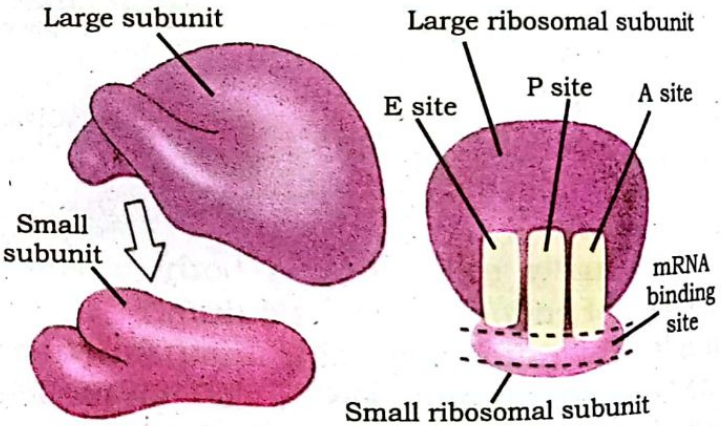



**Fig 3.14 Ribosome**

Each ribosome is consists of two unequal units. The larger sub-unit is dome shaped and smaller one form a cap on the flat surface of larger sub-unit. Eukaryotic ribosome has a larger sub-unit of 60S and smaller sub-unit of 40S particles, on attachment as single unit it becomes 80S particle. Both the unit are attached by magnesium ions. The ribosome is chemically made of nucleoprotein i.e. RNA (40 %) and protein (60%). They are made up of 50 or more different kind of proteins. $Mg^{++}$ form bond between phosphates group of RNA and amino group of amino acids to attach both units at the time of protein synthesis. Recent investigation revealed that the ribosomes are manufactured in nucleolus in eukaryotic cells from where they are transferred to the cytoplasm through nuclear pores via E.R.

During protein synthesis several ribosome are attached to a single mRNA to synthesize number of identical protein molecules. This group of ribosome attached to a single mRNA is known as **polysome**.

### 3.3.5 Golgi complex

After the name of its discoverer an Italian physician **Camilo Golgi** in 1898. It was name Golgi apparatus or Golgi bodies or Golgisome or Golgi complex. Like endoplasmic reticulum it is a canalicular system with sacs, but unlike the endoplasmic reticulum it has parallel arranged, flattened membrane bound vesicles without ribosome. It is basically developed from S.E.R

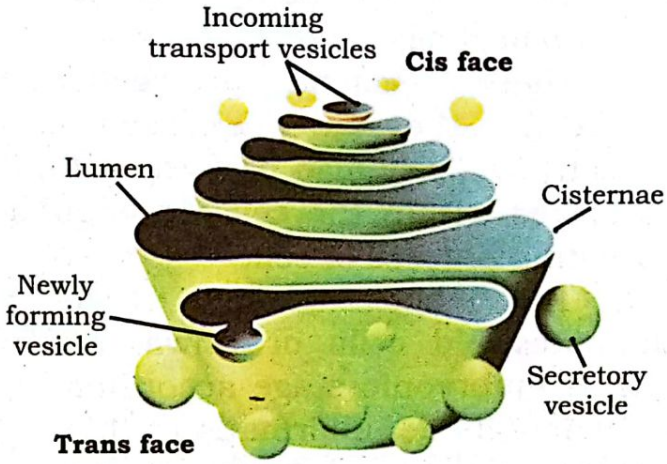



**Fig 3.15 Golgi apparatus**

The Golgi-bodies are found in all eukaryotic cells. It has basically same morphology in plants and animal cells. Each of them is disc shaped and consists of central flattened, plate like compartments called **cisternae**, perephral network of inter connecting tubules and peripherally occurring vesicles called Golgian vesicles. In Golgian system interconnected tubules are formed around the central stock, this process of forming cistarnae tubules remain continue at one end, if this outer or forming face in convex it is called cis - face, generally face towards nucleus, while the inner face which is called maturing face is concave also termed as trans face.

**Function**

Golgi complexes are especially prominent in glandular cells. The products of E.R are modified, stored and then sent to other destination. They perform the function of collection, packaging, processing of cell secretions. These secretions are mainly proteins which they collect from R.E.R transport to S.E.R, modifies to perform specific function and then export in the form of vesicles. It manufactures certain macromolecules by itself. Many polysaccharides secreted by cells like cellulose, chitin to form cell-wall and cell plate are Golgi products. Certain organelles such as lysosome, peroxisome and Glyoxysome develop from Golgi-complex. It is also involved in the formation of different conjugated molecules.

### 3.3.6 Lysosome (Lysis = breakdown; soma = bodies)

These are spherical, single, membrane bounded bodies, a few micrometers in diameter, originated by Golgi-bodies, containing hydrolytic enzymes. They occur only in the cytoplasm of animal cells and function in the digestion of material taken into cells by phagocytosis. Normally, they function as destroyers of foreign particles and worn out cellular component.

The newly formed lysosome before start its functions called primary lysosome. They contain about 40 different types of hydrolytic enzymes.

The lysosme during performing their function attach with the membrane of ingested material like endocytosis, phagocytosis or autophagocytosis.

These lysosome are generally called secondary lysosome but specifically they are endosomes, phagosome and autophagosomes respectively. They also perform autophagy, the process by which unwanted structures within the cell are engulfed and digested by lysosome. This is self-eating process of cell.

The body some time eliminates old cells or unwanted cells at embryonic stage according to their genetic information, this process is called **apoptosis**. During this self destruction process the membrane of lysosome is ruptured at a particular time. As a result the hydrolytic enzyme become free in cell and cell undergoes chemical breakdown or lysis, which cause a cell to destroy itself by digesting its own macromolecules, so the lysosome is referred as "**suicidal sac**" and this process is called **autolysis**.

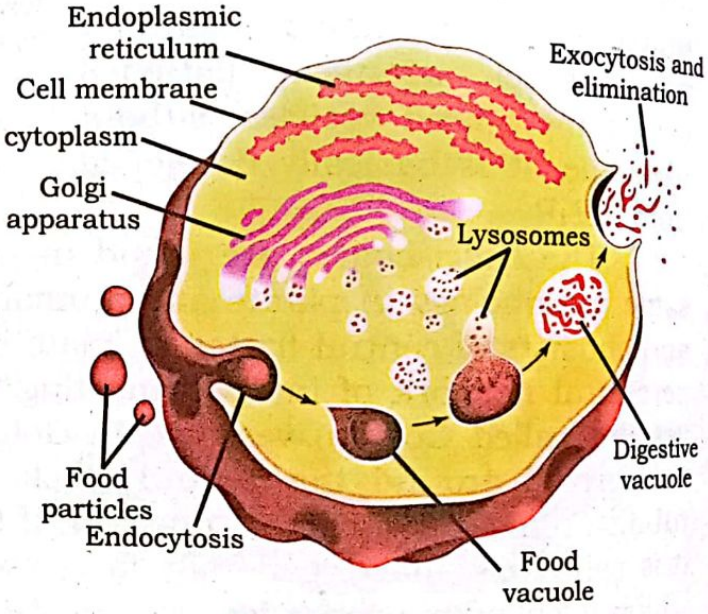



**Fig 3.16 lysosome**

Lysosome is also important in a way that it contains variety of enzyme which maintains metabolic balance of cell. If cell becomes unable to synthesize any one of these enzyme due to heredity and congenital reason. The substrate of that enzyme accumulates in these cells as well as organs which lead to metabolic imbalance at last become fatal at early childhood. These type of diseases cause due to lack of lysosomal enzymes are called **lysosomal storage diseases.** More than 30 diseases are reported as lysosomal storage disease some of them are given below.

**Some lysosomal storage diseases**

| Diseases | Symptoms and problems |
|---|---|
| • Tay-Sachs disease | • Mental retardation, blindness, death by age of 3 |
| • Gaucher's disease | • Liver and spleen enlargement, erosion of long bones, mental retardation in infantile form only. |
| • Krabbe's disease | • Loss of myelin, mental retardation death by the age of 2. |

### 3.3.7 Peroxisome

Peroxisomes are the single membrane bounded organelles like lysosome but smaller in size than lysosome. It is mainly involves in the formation and decomposition of toxic molecules i.e. hydrogen peroxide ($H_2O_2$) so named peroxisome. It also originates from Golgi-complex. It contains variety of enzymes i.e. peroxidase, catalase, glycolic acid oxidase etc. It is found both in animal and plant cells. In animal cell it is involved in lipid metabolism i.e. fatty acid oxidation, either phospholipid synthesis, isoprenoid biosynthesis. It also produces and export cholesterol and an important group of phospholipids called plasmalogen to cytoplasm. Plasmalogen are found in brain and heart tissues.

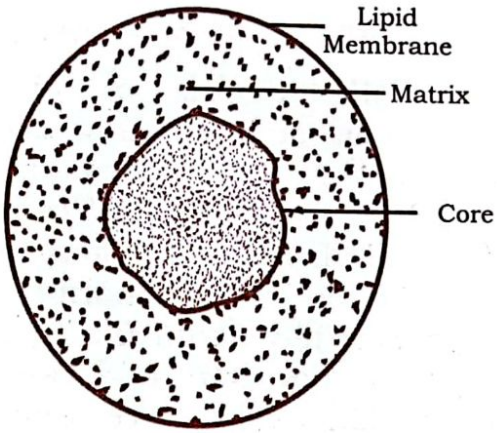


Fig 3.17 Peroxisome

Peroxisome are mainly concerned with the detoxification of alcohol where alcohol is oxidized and form another toxic compound $H_2O_2$ (Hydrogen peroxide) that is immediately breakdown to $H_2O$ (detoxify) by an enzyme **catalase**. They are found abundantly in liver cells as well as in the cells of organisms (like camel, Kangaroos and number of reptiles) which store fats as reserve food and water.

In plants it converts glycolate an acid produced during photorespiration into amino acid glycine. It occurs with the help of an enzyme called Glycolic acid oxidase.

> Peroxisome contain enzyme that break down toxic compounds e.g. peroxysome within liver and kidney cells breakdown and detoxify fully, half of the alcohol of a person drink.

### 3.3.8 Glyoxysome

Another single membrane bounded micro body found in plant also originate from Golgi complex like lysosome and peroxisome. These are also considered as specialized peroxisome. They are found in fats storing tissues i.e. seeds endosperm. Each glyoxysome has a single layer bounding membrane enclosing a fine granular stroma. Glyoxysome contain enzymes that initiate the conversion of fatty acid into sugar. So the germinating seedlings convert stored fatty acids to carbohydrate. This process takes place in cyclic manner, which is called **Glyoxylate cycle**.

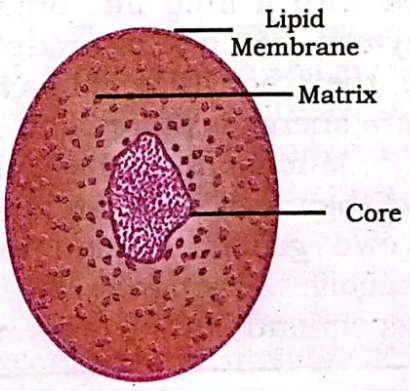


Fig 3.18 Glyoxysome

## Mitochondria (Power house of the cell)

**Gr: Mitos = thread. khondrion = small grain.**

Mitochondria or chondriosome are universily present in the cytoplasm of eukaryotic cells. They appear minute grannular, vesicle, rodlets, thread or strings, depending on the nature of cells, but usually it is considered that it found in bean shaped. They are seen to be in constant motion in living cells. These are the centers of aerobic respiration.

Each mitochondrion is approximately about 0.5 to 1.0 nm in diameter and about 10µm long. They are double membrane bounded organelles. Both membranes are formed of lipids and proteins. The outer membrane is smooth and having pores like sieve made up of proteins called **Porins**. These pores are responsible for the transport of molecules across the membrane; therefore this outer membrane is permeable for all. The inner membrane forms irregular, incomplete partition due to inward folding. These folds are called **cristae** which increase the surface area to attach number of proteins containing molecules. These molecules are ATPase complex, variable types of cytochrome, NAD, FAD etc. These complexes and molecules serves as electron carrier, which metabolize carbohydrates (starch), fatty acid (lipids) and amino acids (protein) into $CO_2$ and $H_2O$ with energy in the form of ATP which is stored in mitochondria. The folds formed by inner membrane is filled with a fluid like organic matrix, with a number of compounds and enzymes in it, due to production of high amount of energy for all cell organs and their activities. Mitochondria is known as power house of the cell, where energy is stored and released wherever required by an organism.

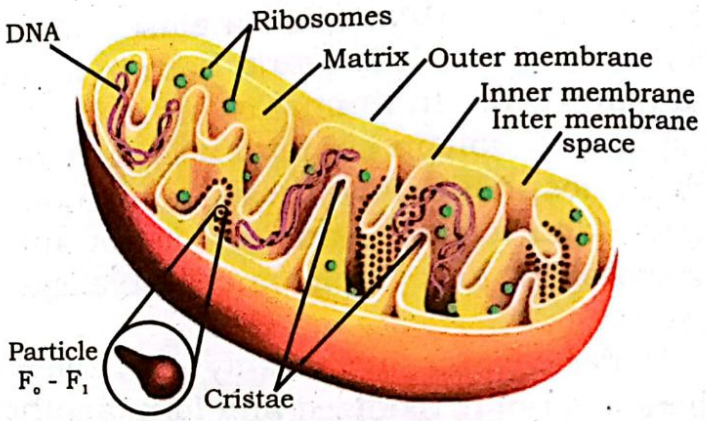



**Fig 3.19 Mitrochondria structure**

Mitochondria have a semi-autonomous existence in the cell. They have their own DNA, all kinds of RNA and ribosomes of 70s. It means it has its own genetic system to synthesize its own enzyme (proteins) for its metabolic function. They can divide in half and thus reproduce independently of the cell's normal cell-division.

Surprisingly, mitochondria are passed an animal only by mother since mitochondria are present in eggs but not in the part of sperm that enters the egg. Thus people can trace their mitochondria back to their mother, grandmother and great grandmother cells.

### 3.3.10 Plastids

They are special protoplasmic, double membrane bound organelles which function as chemical synthesizers and storage bodies. They are found in plants and algal cells mainly. Basically all plastids are originated from specialized structure called proplastids. They are immature, colorless plastids occurring in cells of meristematic tissues. It consists of double membrane enclosing granular stroma. They multiply by division in meristematic cell and distributed to different cell where they become develop as different types, depending upon environmental conditions i.e. intracellular factor and exposure to light. They develop as chloroplast, chromoplast and leucoplast.

**(i) Chloroplast (Chloros = green, plast = living)**

The most common type of plastid, containing chlorophyll which gives green colour to plants and is the site of photosynthesis.

**(ii) Chromoplast (Chroma = colour)**

It is the type of plastid which contain different pigments except chlorophyll i.e. xanthophyll, carotene etc. The chromoplasts are responsible for the various color combinations in flowers, fruits and other colour parts except green. The chloroplast after loosing their green pigments may convert into chromoplast. They help in pollination and dispersal of seeds.

**(iii) Leucoplast (Leucos = colorless)**

These are colorless plastids, which usually develop in the absence of light, they are found in all – underground parts and storage organs of plant. They store food material as carbohydrate, lipids and proteins on the basis of their storage material. They are further classified into amyloplast – carbohydrate (starch) storing elaioplast; lipid storing and proteioplast; protein storing leucoplasts.

**Structure of chloroplast and its function as energy converting organelles:**

Chloroplasts are formed only in green parts of plant and some protist. They vary in shape, surrounded by two membranes; a little space is present between them. The outer membrane is permeable due to presence of protein porins like mitochondria, while the inner membrane is differentially permeable. The inner membrane encloses a semi fluid material called **stroma**. Stroma contain various enzymes, DNA, RNA, ribosome(70S), ATP, NADP etc. The inter connected stacks of hollow membranous sacs are also embedded in stroma. The individual sac is called **Thylakoids** and a stack of sacs is called **granum** (Plural grana). The thylakoid membrane contains green pigment chlorophyll as well as other pigments like xanthophylls and carotene. There is another thylakoid which connect the grana with each other and called **intergrana**. Fifty or more than fifty

thylakoids piled to form a granum. The intergrana are usually colorless due to absence of pigments.

The chloroplast is also a semi-autonomous structure due to presence of its DNA, RNA and ribosome (70s). The chloroplast is special type of energy converting organelle. It converts light energy into chemical or food energy by the process of photosynthesis, therefore called "site of photosynthesis". During photosynthesis chlorophyll captures energy of sunlight and transfer it to other molecule in the thylakoid membranein. These molecules in turn transfer the energy to ATP and other energy carrier molecule like $NADPH_2$. These molecules differentiate stroma where their energy is used to drive the synthesis of sugar from carbon dioxide. Due to this flow of energy from one form to another, chloroplast is an energy converting organelle.

### 3.3.11 Cytoskeleton

A network of different protein fibers which provide three dimensional shapes to cell called **cytoskeleton**. It maintains and change the shape of the cell, secure some organelles at their specific position, enable movement of cytoplasm and vesicle within cell and cell to move in response to stimuli.

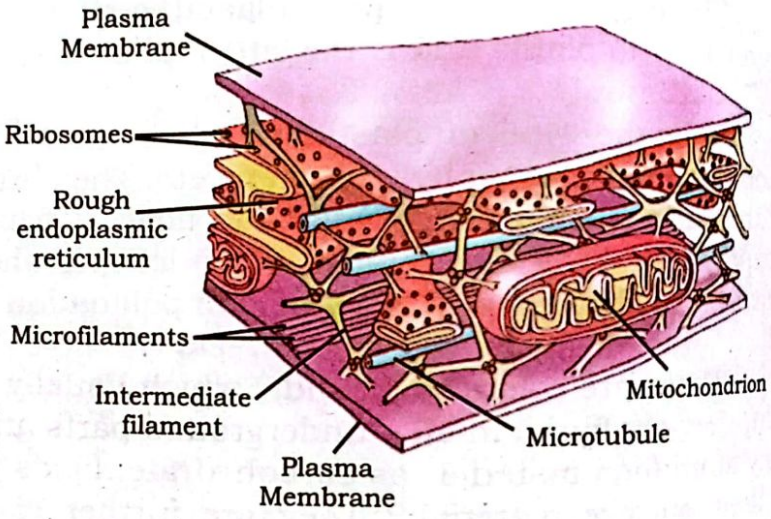



Fig 3.20 Cytoskeleton

There are three types of cytoskeletal elements found in cells.

a) Microfilament, b) Microtubules, c) intermediate filament.

**(a) Microfilament:**

They are solid strands of about 7 nm in diameter. They consist of two actin chains that intertwine in a helical fashion. Some microfilaments also contain myosin, tropomyosin and troponin at intervals. They form myofibrils in muscle cells, perform function of muscle contraction. They also perform function of change in cell shape, division of cytoplasm among daughter cells, cyclosis, movement of pseudopodia etc.


Fig 3.21 Microfilament

**(b) Microtubules:**

These are hollow tubes with an outer diameter of about 25nm. They are composed of protein tubulin. A single microtubule consists of hundreds of thousands of tubulin sub-units usually arranged in 13 columns. Each column is called **proto-filament**. In plant cells freely dispersed microtubule arrange at the time of cell division form spindle fibers whereas in animal cell they form centriole. It means microtubules are responsible for the movement of chromosomes during cell-division, movement of organelles within cytoplasm, movement of cilia and flagella.

**(c) Intermediate filaments:**

They are solid strands of 8 to 12 nm in diameter i.e. intermediate between microfilaments and microtubules. They are made up of at least five different types of proteins collectively called **vimentin**, form rope like polymer. Unlike the other two types of cytoskeleton intermediate filaments do not assemble and disassemble. They usually form network in cytoplasm to provide mechanical support to plasma and nuclear membrane. They are important in maintaining the shape of the cell, attachment of muscle cells and support of nerve cell processes axon.

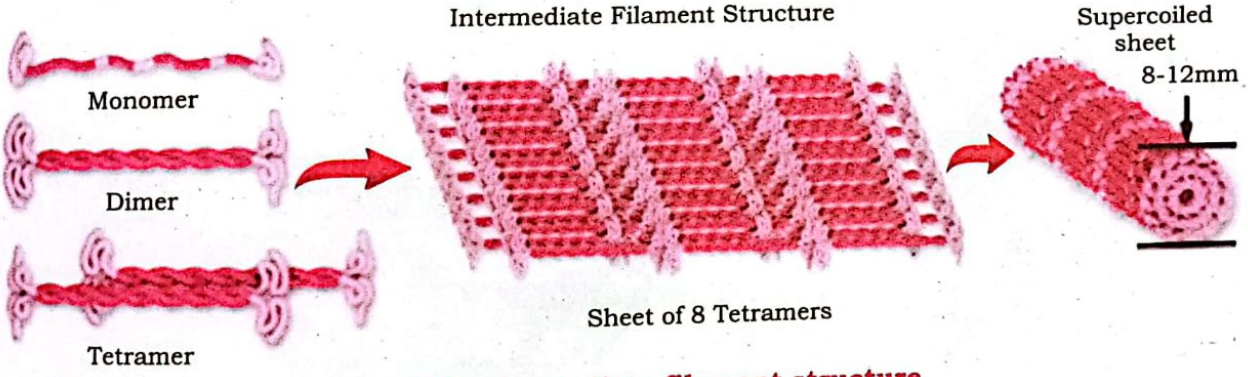



**Fig 3.22 Intermediate filament structure**

### 3.3.12 Cilia and flagella

Cilia and flagella are slender extension of plasma membrane in eukaryotic cell. The flagella are longer and few in number perform independent movement while cilia are smaller in size, and many in numbers. They perform function in synchronized manner i.e. one after the other. Both cilia and flagella share common internal structure, each contains a ring of nine fused pairs of microtubules, with an unfused pair in the center of the ring as shown in Fig 3.23. This pattern of microtubules is produced by a basal body kinetosome, located just beneath the plasma membrane.

The main difference between cilia and flagella lies in their number, length and the direction of force they generate. Cilia (Latin = eyelash) are short i.e. 10 to 25 μm long and numerous. They exert force only toward

plasma membrane. Flagella (Latin = whiplash) are long 50 to 75 μm, usually few in numbers, they exert force perpendicular to plasma membrane. Flagella perform upward and downward movement with a continuous bending wave like motion with distinct power.

**Movement mechanism of Cilia and Flagella**

Flagellary movement occur as planner waves, it is contracting wave that passes either from the base to the tip of flagellum or in the reverse direction to produce forward or backward movement. Movement mechanism of cilia and flagella.

A question arises here how cilia and flagella bends? it is because of the tiny protein "arms". These arms project out from each pair of microtubules in outer ring. These arms attach to neighboring pair of microtubules and flex, thereby moving the first pair along relative to the second. However the basal body firmly anchor the bottom of all microtubules in the entire celium and flagellum. Therefore, adjacent microtubule can slide past one another only if the whole cilium or flagellum bends.

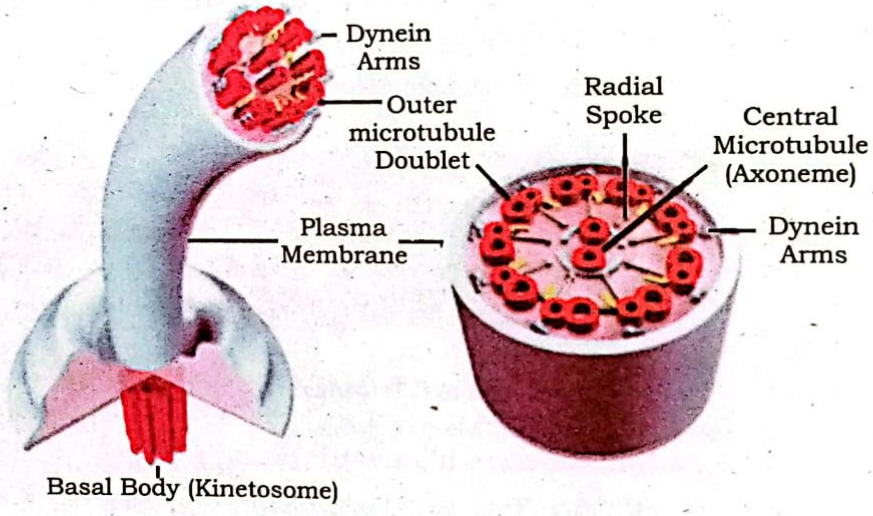



**Fig 3.23 Cilia and flagella structure**

### 3.3.13 Centrioles

Centrioles are short, barrel shaped structure of microtubules, which are non-membranous, lying perpendicular to one another. Each centriole is composed of nine sets of triplet microtubules, arranged in a ring. They appeared in animal cell and fungi like protoctist before cell-division near outer membrance of the nucleus, therefore the place where they are present in

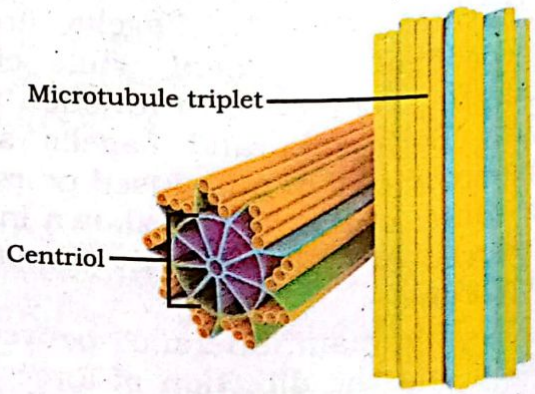



**Fig 3.24 Centriole**

cytoplasm is called **centrosome** (Centro = nucleus, soma = body). At the time of cell division the centriole duplicates and became two pairs, move to opposite sides of the cell and thread like fiber began to radiate from centriole in all directions called **astral rays**. The centriole also forms basal body (kinetosome) which form cilia and flagella.

### 3.3.14 Vacuole

Generally vacuole is non protoplasmic liquid filled vesicle in cytoplasm especially in plant cells. In young cell of plant many small vacuole are present but at maturity of cell they unite to form a large vacuole called **central vacuole**. In plant cell it is surrounded by a membrane called **tonoplast**. The tonoplast is selectively permeable; tono means tension and keep tension on the vacuole. The vacuole in plant cell is filled with cell-sap and acts as store house. The main function of central vacuole is to maintain turgor pressure inside plant cell. Turgor pressure helps the plant cell to keep its shape by pressing the plasma membrane against cell-wall. It maintains a nice rigid structure of plant.

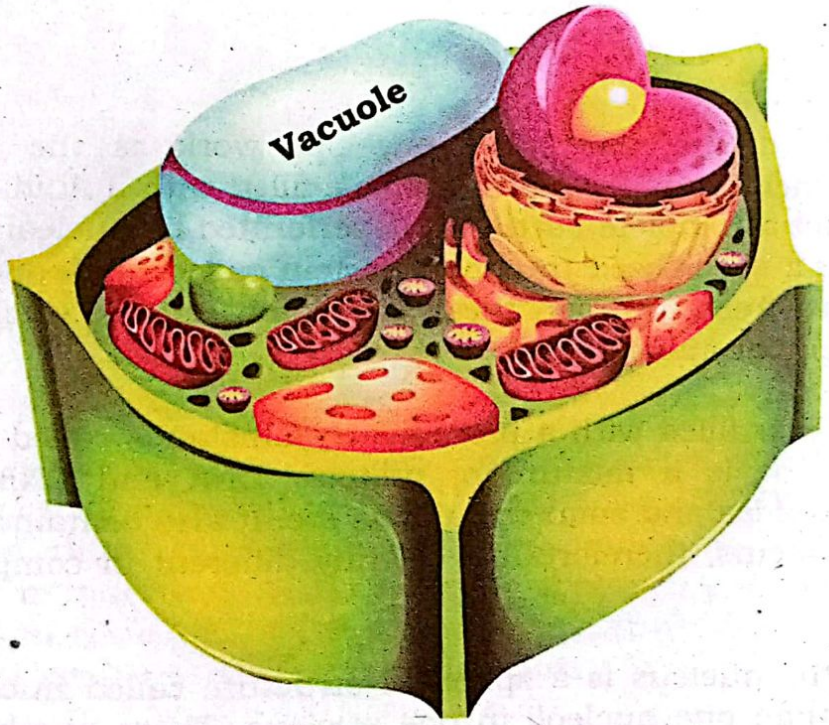



**Fig 3.25 Vacuole**

### 3.3.15 Nucleus

Nucleus was discovered by Robert Brown in 1831. It is the most important and prominent part of the cell which controls all the activities of the cell. It is commonly spherical in shape, in some cells it is lobed in

structure. In eukaryotic cell it consists of outer nuclear membrane, **nucleoplasm** (the fluid filled in it) nucleoli and chromatin.

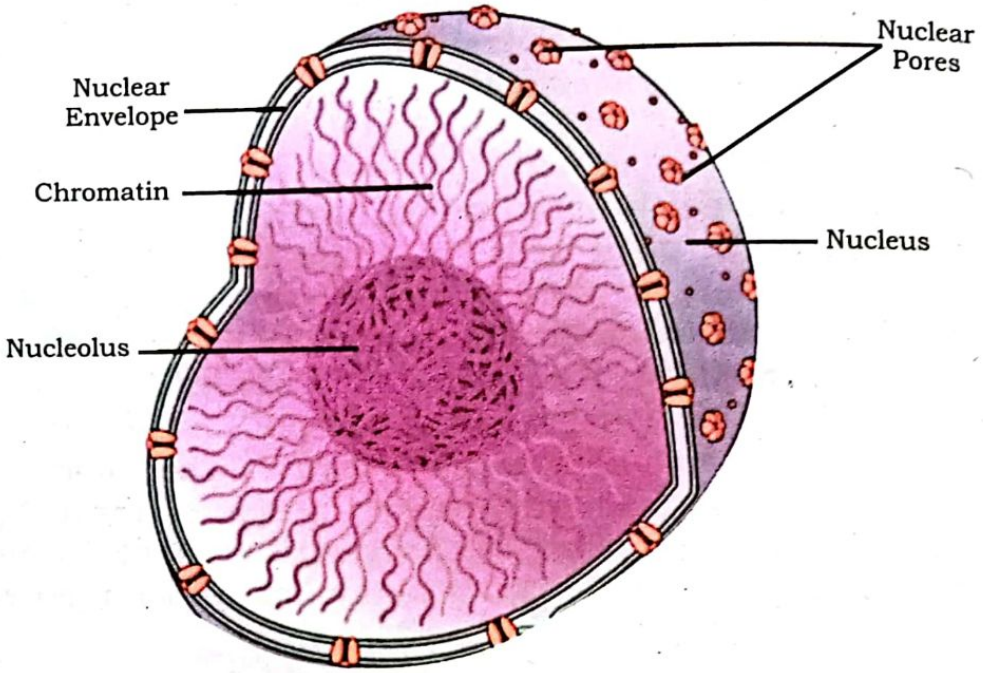



**Fig 3.26 Nucleus of cell**

### Nuclear membrane

It is the double membrane envelope work as the boundary of nucleus. Both membrane have a thin space filled with a fluid. The nuclear membrane is not a complete barrier. It is perforated by nuclear pores which are made up of a specialized transport protein called **nucleoporin**. Certain substances pass freely through these pores between the nucleus and the surrounding cellular substances.

### Nucleoplasm

The nucleus filled with a protein rich substance called nucleoplasm or karyolymph. It is a mixture of protein, DNA and RNA polymerase enzymes, nucleotides and some metal ions etc. It also contains histone and non histone proteins, therefore it is slightly different in composition from cytoplasm.

### Nucleolus

Within the nucleus is a spherical structure called nucleolus. There may be more than one nucleoli in one nucleus. There numbers varies in different kind of cells. It disappears during cell-division and reappear afterward. It is made up of different type of RNA and responsible to synthesize ribosomes.

The nucleus contains numerous fine strands in the form of network throughout nucleoplasm called **chromatin network** or **nuclear reticulum**. It can be seen only in non-dividing cell. This network is made up of

chromatin material i.e. DNA and histone protein. During cell division the chromatin network break into specific number of threads; which start coiling and condensation. After condensation it becomes chromosome. The chromosomes are thick threads, made up of highly condensed chromatin material at the time of cell-division. A chromosome in the beginning of cell-division consists of two genetically identical threads attached at least at centromere called **chromatids or sister chromatids**, chromosome consist of two parts, Arms and Centromere the part of chromosome or chromatids from centromere to end is called **arm**. The arms or chromatids are joined at a constriction called primary constriction or **centromere**.

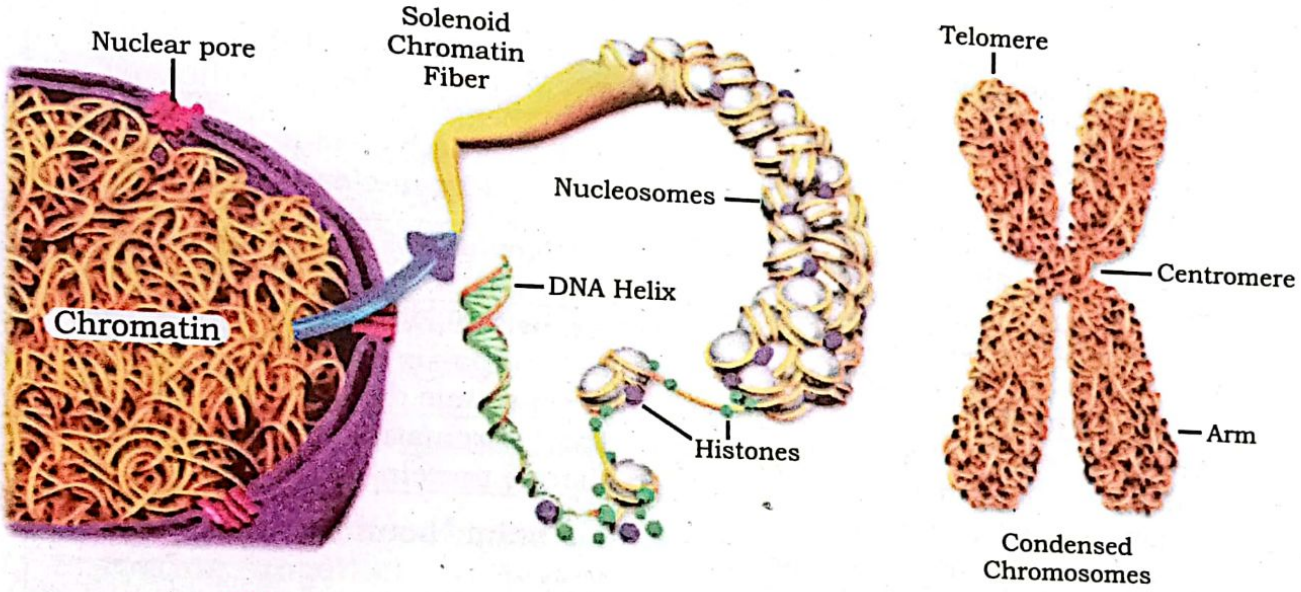



**Fig 3.27 Chromatin and condensed chromosome structure**

Chromosome contains the heredity units called **genes**. The position of genes on chromosome called **gene locus** (plural – loci). Chromosome carry the heredity information from generation to generation. The chromosomes number vary from species to species e.g. 8 in fruit fly, 14 in sweet pea, 20 in corn cells, 46 in human etc. On the basis of shapes and the position of centromere. The chromosomes are of different types, they are as follows.

(i) **Metacentric** – Chromosomes with equal arms. Centromere is present exact in centre.

(ii) **Sub – metacentric:** Chromosomes with slightly unequal arms. Centromere slightly away from centromere.

(iii) **Acro or sub – Telocentric:** Chromosomes with one very long and the other is very short arm. Centromere is far away from centromere.

(iv) **Telocentric:** Centromere is in the end of arms.

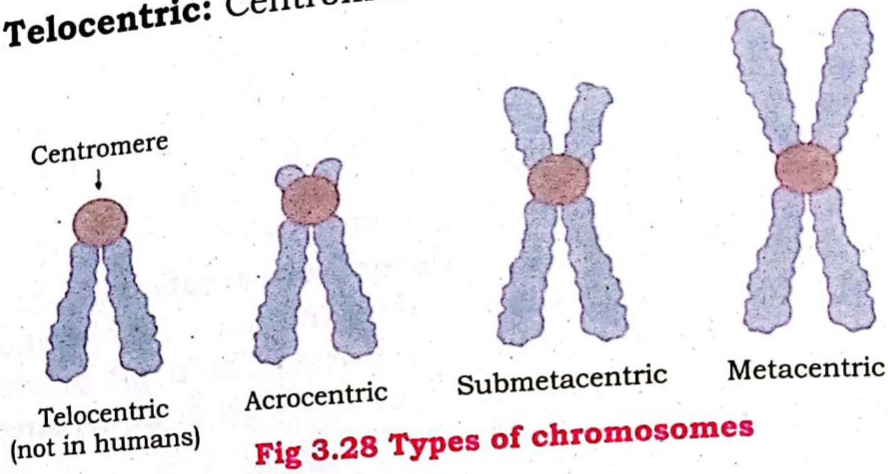



**Fig 3.28 Types of chromosomes**

## 3.4 Prokaryotic and Eukaryotic cell

| Prokaryotic (Pro = first or early, Karyon = Nucleus) | Eukaryotic (Eu = proper, karyon = nucleus) |
|---|---|
| 1. Cell has primitive type of nucleus i.e. does not bounded by nuclear membrane | 1. Cell has true type of nucleus i.e. It is bounded by nuclear membrane |
| 2. Nucleoplasm and nucleolus are absent | 2. Nucleoplasm and nucleolus are present |
| 3. Only one circular, long, interwoven DNA is present as chromatin material. | 3. Number of DNA are present which may appear in the form of chromosome during cell-division. |
| 4. The chromatin material does not contain histone protein | 4. The chromatin material contain histone protein with DNA. |
| 5. All membrane bounded organelles are absent i.e. E.R, golgisome, mitochondria, plastids etc. | 5. Membrane bounded organelles are present. |
| 6. Mesosomes are present. | 6. Mesosomes are absent. |

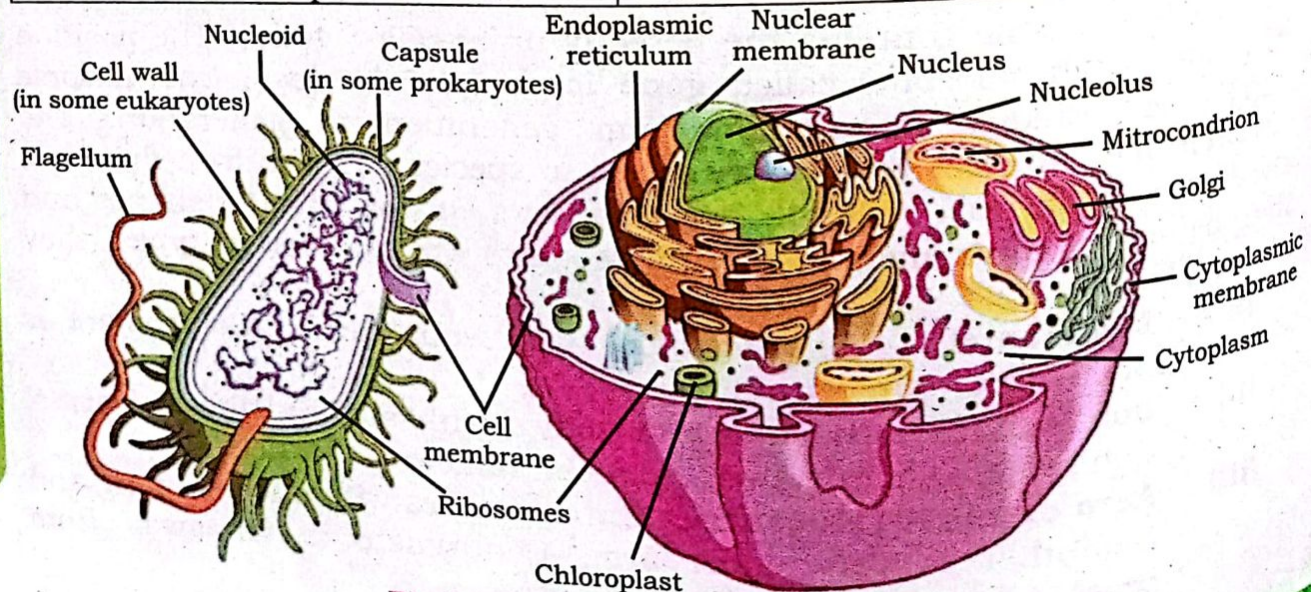



**Fig 3.28 Prokaryotes and Eukaryotes**

## SUMMARY

- Isolation of cellular components to determine the structure and chemical composition is called cell fractionation.
- The process of setting down cell organelles on the basis of density and mass by the process of centrifugation is called sedimentation.
- Microdissection is a technique to isolate specific cell with the help of microscope.
- Chromatography is a technique used for separating different components of mixture.
- A technique used to separate charged molecule based on their size and electrical charge in an electrolytic cell is called electrophoresis.
- Method of measuring light absorption by a particular substance is called spectrophotometer.
- The study of cell and micro-organisms is dependent upon the use of an instrument called microscope.
- Micrometry is the science related to measurement of dimensions and size of an object observing under microscope.
- Cell wall is composed of mainly cellulose, pectin and other polysaccharides.
- All biological membranes have the same basic molecular organization.
- The components of plasma membrane are mobile and capable of coming together to engage in various type of transient or semipermanent interaction.
- Cytoplasm is a translucent, granular liquid. It consists of an aqueous ground substance called cytosol.
- Tube like system of lipoprotein form a complex network of channels, extended from plasma membrane to nuclear membrane called endoplasmic reticulum.
- Each ribosome consists of two unequal units. The larger sub-unit is dome shaped and smaller one forms a cap on the flat surface of large sub-unit.
- Golgi complex is especially prominent in glandular cells. The products of ER are modified, stored and then sent to other destination.
- The newly formed lysosome before starts its functions called primary lysosome.
- Peroxisome are mainly concerned with the detoxification of alcohol.

- Glyoxysome contain enzymes that initiate the conversion of fatty acid into sugar.
- Mitochondria have a semi-autonomous existence in the cell.
- The most common type of plastid, containing chlorophyll which gives green colour to plants is the site of photosynthesis.
- A network of different protein fibers which provide three dimensional shapes to the cell called cytoskeleton.
- Centrioles are short, barrel shaped structure of microtubules.
- The main function of central vacuole is to maintain turgor pressure inside plant cells.

## EXERCISE

**1. Encircle the correct choice**

(i) A primary objective of cell fractionation is to
- (a) View the structure of cell membranes.
- (b) Identify the enzymes outside the organelles.
- (c) Determine the size of various organelles.
- (d) Separate the major organelles so that their particular functions can be determined.

(ii) The volume enclosed by the plasma membrane of plant cells is often much larger than the corresponding volume in animal cells. The most reasonable explanation for this observation is that
- (a) Plant cells are capable of having a much higher surface to volume ration than animal cells.
- (b) Plant cells have a much more highly convoluted plasma membrane than animal cells.
- (c) Plant cells contain a large vacuole that reduces the volume of the cytoplasm.
- (d) Animal cells are more spherical, while plant cells are elongated.

(iii) Large numbers of ribosomes are present in cells that specialize in producing which of the following molecules?
- (a) Lipids
- (b) Starch
- (c) Proteins
- (d) Steroids

(iv) In animal cells, hydrolytic enzymes are packed to prevent general destruction of cellular components. Which of the following organelles functions in the compartmentalization?
- (a) Chloroplast
- (b) Lysosome
- (c) Peroxisome
- (d) Glyoxysome

(v) Tay-Sachs disease is a human genetic abnormality in cells accumulating and becoming clogged with very large and complex lipids. Which cellular organelle must be involved in this condition?
(a) Endoplasmic reticulum (b) Golgi complex
(c) Lysosome (d) Mitochondria

(vi) Which is one of the main energy transformers of cells?
(a) Endoplasmic reticulum (b) Golgi complex
(c) Lysosome (d) Mitochondria

(vii) Organelles other than the nucleus that contain DNA
I. Ribosomes II. Chloroplast III. Mitochondria
(a) I only (b) II only
(c) II and III (d) I and II

(viii) Which structure is common to plant and animal cells?
(a) Chloroplast (b) Cell wall
(c) Central vacuole (d) Mitochondria

(ix) Cell organelle mainly concerned with the detoxification of alcohol.
(a) Chloroplast (b) Peroxisome
(c) Central vacuole (d) Mitochondria

(x) Clarity of image is generally known as
(a) Magnification (b) Contrast
(c) Resolution (d) Sedimentation

**2. Write short answers of the following questions:**

1. Why lysosome is called suicidal sacs?
2. Why plasma membrane is differentially permeable in nature?
3. Why plant cell wall is rigid?
4. Why chloroplast is called energy converting cell organelle?
5. How prokaryotic ribosome is different from eukaryotic ribosome.
6. How mitochondria is similar to bacteria?
7. Why mitochondria is called power house of cell?
8. Differentiate between peroxisome and glyoxysome.

**3. Write detailed answers of the following questions:**

1. Describe structure and functions of rough and smooth endoplasmic reticulum.
2. Explain the chemical composition and functions of plasma membrane in regulating cell's interactions with environment.
3. Explain the structure and functions of lysosomes.
4. Describe structure of mitochondria with suitable diagram.
5. Explain the structure and composition of cell wall.
6. Describe the structure and functions of Golgi complex.
7. Describe the types, structure, composition and functions of cytoskeleton.

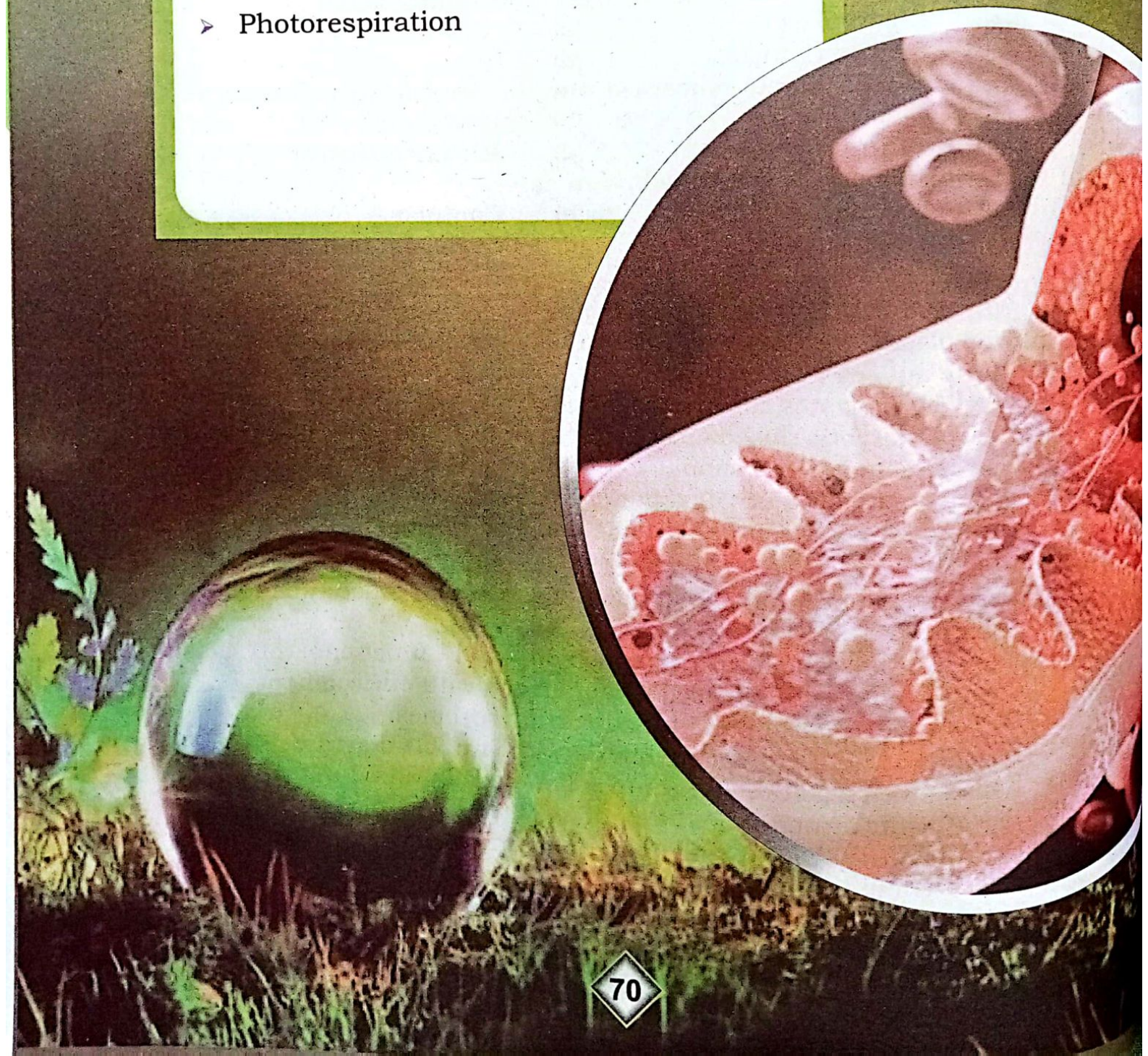
# BIOENERGETICS

Chapter 4

## Major Concept

**In this Unit you will learn:**

- Photosynthesis
- Cellular Respiration
- Photorespiration



**Introduction:**

All living things and cells carry out numerous activities e.g. they generally assemble macromolecules from raw materials, waste products are produced and excreted, genetic instructions flow from the nucleus to cytoplasm, vesicles to Golgi bodies and then to plasma membrane; ions are pumped across the membranes etc. For these activities, a cell needs energy. The energy is used as fuel for life, this energy is derived from light energy which is trapped by plant and converted into energy rich compounds like ATP, $NADPH_2$ and $FADH_2$ which then stored in food molecules like carbohydrate and lipids. Other organisms, which do not have the ability to trap light energy and its conversion, obtain their energy by eating plants or by eating those organisms which eat plants. Capturing and conversion of this energy from one form to another in the living system and its utilization in metabolic activities is called **Bioenergetics**. In other words, bioenergetics is the quantitative study of energy relationships and conversion into biological system. This biological energy transformations obeys the laws of thermodynamics.

The whole biological energy transformation contains, formation and utilization of energy rich molecule ATP. Plant trap light energy and utilize it in the formation of ATP. In living organisms some organic molecules oxidise to produce energy, some of this energy is used to produce ATP. This process of ATP formation from ADP and phosphate is called phosphorylation. There are three types of phosphorylation found is living organisms.

**(i) Photophosphorylation:** The type of ATP formation which utilize energy of light (photon). It occurs in thylakoid membrane of chloroplast.

ADP + Pi + Energy of light $\longrightarrow$ ATP

**(ii) Oxidative Phosphorylation:** Type of phosphorylation where ATP is formed by using energy of oxidation, produce during metabolic reactions in cell. It occurs in cristae of mitochondria.

ADP + Pi + Energy of oxidation $\longrightarrow$ ATP

**(iii) Substrate level phosphorylation:** Type of phosphorylation where one substrate provides phosphate and energy to another substrate.

Under cellular condition ATP formation requires 7.3 Kcal/mole energy, whereas Pi means, phosphate from inorganic source (molecule) like $H_3PO_4$. For ATP formation living organisms has two processes i.e., photosynthesis and respiration.

## 4.1 PHOTOSYNTHESIS:

The living process where light energy converts into chemical energy (ATP, $NADPH_2$) and then into energy rich organic food molecules like carbohydrate called **Photosynthesis** or we can say that Photosynthesis is the biochemicals anabolic process during which carbohydrates are

synthesized from carbon dioxide ($CO_2$) and water in chlorophyllous cells in the presence of light.

### 4.1.1 Role of light in Photosynthesis

Light is a form of energy, has dual nature, described both as a wave and a particle nature. It is composed of packet of energy called quanta and photon. Plants are capable of using only a very small portion of visible light that falls on leaves, absorbed by the pigment complex, present in chloroplast. Each pigment has its own absorption spectrum.

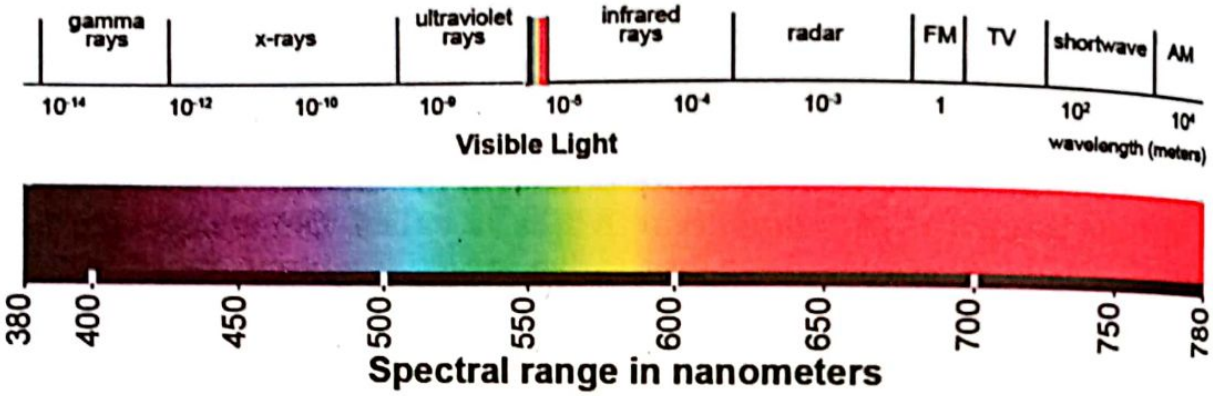



**Fig 4.1 Electromagnetic spectrum**

Light energy captured by the light harvesting complexes which is efficiently and rapidly transferred to the chlorophyll molecules present in the photosynthetic reaction center.

Each pigment has its own absorption spectrum. Absorption spectrum for chlorophyll indicates that absorption is maximum in blue and red parts of the spectrum, two absorption peak are observed in between 430nm and 670nm, respectively. Absorption peaks of carotenoids are different from those of chlorophyll.

Differential absorption spectrum by photosynthetic pigment also plays an important role in photosynthetic activity. Relative effectiveness of different wave length (colour) of light in driving photosynthesis is called action spectrum of photosynthesis.

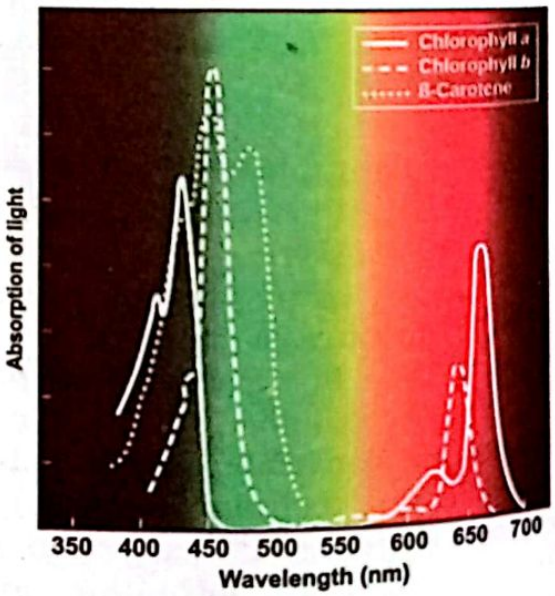



**Fig 4.2 Absorption and action spectrum of pigments**

It is observed from above graphs that the absorption spectrum and action spectrum of chlorophyll are not parallel. By comparing these peaks in absorption spectrum and the peaks in action spectrum are broader and

the valley is narrower not as deep. This difference occurs due to the accessory pigments, the carotenoids. The light absorbed in this zone pass on to chlorophyll and then convert to chemical energy. Red and blue part of spectrum is more efficient in photosynthesis.

### 4.1.2 Photosynthetic Pigments

As light is flashed on matter, it may be reflected, transmitted or absorbed. Substances in plants that absorb visible light are called **pigments.** Different pigments absorb light of different wave lengths. These pigments are important in the conversion of light energy to chemical energy. The most important pigments required in the process are the chlorophylls and carotenoids.

Chlorophyll can be distinguished into a, b, c, d and e. The empirical formula of the **chlorophyll-a** molecule is $C_{55}H_{72}O_5N_4Mg$ and **chlorophyll-b** is $C_{55}H_{70}O_6N_4Mg$.

A chlorophyll molecule has two main parts one flat, square, light absorbing hydrophilic head and the other long hydrophobic, hydrocarbon tail. The head is complex porphyrin ring, made up of four smaller pyrrole rings joined by Mg with Nitrogen (N) of porphyrin rings. Long hydrocarbon tail which is attached to one of the pyrrole rings is phytol ($C_{20}H_{39}$). The chlorophyll molecule is embedded in the hydrophobic core of thylakoid membrane by this tail.

Chlorophyll molecules mainly absorb violet-blue and orange-red from visible light. Green, yellow and indigo are least absorbed by chlorophylls therefore plants appear green.

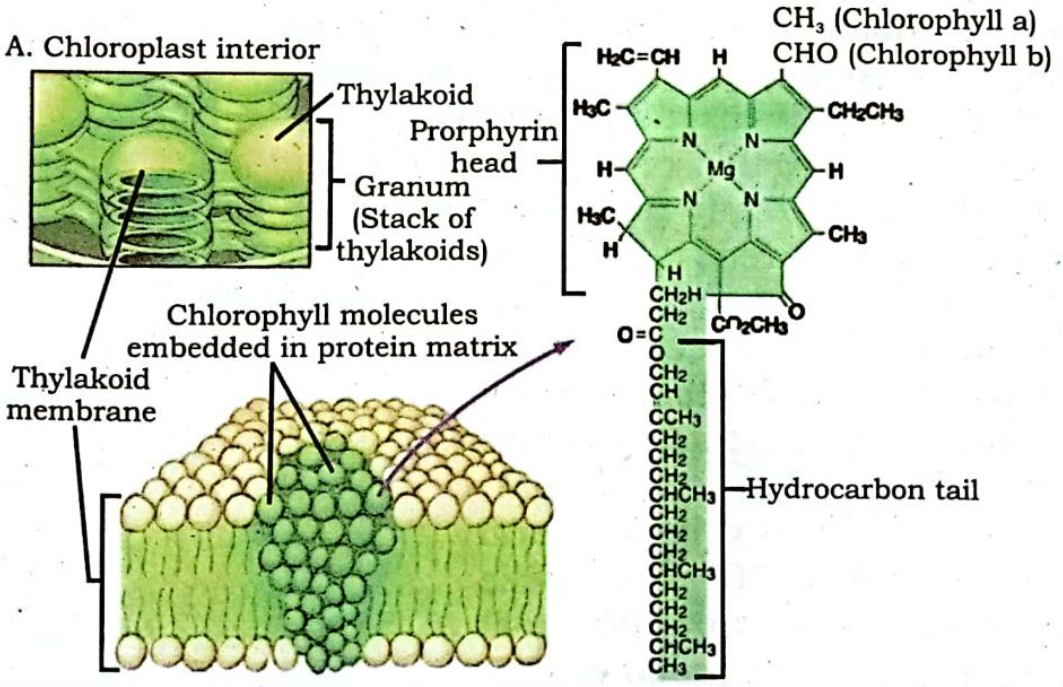



**Fig 4.3 Chlorophyll molecules**

Chlorophyll-a is the most abundant and the most important photosynthetic pigment because it directly takes part is light dependent reactions to convert light energy into chemical energy. It exists in several forms differing slightly in their red absorbing peaks i.e. 670, 680, 690, 700 nm. Chlorophyll-b is found along with chlorophyll-a in all green plants and green algae.

**Carotenoids**

Carotenoids are yellow and red to orange pigments that absorb the light of blue-violet rangeefficiently, which is different from absorption range of chlorophyll. The broad absorption spectra of light provide more energy for photosynthesis.

The carotenoids transfer their energy to chlorophyll-b and then to chlorophyll-a, from here energy transfer to light reaction. The order of energy transfer is shown below:

**Carotenoids** → **Chlorophyll-b** → **Chlorophyll-a**

Some carotenoids also protect chlorophyll molecules from high intensity of light by absorption and dissipation of extra energy.
In human eye carotenoids are also present which protect human eye.

### 4.1.3 Role of photosynthetic pigment in absorption and conversion of light energy

As we have already discussed that each pigment has its own absorption spectra due to their slight structural differences. The light of same wave lengths are not absorbed by chlorophyll a but very effectively absorbed by chlorophyll b and vice versa. Such differences in structure of different pigments increase the range of wave length which are absorbed by different pigments. All accessory pigments transfer the energy to chlorophyll-a and then to photosynthesis for conversion through photosystems, already discussed above.

### 4.1.4 Absorption septum of chlorophyll a and b

As we have already discussed that due to structured differences both chlorophyll a and b has different absorption spectra. This absorption spectra of chlorophyll-a and chlorophyll-b pigments in visible range is measured in a solvent. Chlorophyll-a absorbs violet and orange light (650 to 700 nm) while chlorophyll-b (450 to 500 nm) absorbs mostly blue and yellow light.

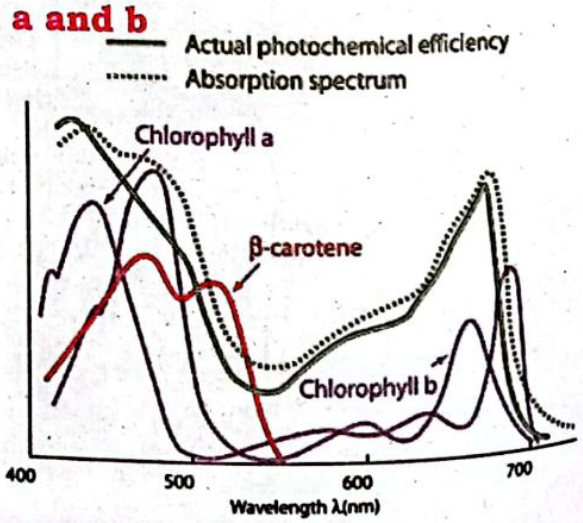



**Fig 4.4 Absorption graph**

### 4.1.5 Arrangement of Photosynthetic pigments in the form of photosystem I and photosystem II

As described in previous sections energy of light is absorbed by pigments and perform photosynthesis. Chlorophyll is organized with other molecules into photosystem, which has light gathering **"antenna complex"**, consist of a cluster of few hundred chlorophyll-a, chlorophyll-b and carotenoid molecules. When any antenna molecule absorbs energy of a photon, this energy is transmitted from one pigment molecule to other pigment molecule untill it reaches a particular chlorophyll a, which is structurally similar to other chlorophyll molecule but located in the region of photosystem called **"reaction center"** where first light driven chemical reaction of photosynthesis occur. It means that the photosystem consist of two parts (a) Antenna complex (b) reaction center. The reaction center consists of one or more molecule of chlorophyll-a along with many $e^-$ (electron) carriers.

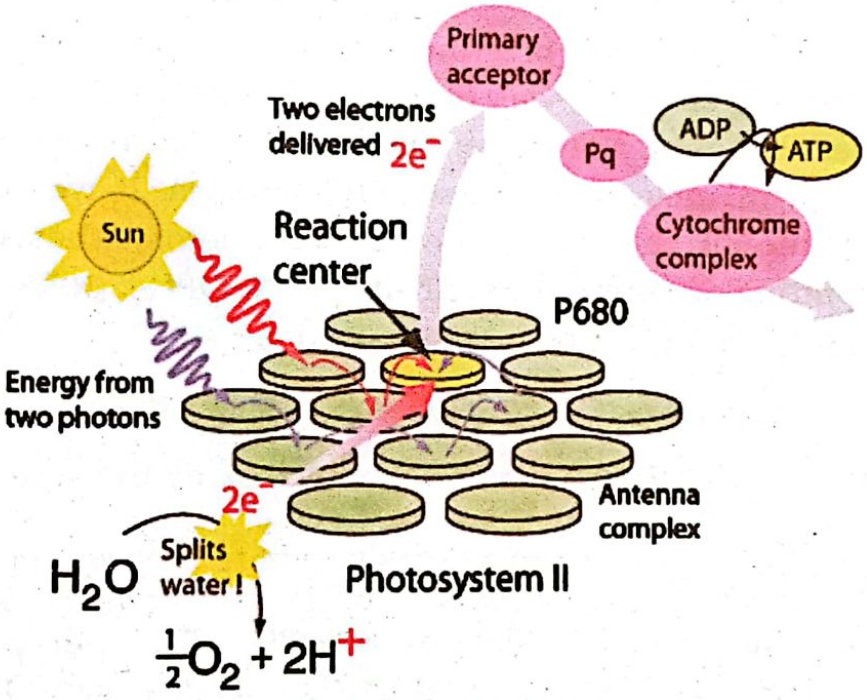



**Fig 4.5 Photosystem**

### 4.1.6 Role of $CO_2$

The final product of photosynthesis is carbohydrate which contain carbon atoms as basic skeleton attached with Hydrogen and oxygen atoms. The carbon form basic skeleton is provided by carbon dioxide during light independent reaction i.e. $C_3$ cycle.

Scientists had studied that $CO_2$ with air enter in the intercellular spaces through stomata of leaves. This $CO_2$ get dissolved in the water absorbed by the cell-wall of mesophyll cells. This entry of $CO_2$ into leaves depends on the opening of stomata on leaves.

### 4.1.7 Role of water

It is clear from above discussion that carbon dioxide provides carbon to $C_nH_{2n}O_n$. It is also clear that $H_2O$ provides hydrogen to $C_nH_{2n}O_n$ but the confusion was developed that which raw material either $CO_2$ or $H_2O$ provide oxygen to $C_nH_{2n}O_n$. In 1930 Von Neil hypothesized that plant split water as s source of Hydrogen and release oxygen as by product. His hypothesis was based on the by-products of photosynthetic bacteria which produce sulphur instead of oxygen.

Neil's hypothesized that the source of oxygen released during photosynthesis is water, not carbon dioxide. It was later confirmed experimentally by other scientists during 1940 by radio-labelling of $O^{18}$ isotopes with $H_2O$ and $CO_2$. They made two groups of plants in first group they supplied $CO_2$ and $H_2O$, the oxygen of this water molecule were labelled with $O^{18}$ and $CO_2$ has normal $O^{16}$. Plants of second group were supplied with normal $O_2$ containing $H_2O$ but with $O^{18}$ containing $CO_2$. It was observed that the plants of group1 produced oxygen gas with $O_2^{18}$ isotopes and no oxygen of $O^{18}$ was found in sugar. On the other hand in the plants of second group the oxygen gas produce did not contain any $O_2$ with $O^{18}$ while sugar molecules contain $O^{18}$ isotopes. It was cleared that water is thus one of the raw materials of photosynthesis, hydrogen produced by splitting of water reduces NADP to $NADPH_2$, ($NADPH + H^+$)

G1 (Group 1) Plants – $CO_2 + H_2O^{18} \rightarrow C_nH_{2n}O_n + O_2^{18}$

G2 (Group 2) Plants - $CO_2^{18} + H_2O \rightarrow C_nH_{2n}O_n^{18} + O_2$

### 4.1.8 Light Dependent Reaction: The event of cyclic and non-cyclic photophosphorylation

The first phase of photosynthesis where energy of photon is captured and converted into chemical energy. The energy of photon is stored in special molecules i.e. ATP and $NADPH_2$. The energy of ATP and $NADPH_2$ will utilize to produce carbohydrate during light independent phase.

In chloroplast the light capturing chlorophyll molecules, membrane bounded proteins and electron carriers all together constitute the electron transport chain. Four major groups of complexes are present in the membrane. These are photosystem-I (PSI), Photosystem-II (PS-II), the cytochrome b/f and an ATPase complex. Some mobile electron carriers are present which carry excited electrons between complexes. These mobile carriers are plastoquinone (PQ), plastocyanin and ferredoxin (Fd).

Photosystem I and II both contain special chlorophyll-a molecules at their centers. These chlorophyll molecules are identical to all other

chlorophyll-a molecules. The change in absorbing spectra are due to their association with the chlorophyll bound proteins. The chlorophyll-a molecule at the reaction center of PS-I has maximum absorption at 700 nm while those of PS-II absorb at 680 nm. These reaction centers are called $\mathbf{P_{700}}$ and $\mathbf{P_{680}}$ where **P** simply stands for pigment.

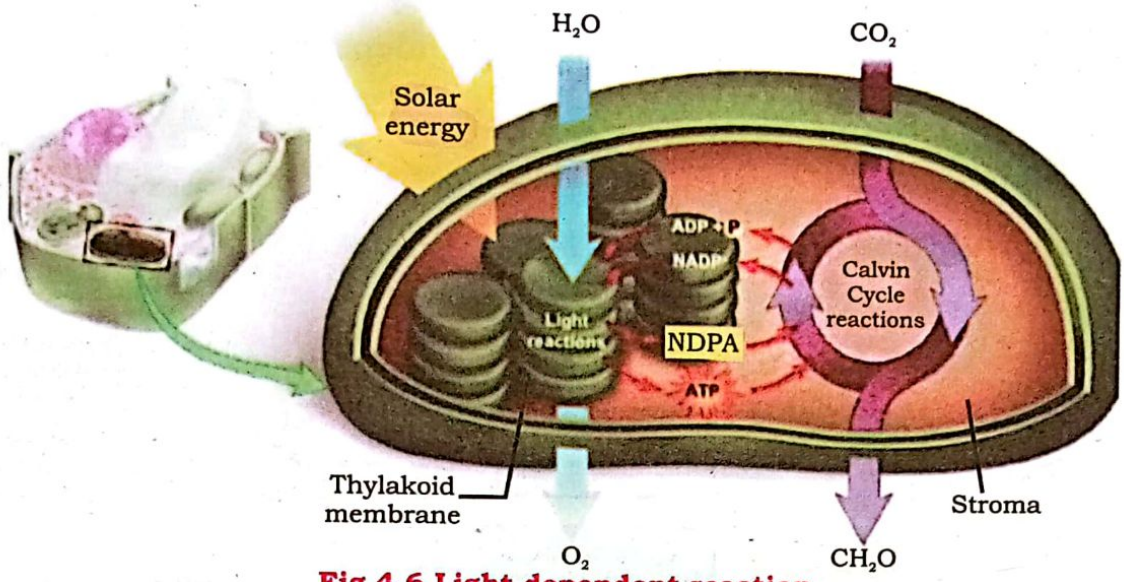



**Fig 4.6 Light dependent reaction**

### (a) Electron Transport Chains:

The light reactions of photosynthesis start from reaction center of PS-II ($P_{680}$) which consist of chlorophyll-a dimer. When a photon of light hits these chlorophyll a molecule, the energy of these photons is absorbed and results in the excitation of an electron from ground state to excited state. The excited electron produced within $P_{680}$ is rapidly transferred to primary ē accepter **phaeophytin** and then to **plastoquinone** (PQ) molecules.

The $P^{+}_{680}$ produced by this primary charge separation and ē transport is compensated (re-reduced) by ē from $H_2O$. The water splitting complex is present on the luminal side of thylakoid membrane and consists of a manganese cluster, Z complex (the immediate electron donor to $P_{680}$) and an associated protein. The water splitting complex produces 4ē from two water molecules and released $4H^{+}$ and one molecule of $O_2$ into the lumen.

The excited electrons are transferred from primary ē acceptor to plastoquinone (PQ), the PQ molecules which accept two electrons and takes up two protons from the stroma. It carriers electrons from the PS-II complex to the Cytb/f complex. This is thought to be the rate limiting step of electron transport. The PQ release protons into lumen. Finally the ē transfer to plastocyanin (PC), PC is reduced which is situated in the lumen.

Plastocyanin acts as an electrons donor to PS-I, the primary electron acceptor of photosystem-I, passes the photo excited electrons to a second $e^-$ transport chain, which transmits them to ferredoxin (Fd) an iron containing protein. An enzyme called NADP reductase then transfers the electrons from Fd to NADP, this NADP with $2e^-$ received proton from stroma and reduced to $NADPH_2$. It stores high energy which will provide reducing power for the synthesis of sugar during light independent reaction.

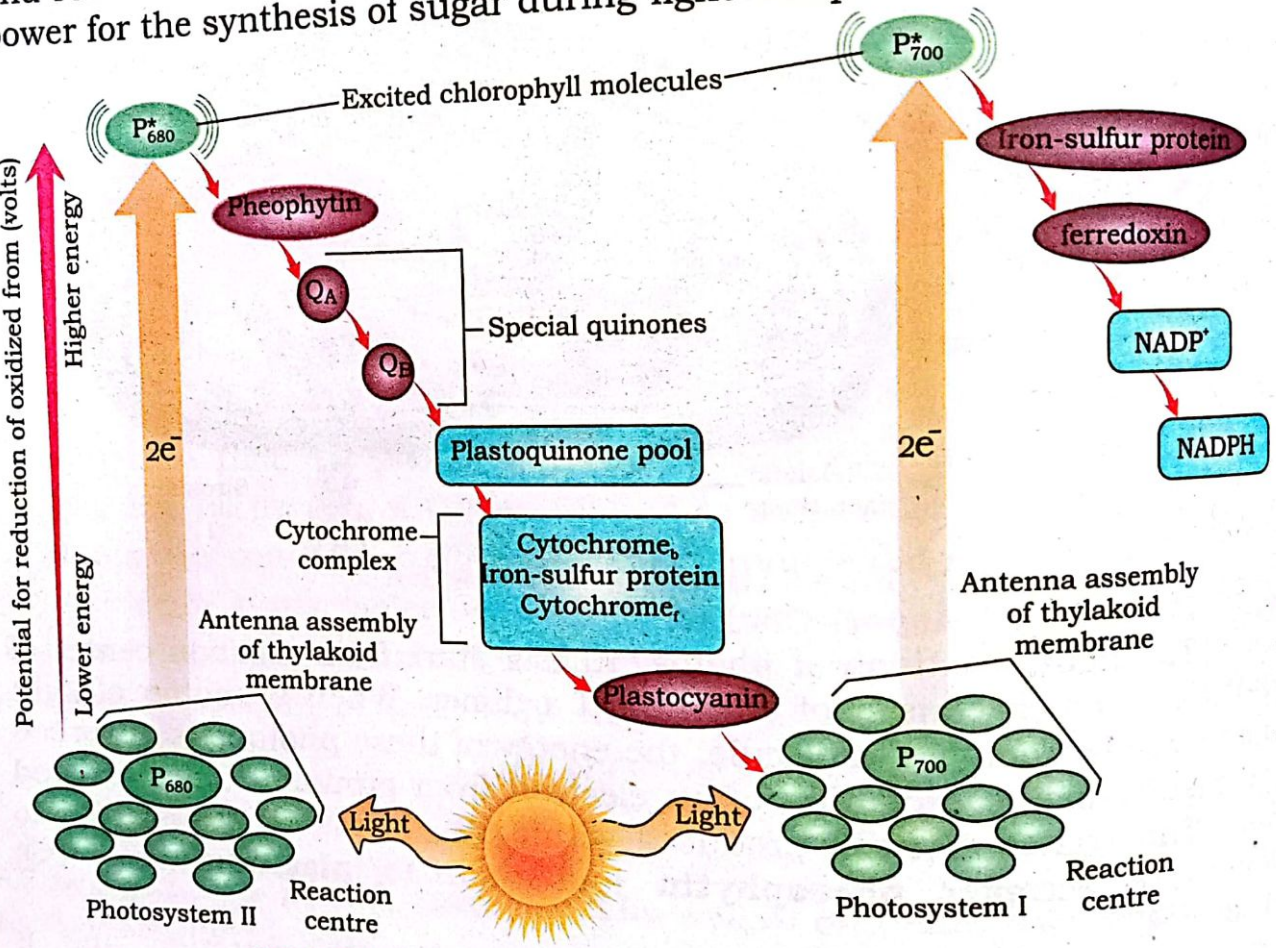



**Fig 4.7 Light dependent reaction of photosynthesis**

### (b) Formation of ATP (Photophosphorylation)

The energy released during movement of excited ē down the cytochrome system is coupled to build up ATP in an indirect manner. Some of the $e^-$ carrier of the cytochrome system pump hydrogen ion ($H^+$) from stroma to thylakoid space (lumen). This thylakoid space acts as a reservoir for hydrogen ions because $H^+$ ion produced by splitting water during the process of photolysis accumulate here.

The high quantity of $H^+$ ion in thylakoid space as compared to stroma develop electrochemical gradient, these $H^+$ ions flow out of the thylakoid space to stroma through a channel protein present in membrane called **ATPase synthase complex.** Hydrogen ions move through this channel by providing energy which is released during down movement of

electrons in PS-II. This energy is utilized for the synthesis of ATP from ADP and Pi. This movement of $H^+$ through ATPase complex due to concentration gradient called **chemiosmosis or chemiosmotic ATP synthesis** because chemical and osmotic event join to permit ATP synthesis. The transport of three proton ($H^+$) through ATPase complex are normally required for the production of one ATP molecule.

The linear flow of electrons from water to $NADP^+$ coupled to ATP synthesis is called non-cyclic photophosphorylation because the electrons pass from water to a terminal accepter and never back to its initial source.

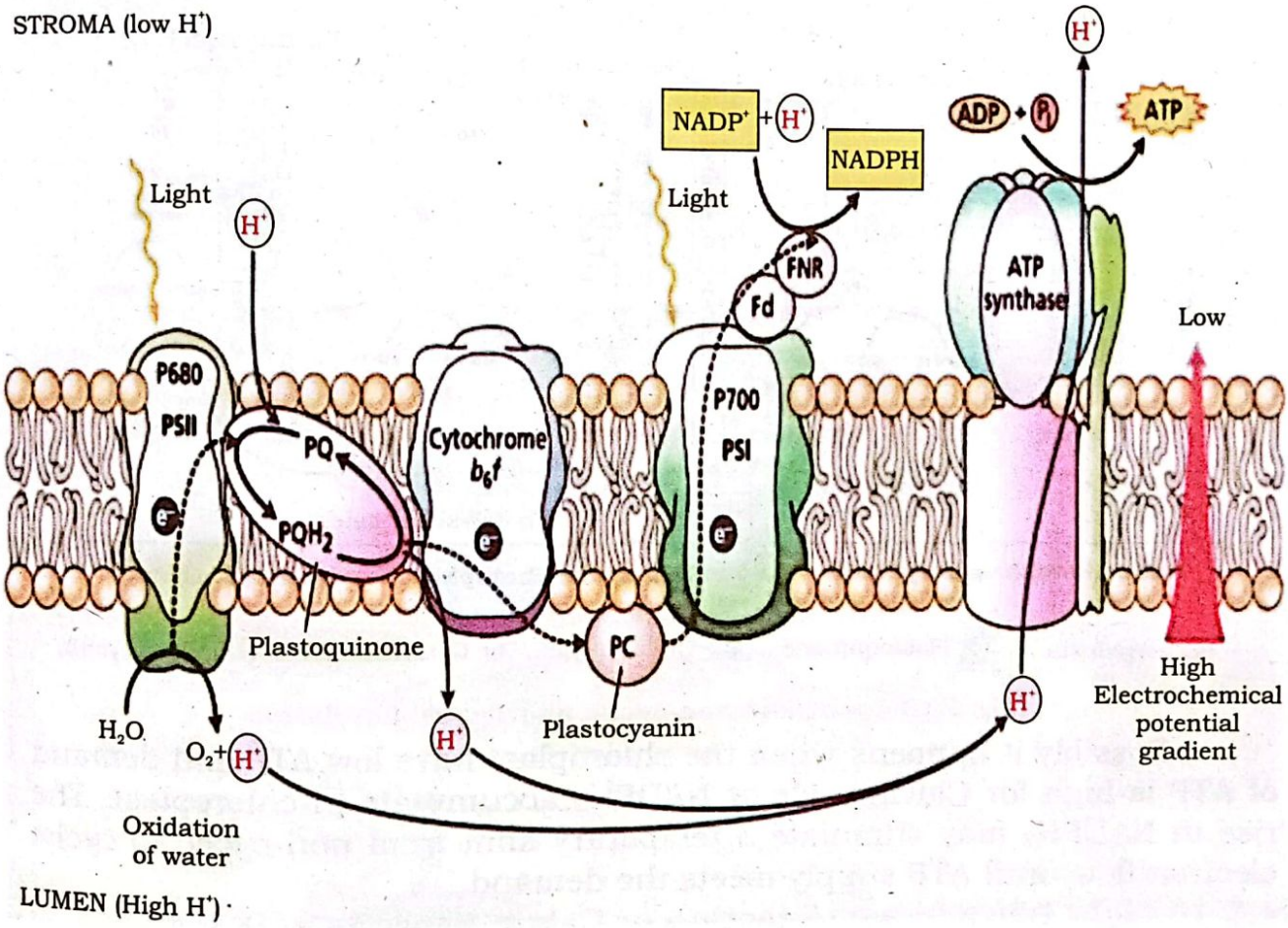



**Fig 4.9 Linear flow of electrons**

Finally four important events takes place during light dependent reaction of photosynthesis.

(i) Photolysis of water
(ii) Electron transport chain i.e. PS II and PS I
(iii) Reduction of NADP into ($NADPH_2$)
(iv) Photophosphorylation

### 4.1.9 Cyclic Photophosphorylation

In some conditions like saturation of NADP, excited electrons do not move towards NADP, they take an alternative pathway i.e. cyclic electron flow. In this pathway they use only PS-I and have short cut. The ē from primary electron accepter to Fd and then to cytochrome complex, ultimately come back to $P_{700}$ chlorophyll a molecule. ATP is generated by coupling of electron transport chain with chemiosmosis, no further NADP is reduced to produce $NADPH_2$ and production of $O_2$ is also stopped during this process. This process of ATP formation is called **cyclic photophosphorylation**, the generation of only ATP.

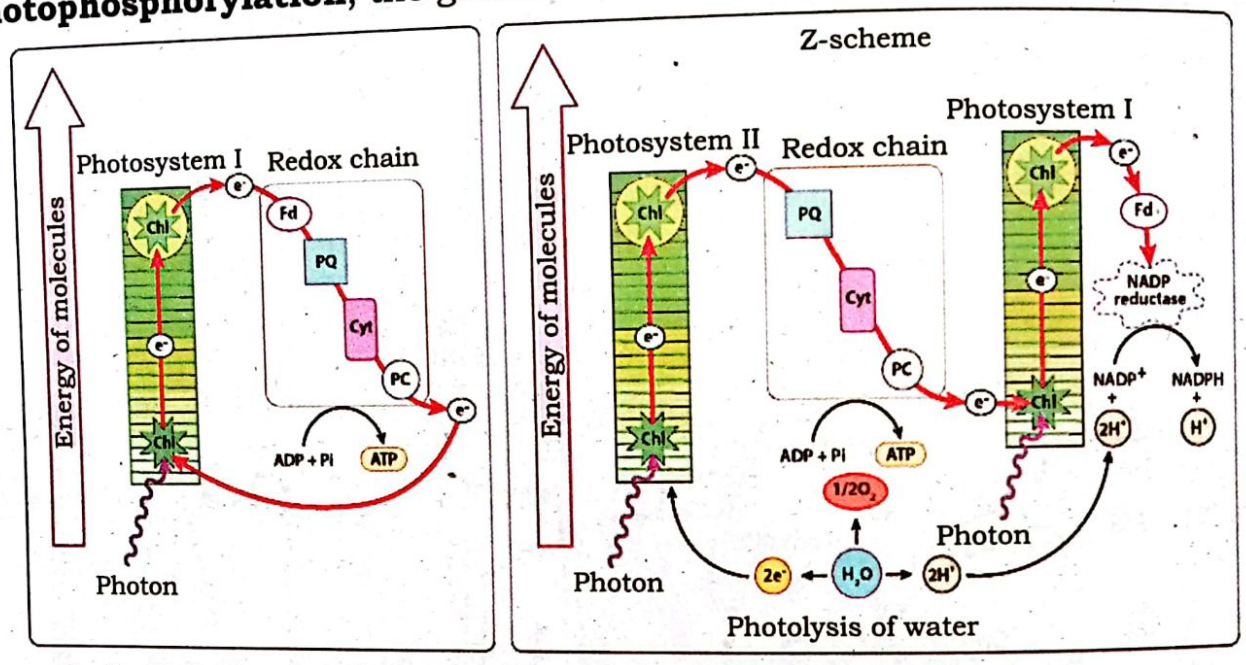



**Fig 4.10 Cyclic and non-cyclic photophosphorylation**

Possibly it happens when the chloroplast have low ATP and demand of ATP is high for Calvin cycle or $NADPH_2$ accumulate in chloroplast. The rise in $NADPH_2$ may stimulate a temporary shift from non-cyclic to cyclic electron flow until ATP supply meets the demand.

### 4.1.10 Light Independent Reaction or Calvin Benson Cycle

The second phase of photosynthesis, where carbohydrate moleculesare formed by fixing atmospheric carbon dioxide. This part of photosynthesis does not require light energy directly, it requires chemical energy of ATP and $NADPH_2$ therefore it is **light independent reaction** or previously called **dark reaction**. The details of this phase were discovered by Melvin Calvin and his colleague Benson therefore it is also called **Calvin Cycle**. During this cycle $CO_2$ is reduced to triose phosphate i.e. 3-phosphoglycerose or dihydroxy acetone phosphate and subsequently via

other metabolic pathways to hexoses, sucrose and starch. The first stable product formed during this cycle is a three carbon containing acid i.e. 3-phophoglyceric acid (3 phosphoglycerate abbreviated by 3-PGA) therefore, this cycle is also called **$C_3$ cycle** and the plants which carry this cycle only called **$C_3$ plants**. The Calvin cycle starts with a phosphorylated five carbon sugar i.e. Ribulose 1,5-biphosphate and ends on this sugar, therefore it is called a **cyclic process**.

Calvin cycle is divided into three distinct phases for the convenience to study.

i) **Carboxylation:** It is the fixation of atmospheric carbon dioxide with five carbon sugar.
ii) **Reduction:** Reduction of three carbon containing acid takes place to form triose.
iii) **Regeneration:** Where reduced carbon utilize to regenerate 5-carbon sugar.

### i) Carboxylation:

This is the first and key step of Calvin cycle where carbon dioxide is fixed with Ribulose 1,5-biphosphate (RuBP), as a result of this fixation a 6 carbon short lived intermediate compound is formed, which immediately breaks, into two molecules of three carbon containing acid called 3-phosphoglycerate (3PGA). This reaction is catalyzed by the enzyme called RuBiSCO(Ribulose 1,5-biphosphate Carboxylase / Oxygenase).

$$3CO_2 + (RuBP) \xrightarrow{RubisCO} 6\ (3\text{-PGA})$$

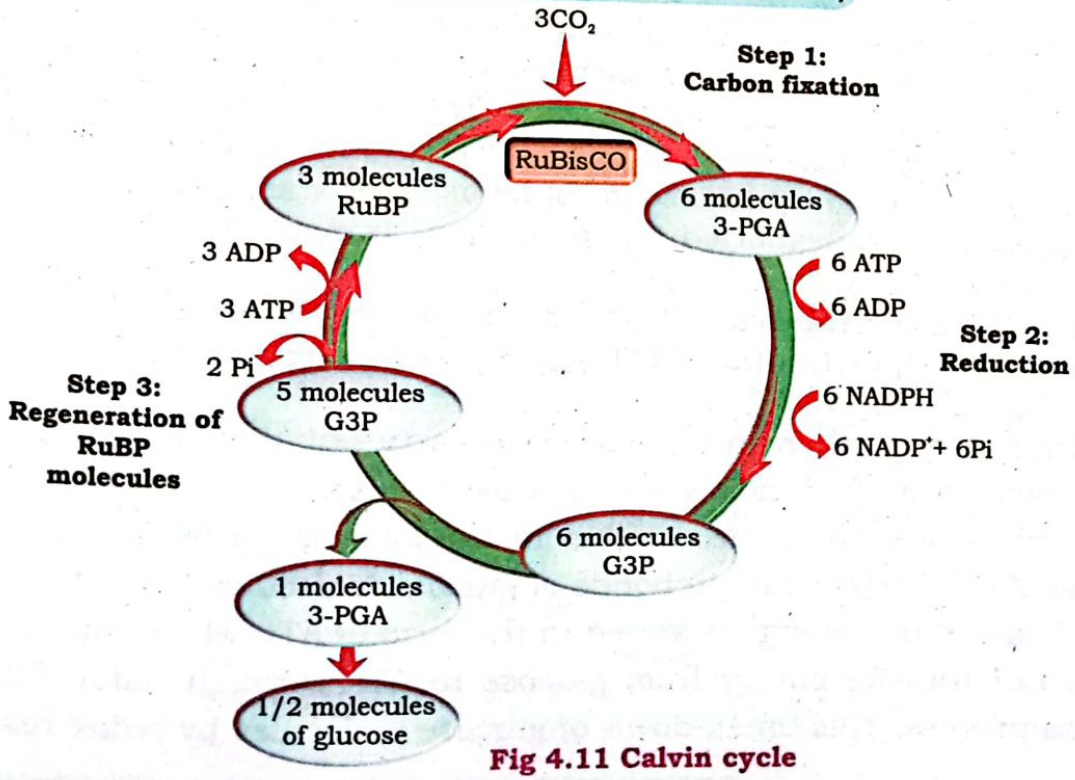



**Fig 4.11 Calvin cycle**

RuBiSCO an enzyme which function as carboxylase as well as oxygenase. If the supply of $CO_2$ inside the leaf is inadequate most of RuBiSCO combines with $O_2$, giving one molecule of 3 PGA and one molecule of phosphoglycerate, where phosphoglycerate rapidly breaks down to release $CO_2$

$$(RuBP) + O_2 \xrightarrow{\text{Rubis CO}} 3\ PGA + \text{phosphoglycerate} \rightarrow CO_2$$

this process is named as photorespiration because in the presence of light (Photon) oxygen is taken up and $CO_2$ is evolved (respiration).

**ii) Reduction:**

This phase comprises of a series of reactions. Simply, during this phase 3-phosphoglycerate (3-PGA) reduce to glycerate 1,3-biphosphate by using ATP from light reaction and then to Triose phosphate by oxidation of $NADPH_2$ from light reaction, these triose phosphates are phosphate and 3-phosphoglyceraldehyde (3-PGAl).

$$6\ (3\text{-PGA}) + 6NADPH_2 + 6ATP \rightarrow 6\ (3\text{-PGAl}) + 6NADP^+ + 6ADP + 6Pi$$

**iii) Regeneration:**

Many carbon rearrangements take place during this phase, 5 molecules of Triose sugar (3-PGAl) in three interlinked $C_3$ cycles rearrange to reform three molecules of 5-carbon sugar (Rub 1-5, $P_2$) while one molecule of Triose sugar is formed as a gain of these three cycles.

$$5\,(3\text{-PGAl}) + 3ATP \rightarrow 3(RuBP) + 3ADP + 2Pi$$

During this cycle three molecules of $CO_2$ fix with three molecules of RuBP which produce six molecules of Triose sugars. These six molecules of Triose rearrange to three molecules of five carbon sugar (RuBP) and one molecules of Triose as net gain. Therefore, only one molecule of three carbon sugar i.e. Triose phosphate is produced which can (a) re-enter the cycle to produce hexose or (b) be used for starch synthesis within chloroplast or (c) be exported via phosphate translocator to cytosol for sucrose synthesis.

For the net synthesis of Triose molecule, the Calvin cycles consume a total of nine (09) molecules of ATP and six (06) molecules of $NADPH_2$.

## 4.2 CELLULAR RESPIRATION:

Every living cell requires energy to carry out their functions. This energy comes from fuel molecules such as glucose. In cellular respiration glucose molecules are oxidized either in the absence of oxygen or in the presence of $O_2$. Carbon-carbon bonds of glucose molecules break to release energy, some of this energy is stored in the form of ATP while other is lost. Thus, a cell transfer energy from glucose to ATP through reduction and oxidation process. This break down of glucose molecules by redox reaction

to synthesize ATP is called **respiration**. This ATP provides energy for metabolism wherever required by removing its terminal phosphate liberate energy ADP and P (Phosphate) are formed.

### Anaerobic Respiration or Fermentation

Fermentation was originally defined by W. Pauster as respiration in the absence of air ($O_2$). It is an alternative term used for anaerobic respiration. The products of anaerobic respiration are either ethyl-alcohol or lactic acid. The type of fermentation where alcohol is formed is termed as **alcoholic fermentation** and the fermentation where lactic acid is formed called **lactic acid fermentation.**

A small but significant minority of organisms obtain energy by anaerobic respiration. Many micro-organisms including yeasts and some bacteria can respire anaerobically.

The anaerobic respiration as well as aerobic respiration has a common phase where glucose breaks anaerobically into two molecule of pyruvate (pyruvic acid) called **Glycolysis**.

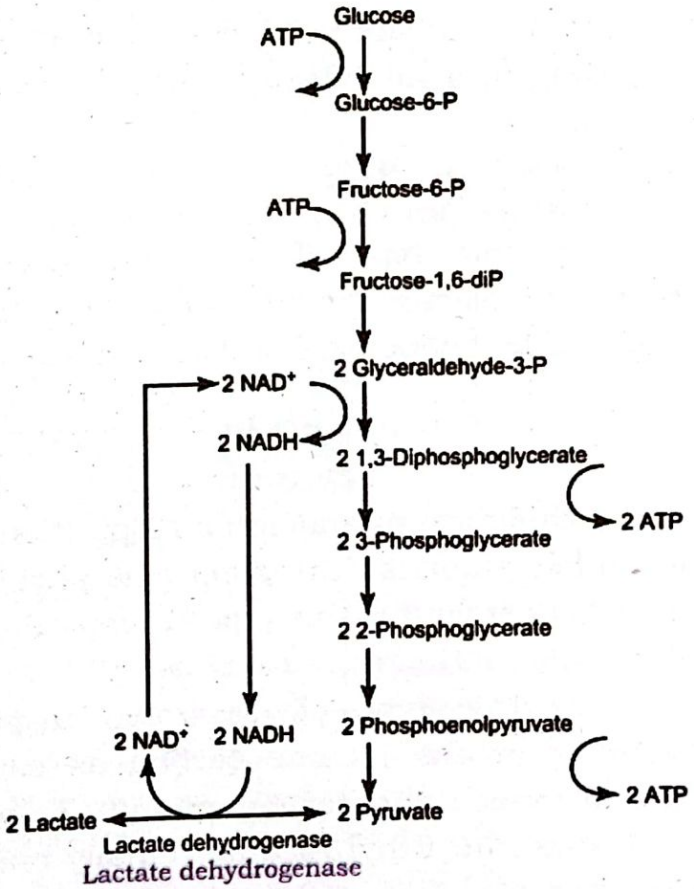
### 4.2.1 Glycolysis

It is anaerobic break down of Glucose into two molecules of Pyruvate. It takes place in a series of steps, each catalyze by specific enzyme. All these enzymes are found in cytosol with these enzymes,ATP and NAD (Nicotinamide Adenine Dinucleotide) are also required.

Glycolysis can be divided into two phases:

(i) A Preparatory Phase – Glucose to the formation of phosphorylated Triose.

(ii) Oxidative Phase – Phosphorylated triose to the formation of Pyruvate.



Lactate dehydrogenase

**Fig 4.12 Glycolysis**

**(i) Preparatory Phase:**

During this phase Glucose become phosphorylated into glucose-6-phosphate which then isomerized into Fructose–6–phosphate. This fructose 6–phosphate further phosphorylated into fructose 1,6-biphosphate. The phosphate comes from ATP molecule, 2 molecules of ATP consumed during this phase. Finally, Fructose 1,6-biphosphate breaks into two molecules of phosphorylated triose i.e. Dihydroxyacetone phosphate and 3- phosphoglyceraldehyde (3-Phosphoglycerose).

**(ii) Oxidative Phase:**

In this phase the molecules of triose phosphate are oxidised as well as two electrons and two proton ($H^+$) are removed from phosphorylated triose (3PGAl) and transfer to NAD to reduce it in $NADH_2$. Therefore, it is called Redox reaction. During this phase 4 ATP molecules are also produced by substrate level phosphorylation at two different steps of glycolysis. Finally, 2 molecules of pyruvate, 2 molecules of $NADH_2$ and 4ATP are formed, where as the net gain of 2 ATP takes place.

The Pyruvate produces at glycolysis have three metabolic pathways according to availability of enzyme in organisms. It may be anaerobic or aerobic.

### 4.2.2 Anaerobic Respiration (Pathway)

**(i) Lactic Acid Fermentation**

In this type of anaerobic respiration three carbon containing Pyruvate molecule directly converted into another three carbon containing acid lactate (Lactic Acid) in the absence of oxygen.

$$\underset{\text{Pyruvate}}{2\,(C_3H_4O_3)} \xrightarrow{2NADH_2 \rightarrow 2NAD} \underset{\text{Lactate}}{2(C_3H_6O_3)}$$

This form of anaerobic respiration occurs in muscle cells of human and other animals during extreme physical activities. Only two molecules of ATP is net gain of this type of respiration.

**(ii) Alcoholic Fermentation**

In this type of anaerobic respiration three carbon containing Pyruvate breaks its one carbon as carbon dioxide and remaining two carbon formed another compound i.e. Acetyl. In the next step this Acetyl converted into Ethyl Alcohol. Finally one molecule of carbon dioxide and one molecule of ethyl alcohol is formed from one molecule of Pyruvate, with these products one molecule of NAD is reduced to $NADH_2$ in first step

which is oxidized into NAD again in the next step. So a large amount of energy is produced in comparison of lactic acid fermentation i.e. net gain 2ATP and $2NADH_2$. It occurs in bacteria, yeast etc.

$$\underset{\text{Pyruvate}}{2(C_3H_4O_3)} \xrightarrow[\text{Decarboxylation}]{} 2CO_2 + \underset{\text{Acetyl}}{2(C_2H_4O)}$$

$$\underset{\text{Acetyl}}{2(C_2H_4O)} \xrightarrow[\text{Reduction}]{2NADH_2 \rightarrow 2NAD} \underset{\text{Ethyl Alcohol}}{2C_2H_5OH}$$

### 4.2.3 Aerobic Respiration (Pathway)

The third pathway of Pyruvate is towards aerobic respiration where aerobic break down of Pyruvate occurs.

#### (i) Oxidation of Pyruvate

Pyruvate does not enter in Kreb's Cycle directly, the pyruvate break down occur in one molecule of $CO_2$ and one molecule of Acetyl. The Acetyl is 2 carbon radical, enters into mitochondria and combine with co-enzyme. During this phase NAD is reduced to $NADH_2$, the 2 molecules of Pyruvate which produce as the end product of glycolysis now produce two molecules of $CO_2$, two molecule of Acetyl CoA and two molecules of $NADH_2$.

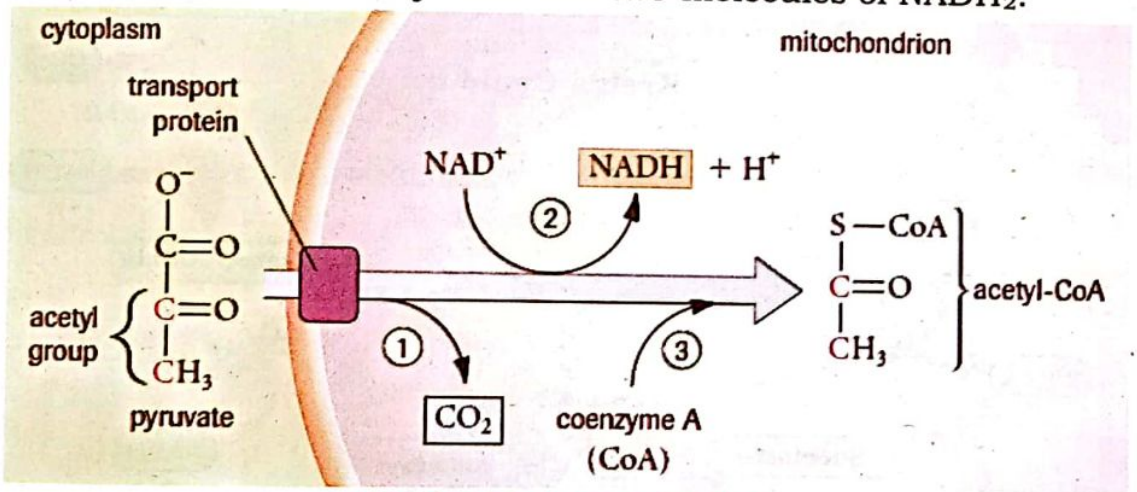



Fig 4.13 Pyruvate oxidation

#### Kreb's Cycle

Acetyl Co-A now enters in a cyclic series of chemical reactions during which oxidation of glucose is completed in the form of oxidation of Acetyl. This cyclic series is called Kreb's cycle or Citric Acid Cycle or Tri-carboxylic Acid cycle. Kreb's cycle is named after the name of H.A. Kreb who discovered it. The citric acid cycle is named due to the reason that first compound formed during this cycle is Citric acid and this Citric acid has three carboxylic acid groups in its structures, therefore it is also called Tri-carboxylic Acid Cycle (TCA). This cycle starts with four carbon acid i.e.

oxaloacetate (oxaloacetic acid) and ends at the same, the events are given in (Fig 4.13). As a result of it, one ATP by substrate level phosphorylation, three $NADH_2$ and one molecule of $FADH_2$ are formed. Complete oxidation of one glucose molecule requires two Kreb's cycles, where double amount of these molecules are formed.

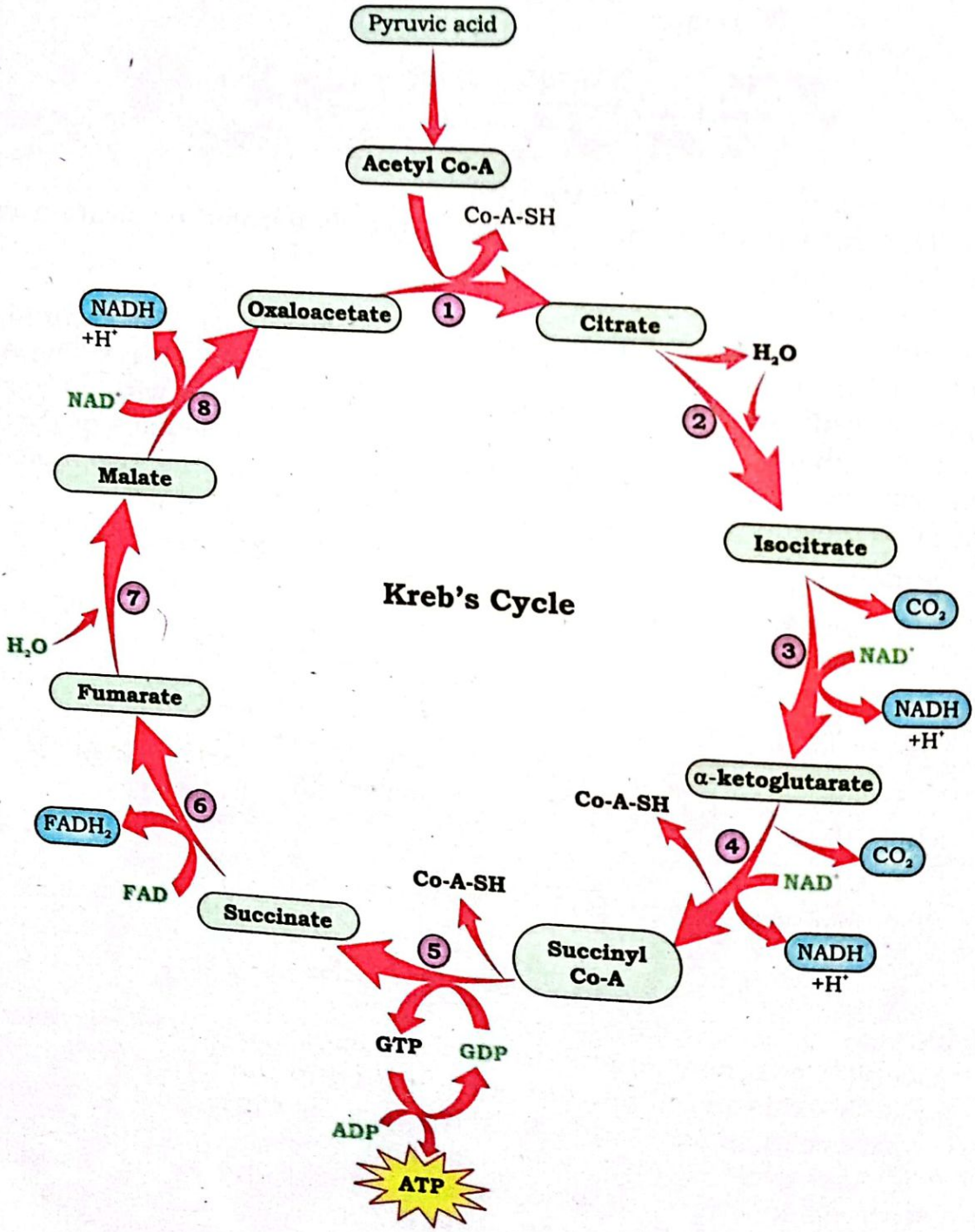



Fig 4.14 Kreb's cycle

### (iii) Electron Transport Chain

It is the third phase of aerobic respiration, the $NADH_2$ and $FADH_2$ are produced during glycolysis,intermediate phase and Kerb's cycle are now oxidized here to liberate oxidation energy. The oxidation energy will utilize to produce ATP. This type of phosphorylation is called oxidative phosphorylation. During this process electrons and protons transfer to electron transport chain coupled with chemiosmosis.

The substances which reduced and oxidized take part in this chain are as follow:

(i) A co-enzyme Q
(ii) A series of cytochrome from Cyt b, Cyt c, Cyt a to Cyt $a_3$
(iii) ATPase complex ($H^+$ Pump)

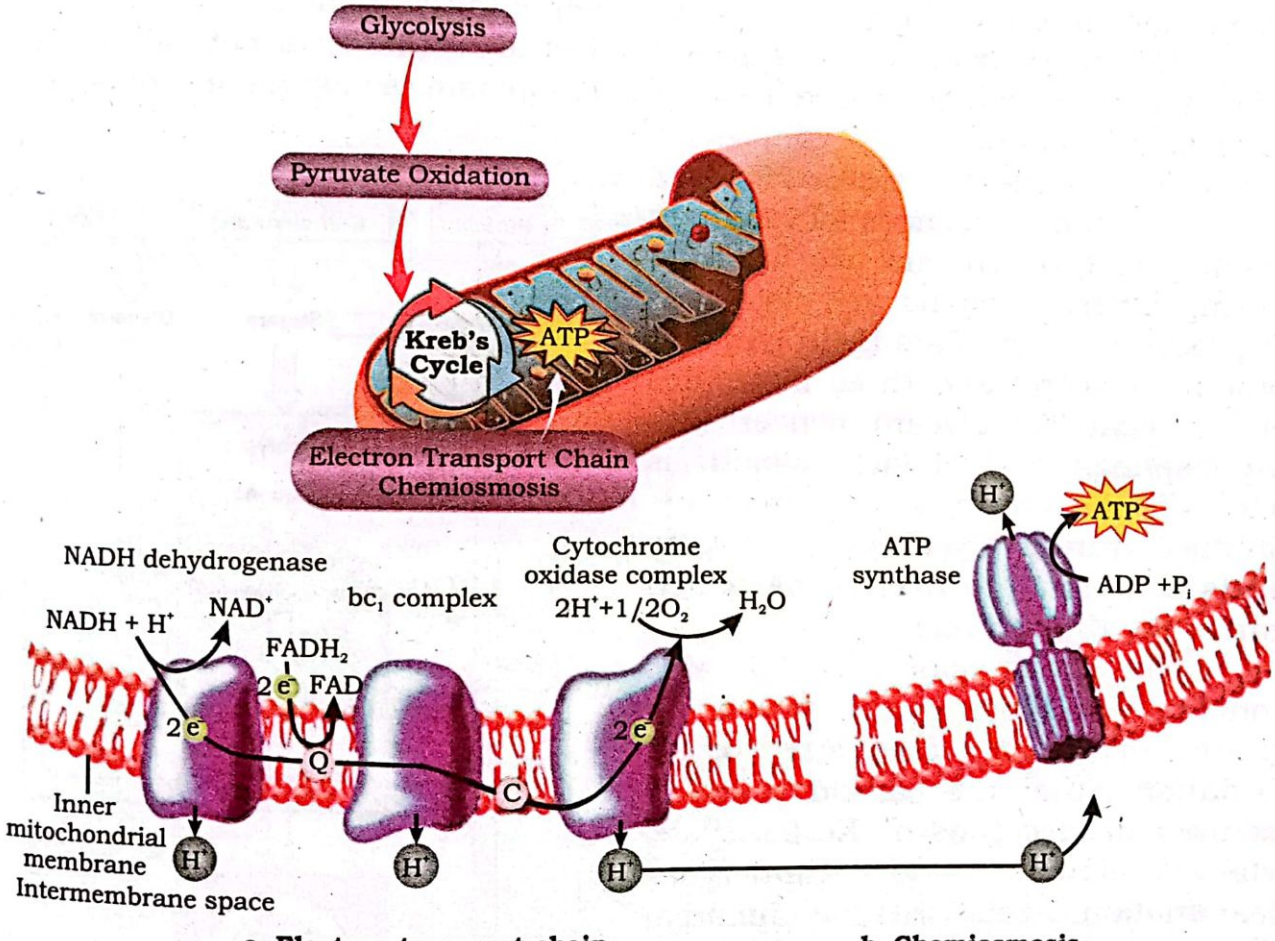



**Fig 4.15 Electron transport chain during oxidative phosphorylation**

It starts with the oxidation of $NADH_2$ which release $2\bar{e}$ and $2H^+$, the energy is also released, this energy will utilize to synthesis first molecule of ATP. This $NADH_2$ is oxidized by co-enzyme Q. The $FADH_2$ is also oxidized by co-enzyme Q. the co-enzyme Q is now oxidized by cytochrome b, which after that oxidized by cytochrome c. At this stage enough energy is

liberated it is also coupled with ATPase complex. This energy is utilized for synthesis of another molecule of ATP. After it cytochrome is oxidized by two enzyme cytochrome a and $a_3$. In the last, cytochrome $a_3$ is oxidized by an atom of oxygen and the electrons arrived with proton. A molecule of water is formed by these combinations.

In addition, the enough energy is liberated which is also coupled with ATPase to synthesize third and final ATP molecule from one molecule of $NADH_2$

The synthesis of ATP during electron transport chain in the presence of oxygen is called **oxidative phosphorylation**. As discussed above ATP molecules are formed at three steps of respiratory chain. It takes place in the inner membrane (Cristae) of mitochondria.

Complete oxidation of glucose molecule results in a net gain of 36 ATP molecules which are released in cytoplasm available for different metabolic reactions.

### 4.2.4 Cellular Respiration of Protein and Fats

In the absence of enough sugar, living organisms use fats and during illness proteins are also used to produce energy. Fats hydrolyze and produce glycerol and three molecules of fatty acid. The glycerol convert into 3-phosphoglyceraldehyde. Which is one of the triose-sugar molecule produce during glycolysis. The fatty acids converts into Acetyl-CoA which enters the Kreb's cycle.

The amino acids of protein also convert into amyl group, whose R-group determine the site of it oxidation either the carbon chain is oxidized in glycolysis or Kerb's cycle, when amino acid undergoes deamination, this $NH_3$ (ammonia) enters in the urea cycle.

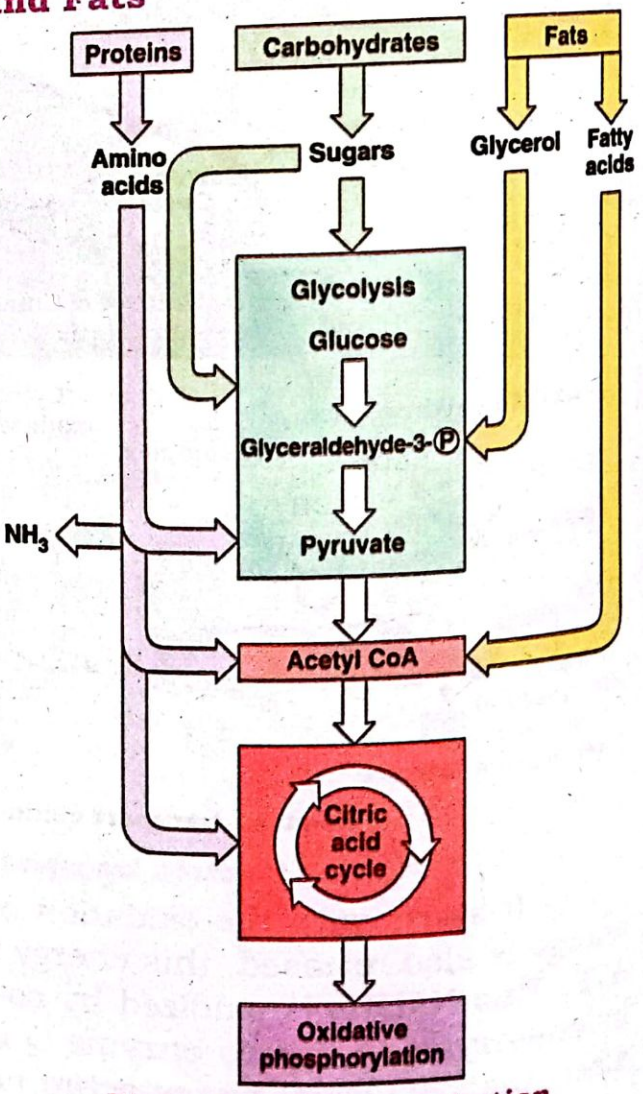



Fig 4.16 Cellular respiration

## 4.3 PHOTORESPIRATION

Sometimes plants oxidized sugar in chloroplast during day time without production of energy or ATP called **photorespiration**. During this process carbon dioxide is released and oxygen is absorbed like aerobic respination. It means that the photorespiration is the process in which RuBiSCO perform oxygenation instead of carboxylation.

During photorespiration RUBP react with oxygen produces one molecule of 3 phosphoglycerate (3 carbon compound) and one molecule of glycolate (2 carbon compound)

$$RUBP + O_2 \xrightarrow{RuBiSCO} Glycolate + 3PGA$$

The glycolateproduced during oxygenare this process diffuses into the membrane bounded organelles known as **peroxisome**. Where the glycolate is converted into an amino acid i.e. glycine through a series of reactions

$$Glycolate \xrightarrow{Peroxisome} Glycine$$

The glycine rapidly diffuses into the mitochondria where two glycine molecules are converted into another amino acid serine and a molecule of carbon dioxide is also formed.

$$2\ glycine \longrightarrow serine + CO_2$$

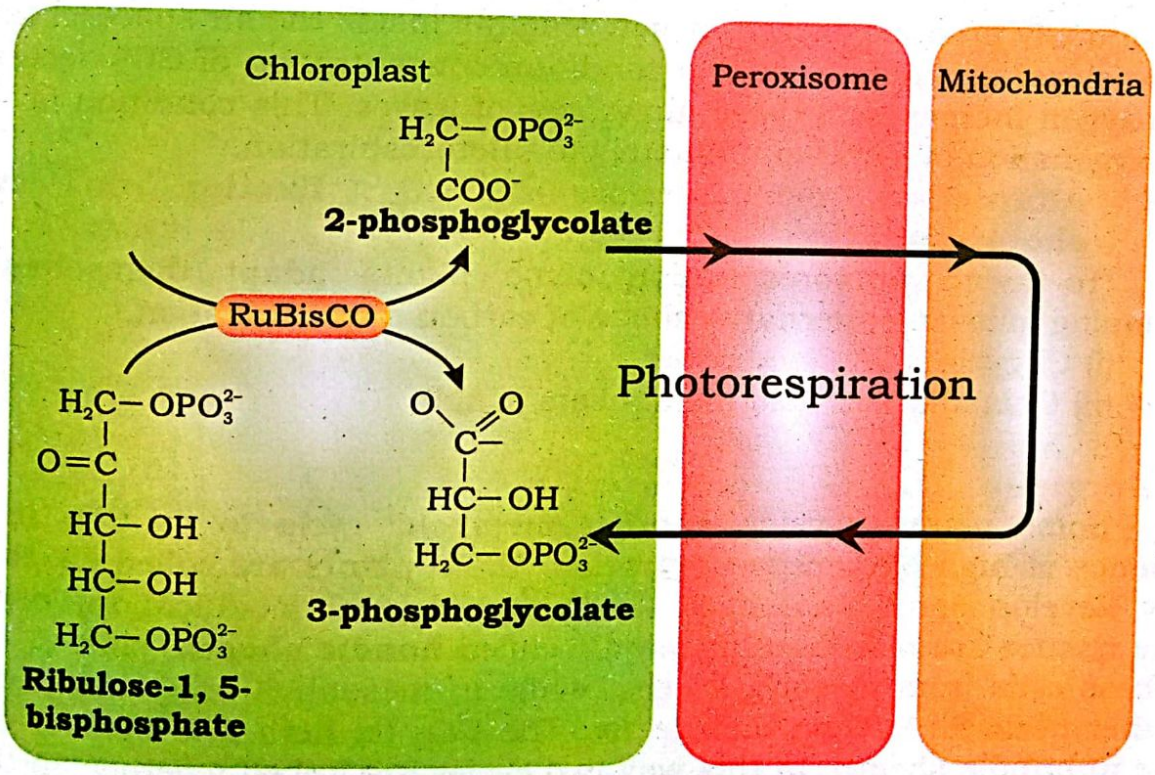



Fig 4.17 Photorespiration

### 4.3.1 How disadvantageous process of photorespiration evolve

Photorespiration is considered as wasteful process because during photorespiration energy is not evolved, ATP and $NADH_2$ do not synthes on contrary ATP and $NADPH_2$ produced during light reaction also consumed. During this process $CO_2$ is released, instead of its fixation into carbohydrates. The growth of plant is also reduced up to 25% due to photorespiration.

Apparently photorespiration reduces the photosynthetic process. It is thought that the photorespiration is not essential for plant. It is also observed that if photorespiration is inhibited chemically, the plant can grow so question arises here that why does photorespiration evolved and Exist? We can answer this questions in a way that the RUBISCO had evolved to bind both carbon dioxide and oxygen at its active site. In the beginning it was not a problem because the oxygen was very low in atmosphere at that time, it could not compete with carbon dioxide, only carbon dioxide binding site of Rubisco remained active. This problem starts to occur when oxygen quantity increased in atmosphere.

### 4.3.2 Effect of Temperature on Photorespiration

On hot, dry day, most of the plants close their stomata to conserve their water. This response also reduces photosynthesis yield by limiting access to $CO_2$, when stomata close carbon dioxide concentration decreases in the air spaces of leaves, while light reaction continues which continuously produce oxygen, which remains inside the air spacesof leaves due to closer of stomata. In this condition concentration of $CO_2$ decreases and oxygen increases in these air spaces of leaves. This condition favours the oxygenation of Rubisco ultimately to photorespiration.

### 4.3.3 Alternative mechanisms of $CO_2$ fixation to avoid photorespiration

To avoid photorespiration some plants adapt themselves by developing following alternative mode of carbon dioxide fixation.

(i) $C_4$ cycle

(ii) Crassulacean acid metabolism (CAM)

#### (i) $C_4$ cycle

Some plants develop another metabolic cycle to fix $CO_2$ in the presence of high oxygen concentration, these plants are called $C_4$ plants. They develop some anatomical and physiological modification, develop some tissues around vascular bundle called **bundle sheath**, shift $C_3$ cycle in these cells from mesophyll cells, while in mesophyll cells they develop another cycle for carbon dioxide fix. The $CO_2$ fix here will transfer to $C_3$ cycle in bundle sheath. In this way two cycles are linked together. In these plant atmospheric carbon is fixed by a three carbon compound Phospho

Enol Pyruvate (PEP) instead of RuBP. As a result of $CO_2$ fixation a four carbon compound is formed called oxaloacetate (oxaloacetic acid) therefore this cycle is called $C_4$ cycle.

The oxaloacetate transfer carbon through malate to RuBP for $C_3$ cycle in bundle sheath. Among $C_4$ plants, some important agriculture plants are sugar cane and corn.

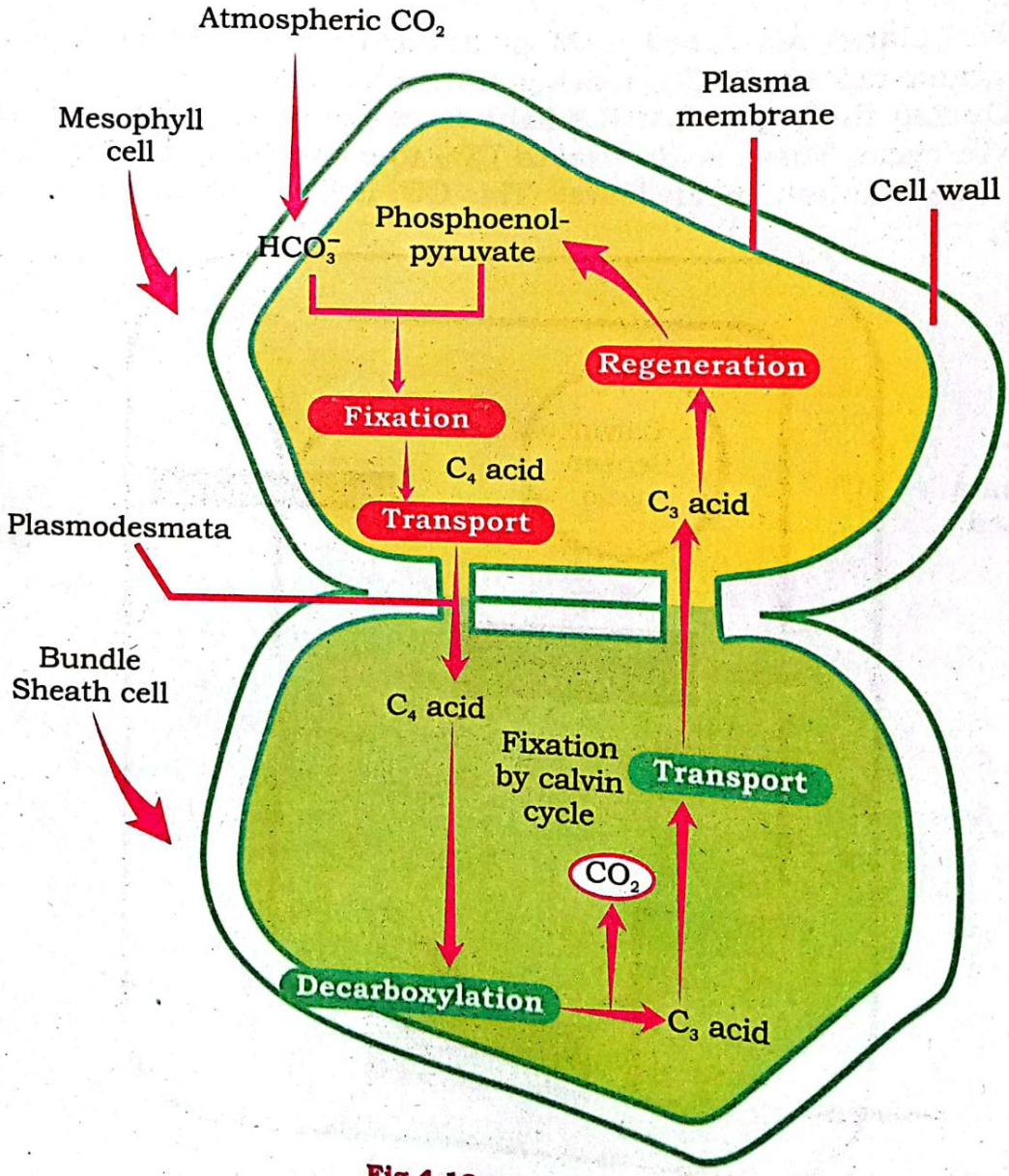



**Fig 4.18 C4 cycle**

### (ii) Crassulacean Acid Metabolism (CAM)

Another adaption to avoid this condition has evolved in succulent plants like cacti, pineapples and many others. These plants open their stomata during night and close them during the day, just reverse of normal behavior. Closing stomata during day helps these plants to conserve water. During the night, when their stomata are open, these plants takes up $CO_2$ and incorporate into a variety of organic acids. This mode of carbon dioxide fixation is called **crassulacean acid metabolism** or CAM.

The plants are called CAM plants (CAMP). The CAM plants store these organic acids with $CO_2$ moving in their vacuoles.

During the day, when the light reactions supply ATP and $NADPH_2$ for Calvin cycle. These acid released $CO_2$ to compete with $O_2$. In this way ratio of $CO_2$ maintain inside leaves. This $CO_2$ is fixed through $C_3$ cycle.

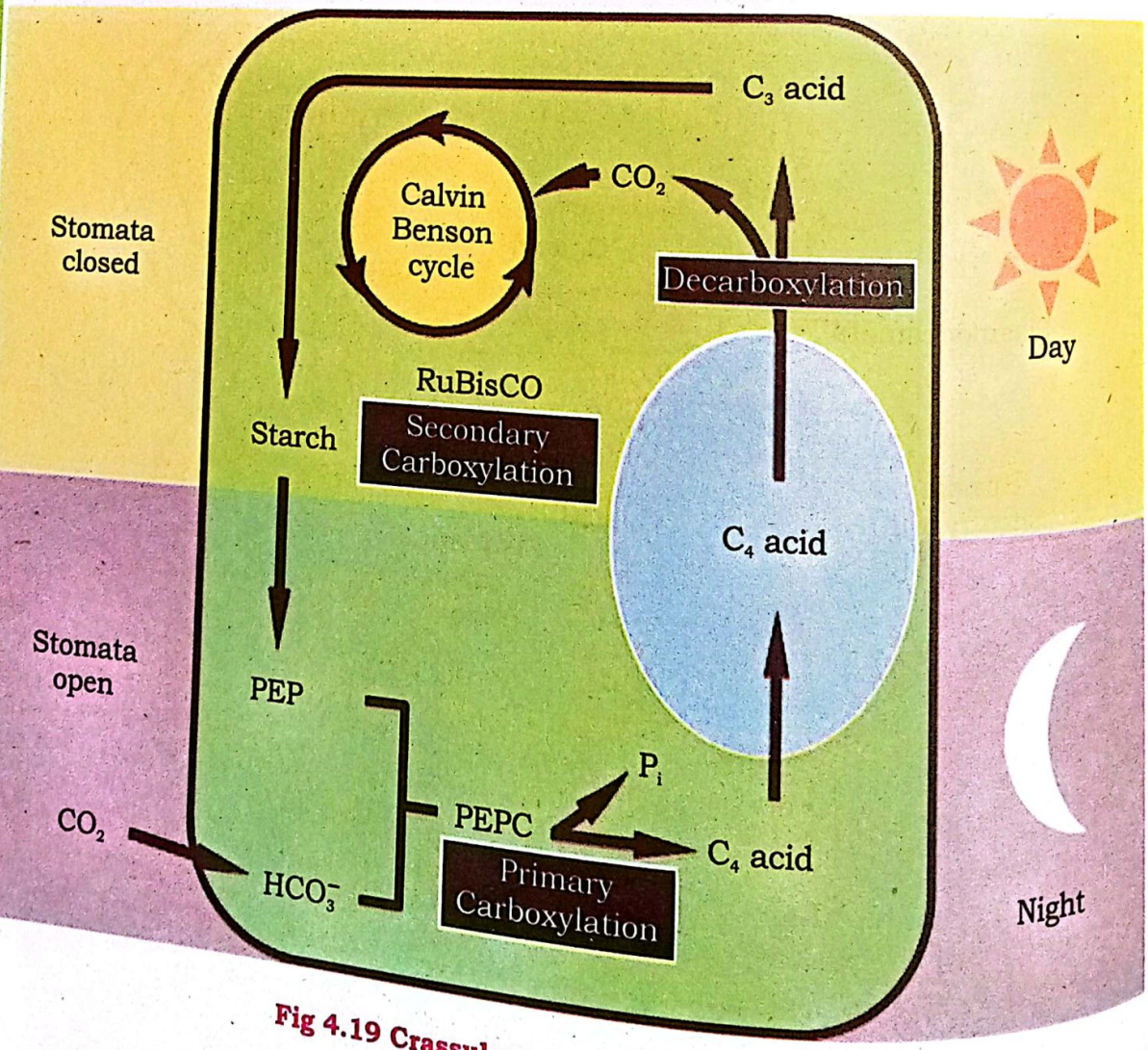



Fig 4.19 Crassulacean acid metabolism

## SUMMARY

- Capturing and conversion of energy from one form to another in living system and its utilization in metabolic activities is called bioenergetics.
- Biological energy transformation obeys the laws of thermodynamics.
- The living process where light energy converts into chemical energy (ATP, $NADPH_2$) and then into energy rich organic food molecules like carbohydrate called photosynthesis.
- Light is a form of energy, has dual nature, described both as a wave and a particle nature.
- Substance in plants that absorb visible light are called pigments.
- Chlorophyll is organized with other molecules into photosystem, which has light gathering "antenna complex".
- Neil's hypothesized that the source of oxygen released during photosynthesis is water.
- The first phase of photosynthesis where energy of photon is captured and converted into chemical energy.
- The linear flow of electrons from water to $NADP^+$ coupled to ATP synthesis is called non-cyclic photophosphorylation.
- The second phase of photosynthesis, where carbohydrate molecules are formed by fixing atmospheric carbon dioxide.
- Break down of glucose molecules by redox-reaction to synthesis ATP is called respiration.
- Glycolysis is anaerobic break down of glucose into two molecules of pyruvate.
- Oxidation of glucose is completed in the form of oxidation of acetyl. This cyclic series is called kreb's cycle or citric acid cycle.
- The synthesis of ATP during electron transport chain in the presence of oxygen is called oxidative phosphorylation.
- Sometimes plants oxidized sugar in chloroplast during day time without production of energy or ATP called photorespiration.
- On hot and dry day their stomata remains close to conserve their water
- Some plants develop another metabolic cycle to fix $CO_2$ in the presence of high oxygen concentration, these plants are called C4 plants

## EXERCISE

**1. Encircle the correct choice**

(i) Chlorophyll-a is almost identical to chlorophyll-b but slight structural difference between them is enough to give
- (a) Similar energy during the light reaction
- (b) Different absorptive spectrum
- (c) Different product during the Calvin cycle
- (d) All of these

(ii) Chlorophyll is organized along with other molecules into photosystem, which has light gathering
- (a) Reaction Centre
- (b) Carotenoid compound
- (c) Antenna complex
- (d) Cytochrome

(iii) Select the correct statement
- (a) PSI and ATP synthase complexes are located in the appressed part of thylakoid.
- (b) PSI and NADP reductase are located in the appressed part of thylakoid membrane
- (c) Appressed part Contain NADP reductase and ATP synthase
- (d) Non appressed (non-stacked) Having PSI

(iv) The linear flow of electrons from water to $NADP^+$ coupled to ATP synthesis is
- (a) Cyclic photophosphorylation
- (b) Non-Cyclic photophosphorylation
- (c) Chemiosmotic phosphorylation
- (d) Oxidative phosphorylation

(v) The intermediate carbon fixing compound in the member of grass family to pass $CO_2$ to calvin cycle is
- (a) Citric acid
- (b) Oxaloacetic acid
- (c) Pyruvic acid
- (d) Crassulacean acid

(vi) Oxidative decarboxylation of isocitrate form?
- (a) α-ketoglutarate
- (b) Succinate
- (c) Cis-aconitate
- (d) Fumarate

(vii) How many ATP molecules are forms during substrate level phosphorylation in kreb's cycle when one glucose is consumed?
- (a) One
- (b) Two
- (c) Three
- (d) Four

(viii) Enzyme involves during carboxylation
- (a) Rubisco oxygenase
- (b) Rubisco carboxylase
- (c) Rubisco dehydrogenase
- (d) No need of enzyme during carboxylation

(ix) The oxygen consumed during cellular respiration is involved directly in which process or events?
- (a) Glycolysis
- (b) Accepting electrons at the end of the electron transport chain
- (c) The citric acid cycle
- (d) The oxidation of pyruvate to acetyl CoA

(x) How many carbon atoms are fed into the citric acid cycle as a result of the oxidation of one molecule of pyruvate?
- (a) 2 (b) 4
- (c) 6 (d) 8

## 2. Write short answers of the following questions:

1. Why antenna complex contains other pigments with chlorophyll?
2. Why photosynthesis is called redox process?
3. How cyclic photophosphorylation helpful in photosynthesis?
4. Why ATP is called common energy currency of living system?
5. Why Calvin cycle is also called C3 cycle?
6. Why CAM plant close stomata in day time?
7. Why oxidation of pyruvate provide more energy than lactic acid fermentation?

## 3. Write detailed answers of the following questions:

1. Explain in detail light independent phase of photosynthesis.
2. What is cellular respiration? Explain types of respiration in detail.
3. Explain event takes place in breaking of glucose in cytosol.
4. Discuss cyclic and non-cyclic photophosphorylation during light reaction.
5. Describes tricarboxylic acid cycle in detail.
6. Explain alternative mechanism of $CO_2$ fixation in plant
7. Explain chemiosmosis and oxidative phosphorylation.

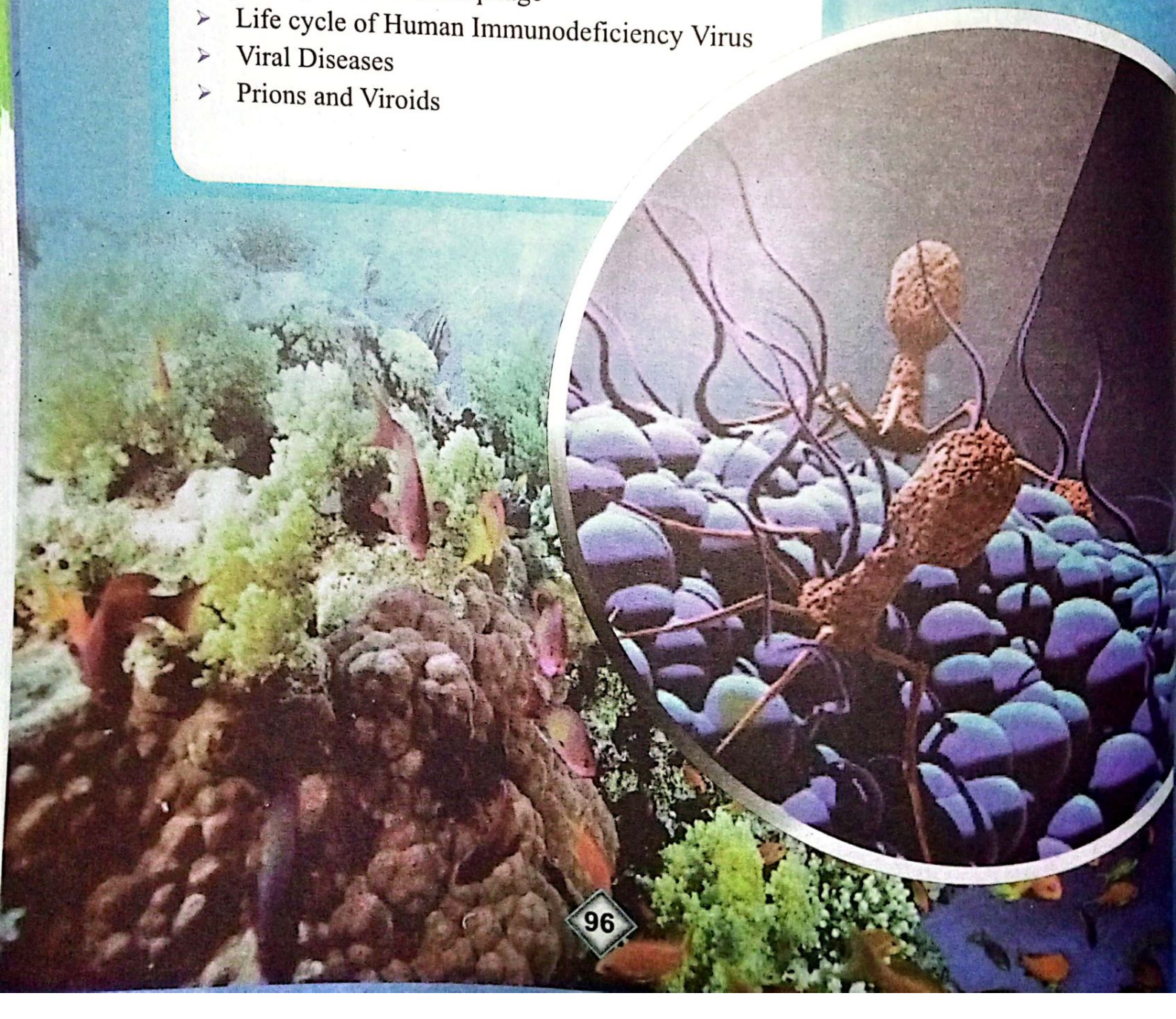
# ACELLULAR LIFE

Chapter 5

## Major Concept

**In this Unit you will learn:**

- Viruses - Discovery and Structure
- Parasitic Nature of Viruses
- Life cycle of Bacteriophage
- Life cycle of Human Immunodeficiency Virus
- Viral Diseases
- Prions and Viroids



## Introduction

Evolution reveals that life originated on earth at the level of variety of molecules like DNA and protein which later on evolved into cellular life. In the beginning some structures emerged which lack intact cells or a living entity without cells called noncellular living things, such as viruses, prions and viroids. Living things are categorized into two groups, firstly, living entities or molecules and secondly the complete cell-based organisms.

Viruses are a major threat to the human health and countries economy. Viruses like small pox and influenza caused millions of deaths in different era. Recently due to **Corona** world has suffered millions of deaths and massive decrease in industrial productions of different goods by the year 2022. Many viruses also damage crops and livestock of economic importance.

## 5.1. VIRUS EITHER LIVING OR NON-LIVING

Viruses characters of both living and non-living things. A comparison of these characters is given below for clear understanding.

### Living characters of a virus

Viruses replicate like living organisms by using host cellular contents. They have their own nucleic acid either DNA or RNA as genome and undergo mutation. Viral genome determines its functionality and formation of important biomolecules of its own structural importance. Viruses also contain some proteins which work as enzyme in host cell. Viruses interact genetically and physiologically with the host organisms they infect. Viruses are intracellular obligate parasites. Ultraviolet rays can harm viruses like other living cells.

### Non-living characters of a virus

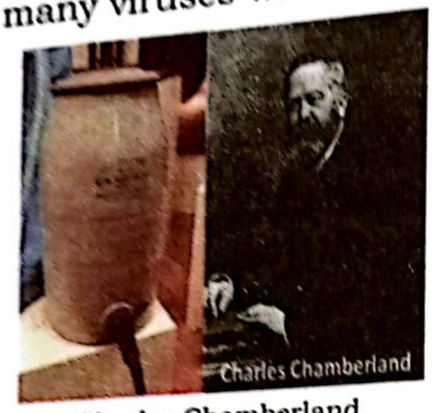
Viruses may become inactive for indefinite period of time without replication. They lack cellular organelles. They can't perform metabolism and generate energy molecules either. They can crystalize and store. They do not express vital activities like respiration, excretion, movement etc. They act as non-living, non-reactive particle outside the cell.

### 5.1.1. Viruses- discovery and structure

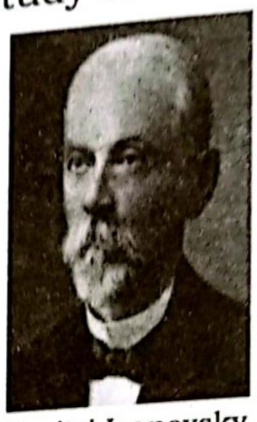
The name virus was derived from the Latin word meaning slimy liquid or poison. In 1984 an assistant of louis pasture named Charles Chamberland invented a porcelain water filter (Chamberland-Pasteur filter) to isolate the microorganisms from some infectious samples. Porcelain Chamberland filters have a pore size of 0.1 μm, which is small enough to remove all bacteria ≥ 0.2 μm from any liquids passed through the device. Later on, **Chamberland filter** was first used by Dmitri Ivanovsky in 1892 to examine the infectious tobacco plant leaf extract. During his research he found that the contagious filtrate of infected tobacco leaf, after removal of

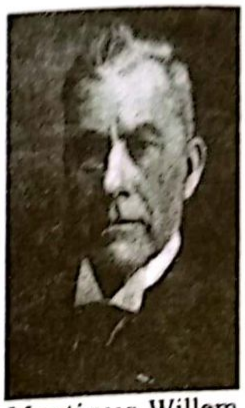
bacteria still caused the disease in plant, he concluded that the filtrate contains infectious component smaller than a bacterium that causes tobacco mosaic disease (TMD). After few years in 1899 another scientist Martinus Beijerinck, proceeded the investigation about the cause of TMD and reported that the pathogenic agent responsible was a "contagious living fluid,". These pathogenic fluids were known as filterable agents and was later named as virus. In 1935 W.M. Stanley crystalized the infectious particle, now known as tobacco mosaic virus (TMV). The invention of electron microscope revealed the discoveries of many viruses which being study under the virology.


Adolf Mayer



Charles Chamberland


Dmitri Ivanovsky


Martinus Willem Beijerinck

Viruses have variety of shape and structure they are filamentous, enveloped with nucleic acid inside or nonenveloped, icosahedral and some have head and tail. Enveloped viruses have outer lipid covering e.g., COVID-19, Influenza, Hepatitis B and C, Ebola virus etc., while non-enveloped viruses do not have a lipid covering and more resistant to environmental stresses like drying out and heat these include common colds (Rhinovirus) and Polio viruses. Filamentous viruses appear as elongated and cause diseases in many plants for example **Tobacco mosaic virus**. The head and tail group of viruses are pathogenic for bacteria example bacteriophage virus.

**General structure of viruses**

The structure of viruses are very simple, usually it consists of two parts:

i) The outer coat ii) The inner core

**i) The coat:**

outer covering of virus which is also called capsid. In some viruses envelope is also present with capsid to form its coat. The capsid is made of identical units of protein called capsomeres. The arrangement and number of capsomeres are specefic in particular kind of viruses. The capsid may be icosahedral or helical. In icosahedral the capsomers are arrange in 20 triangle to form either polyhedron or spherical structure where as in helical structure capsomeres are arranged in a hollow coil, gives rod shape to virus.

In some viruses another outer layer of lipoprotein is also present which covers the capsid this lipoprotein layer is called envelope which is also

provided by glyco protein spikes which help to recognise the host cell. The lipoprotein layer of envelop is derived from the cell surfsce membrane of host cell. It also contain virally encoded proteins.

**ii) The inner core**

The inner side of capsid contain another part which is called genome. Genome is generally called total genetic material of a living thing. tn the case of viruses this genome may be DNA or RNA. Which may be single stranded (Ss) or double (Ds) stranded. Sometime proteins are also present with it which work as enzyme and facilitate viruses during its action in host cell.

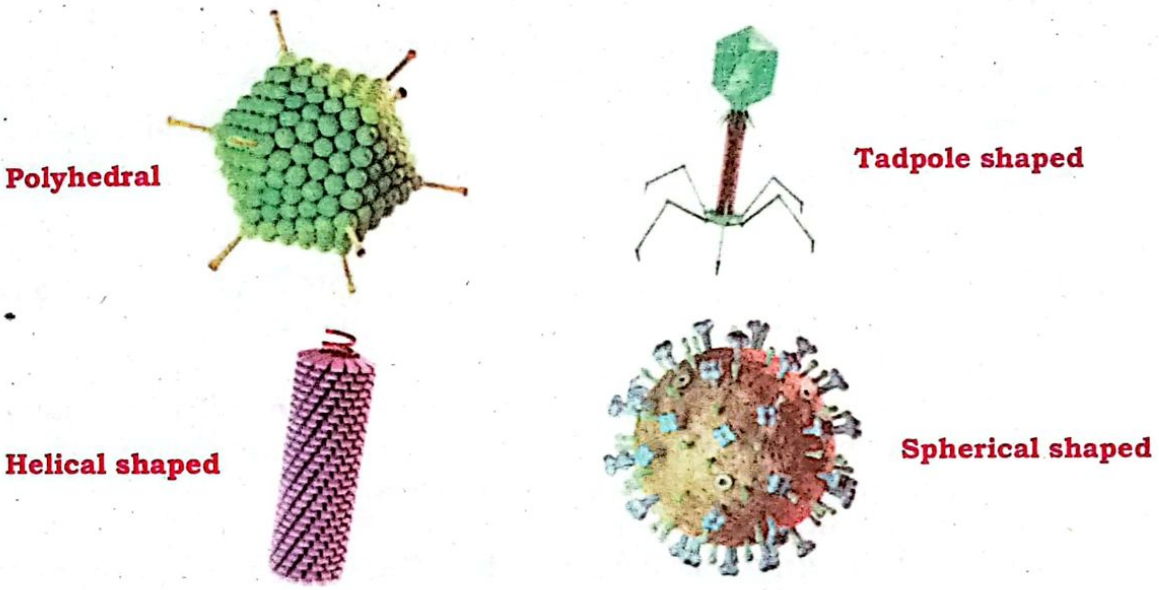



**Fig. 5.1 Different shapes of viruses**

### 5.1.2 Classification of Viruses

Viruses are obligate parasite so it can be classified on the basis of host or shape or genome

| Classification on the basis of host | | |
|---|---|---|
| **Phytophage** (Plant viruses) | **Zoophage** (Animal viruses) | **Bacteriophage** (Bacterial viruses) |
| ➢ More than 2000 types RNA genome | ➢ DNA or RNA genome both | ➢ ds DNA as genome |
| ➢ Rod shaped capsid usually | ➢ Spherical in shape usually | ➢ Have head and tail |
| ➢ E.g. T.M.W, CaMV, (Cauliflower mosaic viruses) etc. | ➢ E.g. Rhino viruses, Covid-19 etc. | ➢ E.g. T phages, X phages |

| Classification on the basis of capsid | |
|---|---|
| **Shape of capsid** | **Viruses** |
| ➢ Helical shape | ➢ TMV |
| ➢ Polyhedron | ➢ Adenoviruses |
| ➢ Tadpole shaped | ➢ Bacteriophage |
| ➢ Enveloped shape | ➢ Flu viruses |
| ➢ Spherical shaped | ➢ CaMV |
| ➢ Circular | ➢ HIV |

### Virus Classification on the basis of genome

**Viruses** are diversified in their structure. David Baltimore 1971, a Nobel Prize-winning virologist classified viruses in seven different groups on the basis of their genomic constitution. Recently in 2018-2019 The Baltimore classification was slightly modified in view of some evolutionary aspects that some groups of viruses arise from common ancestors. The modified classification of viruses is given below.

### DNA viruses

These viruses have deoxyribonucleic acid (DNA) as their genome and further classified into two groups which are as follows.

#### i. Double-stranded DNA viruses

Their DNA is double-stranded which synthesize mRNA by using host cell enzymes in the host cell nucleus. Some of them may cause cancer but no one known to infect a plant. Example Herpes.

#### ii. Single-stranded DNA viruses

They have a single-stranded DNA. They also prepare mRNA by transcription but first they become double stranded in host cell and then synthesize mRNA after that new progeny again have single stranded DNA. Example Parvoviruses.

### RNA viruses

These viruses possess RNA as their genomes and are categorized into following groups.

#### iii. Double-stranded RNA viruses

Their RNA is double stranded and present as genome. When they enter the host cell, they prepare single stranded mRNA by using cell enzymes. The newly formed mRNA is used either for translation or replication of double stranded RNA's which act as genome for new progeny. Example Reoviruses.

#### iv. Positive sense single-stranded RNA viruses

They have a single stranded RNA. Positive sense means that their RNA function as mRNA and directly translated by host cell without involving transcription. Example Corona virus, Dengue virus, Hepatitis C virus.

**v. Negative sense single-stranded RNA viruses**

These have single stranded RNA. When they enter the host cell, they prepare mRNA from their RNA in the host cell for any translation. Rhabdo virus, Paramyxovirus

**Reverse transcribing viruses**

The process of making DNA form RNA is called reverse transcription. This group of viruses are further classified which are as follows.

**vi. Single-stranded RNA viruses with a DNA intermediate**

They have single stranded positive sense RNA, but it needs to replicate via DNA intermediate. At first their RNA forms a DNA by using an enzyme reverse transcriptase inside the host, later on that DNA is integrated into the host genome for transcription and translation by using enzyme integrase. This includes retroviruses such as *HIV* (Have two single strand RNA).

**vii. Double-stranded DNA viruses with an RNA intermediate**

Their genome is DNA which forms RNA during its replication cycle. That RNA is then used for reverse transcription to replicate their genome inside the capsid. Example Hepatitis B.

Besides the genome-based classification mentioned above, viruses may also be grouped on the basis of their host parasite relationship e.g., bacteriophages that infect bacteria, phytophages which infect plants e.g., TMV and the zoophages infect animals and humans e.g., HIV, COVID-19.

## 5.2 PARASITIC NATURE OF VIRUSES

**Virus needs a host cell to complete its life cycle**

Viruses are noncellular living entity so they are nonfunctional without any host cell. Since they do not possess any kind of organelle and metabolic machinery to generate energy of their own or to prepare protein or any other macromolecule essentially require to develop its own structure therefore it must need a living cell that provide facilities to accomplish its requirement. A cell that represents all the vital activities of life and has all the necessities to regulate these activities. It can also provide assistance to an invader like virus upon demand. Viruses have nucleic acid that contain such powerful genes which can overtake and forcefully derive all the cellular metabolic machinery including enzymes, organelles to work according to the directions of viral genome.

### 5.2.1. How virus survive inside a host cell?

Viruses have variety of host cells that includes prokaryotes and eukaryotes both. viruses resist from host cell immune system by different means which are as follows

**1. Degrading host cell genome**

When a phage virus attacks bacterium, its DNA synthesizes endonuclease enzymes to degrade bacterial DNA and control the process of replication,

transcription, and translation to prepare viral proteins required for making new phage viruses.

**2. Deactivating the complement system**

Complement system is a part of innate immunity. It comprises of plasma protein that are activated upon the detection of pathogen. Viruses when enters the host cell they prepare proteins that mimics the complement proteins activators and blocks the complement protein.

**3. Viruses block the interferon response**

Interferons are the proteins released from virally infected cells that provide signals for immune system to respond. In contrast viruses blocks the specific genes and interrupt the metabolic activities to produce proteins.

**4. Inactivation of major histocompatibility complex (MHC)**

Viruses suppress the helper T cells to display viral components presented by MHC which delays the detection of virus invasion.

**5. Viruses suppress B cell activation**

Some viruses develop a system to reduce the functions B cell to anticipate viral activities and inhibit B cells proliferation and differentiation.

**6. Viruses can alter their genome**

Viruses can mutate and frequently change their genomic constitution so that drugs and vaccines become less effective and they survive in host cell.

### 5.2.2. Virus survival in environment

Viruses growth and survival can be influence by different environmental limiting factors like temperature and moisture, some organic compounds like mucous, radiations like UV etc. Here we are going to discuss about the effect of some factors.

**1. Virus survival and temperature**

Temperature affects viral survival through protein denaturation, damage to nucleic acid, or capsid dissociation. Usually, it is observed that DNA viruses have more endurance than RNA viruses but extreme temperature makes no difference in damaging both. Generally, temperature 60$^0$C and above is enough to inactivate most of the viruses but in this condition a virus take shelter from the surrounding organic material like blood, feces, saliva etc. contagious airborne viruses like influenza and Corona use saliva and mucous as cover and barrier for external unfavorable environment during coughing and sneezing when expelled out form the opening like mouth and nose.

**2. Airborne virus survival and relative humidity**

Virus survival in external environment without host depends upon levels of relative humidity. The difference in the percentage of water vapor presents in between normal condition at specific temperature and time. Lipid enveloped viruses are more vulnerable than non-lipid enveloped viruses.

Enveloped viruses including influenza, coronaviruses, tend to survive at the range of 20-30%, while viruses without enveloped like adenoviruses and rhinoviruses can tolerate and survive longer at higher level of humidity i.e., 70–90%.

### 3. Virus survival and light

Viruses living in aquatic environment influenced by light particularly phytoplankton viruses in both negative and positive way. It is required not only for plankton growth but also for the viral replication cycle which is very energy demanding and the requirement is fulfilled by light energy. It limits the viral attachment to the host cell. Light can also have the negative effects on viral replication like UV radiation is the major cause of viral decay moreover it also effects the photosynthetic viral hosts.

### 4. pH factor affecting viral survival

Viral activation requires appropriate pH environment. Studies reveal that favorable pH for viral survival is around 6.5 high while value around 7.2-8 and 5.0 to 5.5 damage its structure. Lipids are vulnerable and hydrolyze in very high basic pH value. Many viruses contain lipoprotein envelop that protect from environmental affects but on the other hand it is more interactive with the organic solvents, detergents and sanitizers of alkaline nature that degenerate its structure destroy virus. Nonenveloped viruses may not be destroyed but their replication abilities are affected therefore

## Structure of viruses

### Bacteriophage

A virus Bacteriophage means 'bacteria eater'. Bacteriophage is a group of viruses that kills bacteria. These viruses are grouped on the basis of different shapes like T-phages which contain developed tail fibers and λ (lambda) without or less developed tail fibers phages, enveloped and nonenveloped bacteriophage. Here we are going to discuss the structure of tailed bacteriophage virus. Tailed bacteriophage T4 virus has three major structures:

1. Head with DNA inside
2. A tail, that act as a channel that allow transport of DNA into host cell
3. A base plate at the bottom of the tail which is adhesive and helps to identify the host cell for attachment.

### 1. Head

The head is three dimensional called polyhedral and consist of small protein units called capsomeres. These capsomeres are connected with each other in geometrical manner called icosahedral. The DNA of bacteriophage is present in their head region and contain different genes.

### 2. Phage tail

Bacteriophage tail is formed by different proteins. The upper most part of the tail which connects it with the head is called collar. Tail is a tube like structure and has two regions, an outer region is a contractile sheath and other inside region is a non-contractile tube. The contraction of the outer sheath drives the inner tail tube creating a channel for DNA delivery into the host cell.

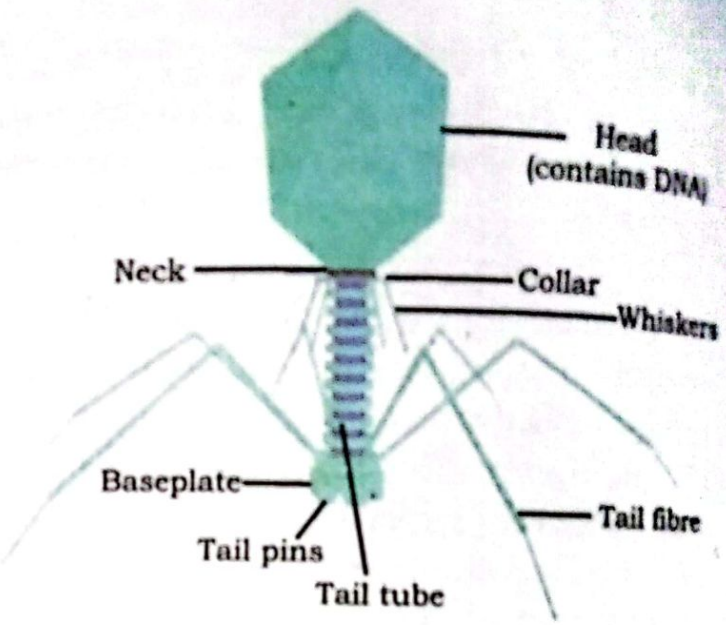



Fig. 5.2 Bacteriophage

### 3. Base plate

At the end of phage tail, a discoidal base plate is located. It has tail fibres usually 6 in numbers. These fibres provide strong attachment with host cell Its adsorption apparatus located on the distal end and recognizes host cell receptors and ensures DNA transfer to the cell cytoplasm. Base plate is surrounded by proteinaceous retractile "pins" at the base. These pins penetrate the bacterial coverings with the help of an enzyme lysozyme present at the base plate and helps to injects phage genome inside the bacterial cell.

### 1. Tobacco mosaic virus (TMV)

TMV is the virus of tobacco plant and cause Tobacco mosaic disease. It is made up of centrally located single stranded RNA as genetic material surrounded by protein coat called capsid. Most of its structure formed by protein coat with estimated 2,130 subunits named capsomeres arranged in a helical manner. Each capsomere contains about 158 amino acids and arranged in about 130 turns per rod.

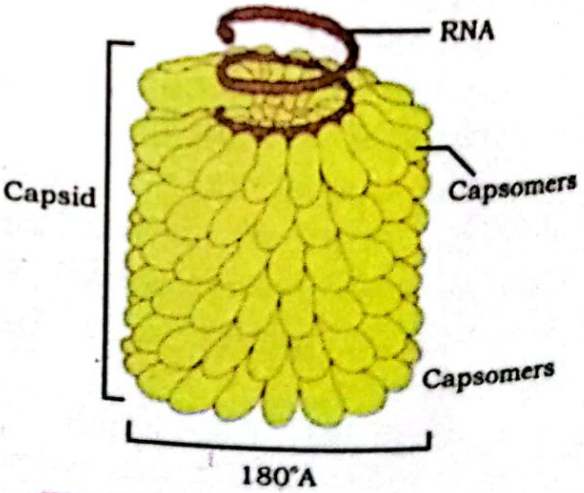



Fig. 5.3 Tobacco mosaic virus

## 5.3 LIFE CYCLE OF BACTERIOPHAGE

There are two types of life cycles are found in bacteriophage, the lytic cycle and lysogenic cycle.

### Lytic Cycle

During a virus attack on a bacterium, it replicates inside the host cell kill the cell by plasmolysis and releases the new virus progeny, so they can infect more bacterial cells. This type of life cycle called lytic life cycle.

**Step 1: Phage attachment**

Bacteriophage virus starts lytic phase of life cycle by attach itself to the bacterium. At this stage virus interacts with specific bacterial surface receptors. This attachment is reversible and specific to the host bacterium.

**Step 2: Genome penetration**

Bacteriophage strikes by its contractile tail sheath on the surface wall of bacterium and break it down. Virus injects its DNA in to the bacterium through a hollow tube and phage head and remaining components remain outside the bacteria and called the "ghost".

**Step 3: Biosynthesis or Replication of Phage DNA**

The cell's metabolic machinery, directed by phage DNA, produces phage proteins, and nucleotides from the cell's degraded DNA, are used to make copies of the phage genome. The phage parts come together. Three separate sets of proteins assemble to form phage heads, tails, and tail fibers forming daughter phages.

**Step 4: Maturation**

When all the component of phage structure synthesized including proteins and nucleic acid then assembling of these components begins to form new phages. During this phase new phage DNA are created called virions.

**Step 5: Lysis and release of phage viruses**

The newly formed bacteriophages releases and enzyme lysozyme to break bacterial wall and cause lysis, releasing 100-200 phage progeny into the surrounding and infect new bacterium.

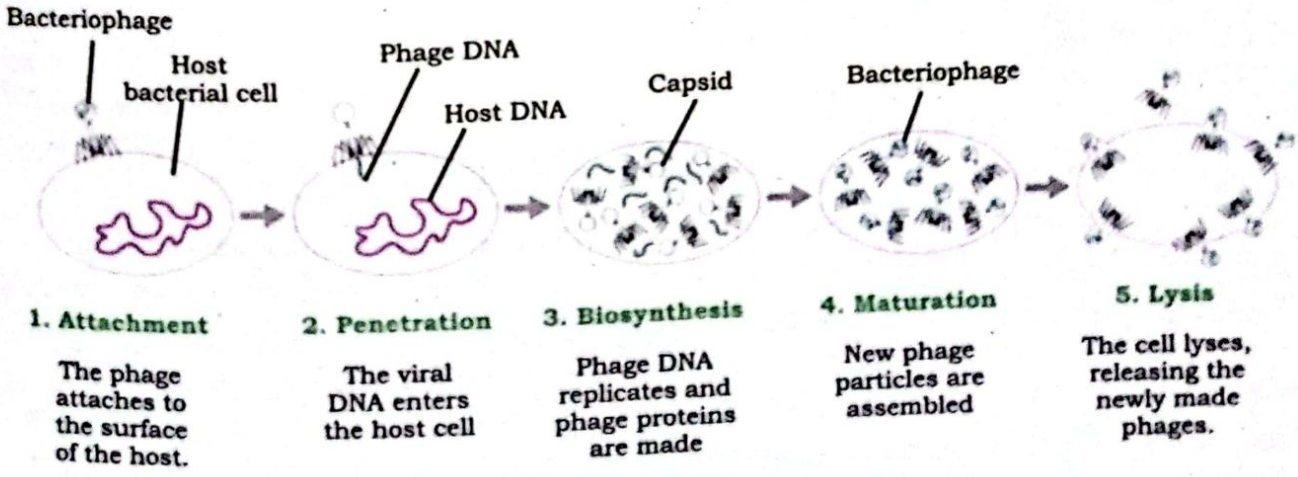



**Fig. 5.4. The lytic life cycle stages of bacteriophage virus**

## Lysogenic life cycle

In lysogenic cycle bacteriophage virus does not involve the killing of bacteria infect viral genome joins with the host bacterial nucleic acid and creating a **prophage**. The bacterium survives and multiply normally while during reproduction the conjugated genetic material (prophage) is transferred in to the next progeny of bacteria without any interference. Lysogenic life cycle can be explained by following steps

**Step 1:** In the first step phage virus injects its DNA into the bacterial cell. The attachment of virus with bacteria follows the same process as it occurs in lytic phase.

**Step 2:** Phage genome is incorporated with host DNA and called prophage.

**Step 3:** The viral DNA replicates along with the bacterial DNA during bacterial division and remain calm without affecting the host cell.

**Step 4:** The prophage may active under the unfavorable conditions and switch to the lytic cycle.

The phage genes remain inactive during lysogenic phase if any environmental trigger like radiations and chemicals stimulates, then they start the synthesis of specific enzymes to cut down the integrated viral DNA from the bacterial DNA and thus now act las a virus of lytic stage. Now the specific proteins which are required to develop their structures are produced and new phages are produced.

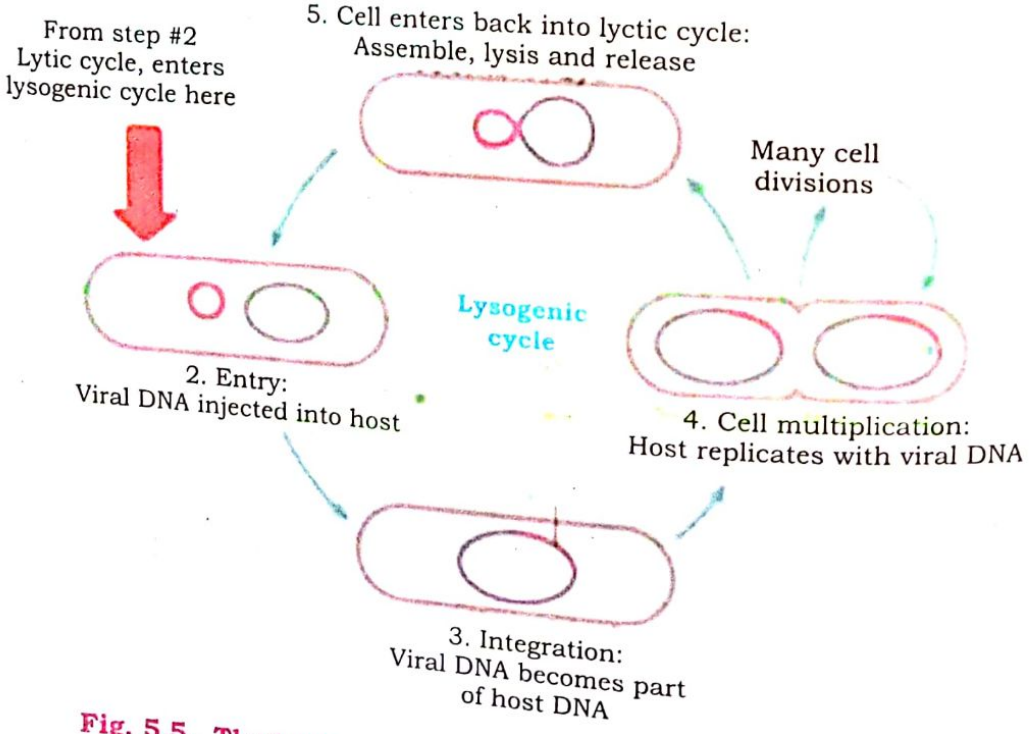



**Fig. 5.5. The lysogenic life cycle stages of bacteriophage virus**

### 5.3.1. Bacteriophage and genetic engineering

Bacteriophages are abundantly present on earth. They are used in genetic engineering for the transfer of required gene form one cell to another which benefit the organism or produce valuable products. Recently these phages are used to treat bacterial infections. The genetically modified phages when inducted in the body they attack the pathogenic bacteria inside the body and destroy them by using their genome as a weapon. Keeping In view that they are host specific and do not harm the other microbes and cells of the body. Phages are also used to present antigens which provide identification for the immune system to activate and destroy the pathogens that invades on our body.

## 5.4 HUMAN IMMUNODEFICIENY VIRUS (HIV)

AIDS (Acquired immune Deficiency Syndrome) caused by a virus called HIV. It was first reported in 1981 in California. AIDS spread more in poor developed countries. According to UNAIDS in 2019 above 35 million people around the world caught by AIDS in which 5% are children aged under 15 years.

### Structure of human immunodeficiency virus (HIV)

HIV belongs to the group retroviruses which are known to use their genetic material for reverse transcription. HIV size is about 60 times lesser than an RBC. It is spherical in shape and contains two RNA molecules in somewhat coiled and folded form with 9 genes enveloped in protein coat called capsid. These genes serve to prepare structural protein that form virus structure and develop ability to infect the host cell. HIV is an enveloped virus which is made of two layers of lipids with spikes made of glycoprotein, which helps virus to get stuck on the surface of target cell receptors and enters the cell.

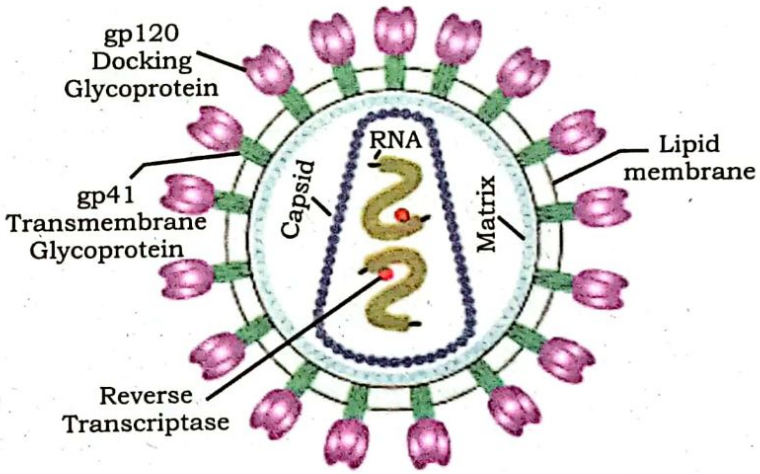



**Fig. 5.6**
**Human immuno-deficiency virus**

This virus has unique capability of reverse transcription means making DNA from its own RNA by using own enzymes namely the reverse transcriptase and integrase. The former is used to make DNA from RNA while later enzyme helps the viral genome remain intact inside the host cell.

## HIV life cycle

Life cycle of HIV consists of series of steps to multiply in the body which are: 1) binding; 2) fusion; 3) reverse transcription; 4) integration; 5) replication; 6) assembly; and 7) budding.

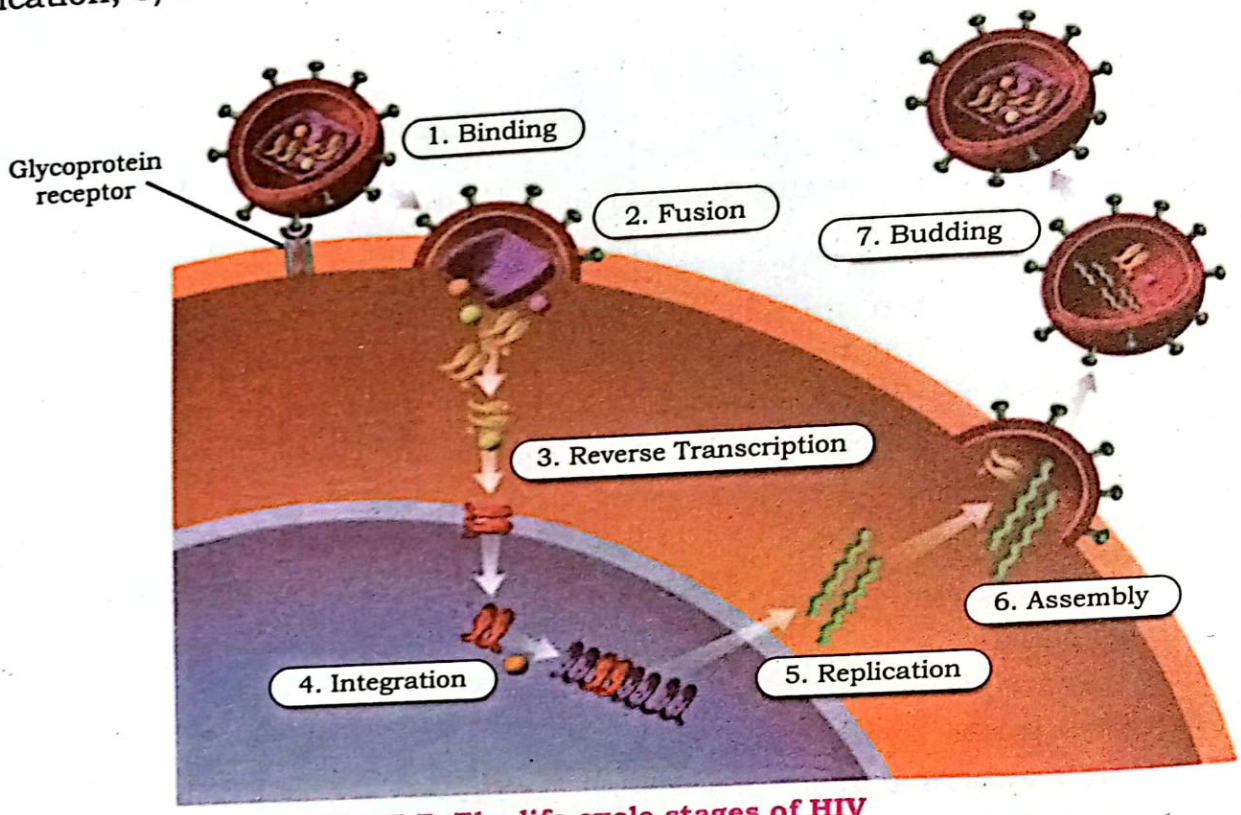



**Fig. 5.7. The life cycle stages of HIV**

1. **Attachment:** At first the virus attaches with a lymphocyte cell surface glycoprotein receptor that allow HIV to enter the cell.
2. **Fusion:** While remain attached the virus injects its RNA into the host cell.
3. **Reverse Transcription:** The viral RNA makes a new DNA this process is called reverse transcription. In this process virus uses its own enzyme called reverse transcriptase.
4. **Integration:** The viral DNA enters the host cell's nucleus, where it integrates with host DNA by an enzyme integrase. This DNA is called provirus, which may remain inactive for several years, producing few or no new copies of HIV.
5. **Transcription:** Now integrated host DNA develops mRNA for the process of protein synthesis to make viral protein and also by using host cell enzyme called RNA polymerase it creates the copies of HIV genomic material as mRNA which is used to direct the making of long chains of HIV proteins.

6. **Assembly:** When proteins are formed HIV use its another enzyme called protease to cut down protein in to small fragments that later join together with the HIV genome and develop new progeny.
7. **Budding:** New progeny of virus when matures it connects with the cell membrane and forms a small projection as bud from infected cell. The bud acquired some of the glycoprotein part of the cell membrane for its own covering. They released out of the cell and move on to infect other cells.

### 5.4.2. HIV specificity for the host cell

The virus HIV termed as human immunodeficiency virus because it destroys the most precious and valuable asset of our body immune system component the T lymphocyte cells and particularly Helper T lymphocyte cells. These cells are the part of adaptive immunity and not only help to activate their own fellow cytotoxic lymphocyte but also B cells to secrete antibodies and macrophages to ingest and destroy foreign invaders. Therefore, these cells act as activators for our immune response.

Now the question arises why T lymphocyte cells why not other cells as target for HIV? It is just because the T cells has specific protein receptors which are recognized and identified by HIV glycoprotein surface spikes that binds with these receptors as lock and key manner and initiate cell mediated endocytosis which brings the viral content into the cell. HIV controls cellular activities particularly protein synthesis and parasitize host cell.

### 5.4.3. Symptoms of AIDS

In the beginning of HIV infection symptoms appear for short duration like fever, flu, headache appears within the duration of six weeks repeatedly and that person can infect others. In the next stage the virus may last for an average of ten years without any symptoms but person may have lymph glands swollen in neck region. While immune system weakens other infections like tuberculosis (TB), pneumonia and cancers (Kaposi's Sarcoma) may occur. Some other viral infections may occur like Herpes and Influenza (flu). Finally, the immune system weakens due to destruction of T lymphocyte cells weight loss, night sweats, diarrhea, septicemia, dementia like infections causes death of a person.

### 5.4.4. Treatment of AIDS

At first a test for HIV is needed to detect the presence of virus that can be done by sample of blood or saliva. Other ways to check virus are antibody tests and nucleic acid tests (NATs). Different medicines are used in combinations to treat HIV this method is called Antiretroviral therapy (ART). The drugs used in AIDS therapy belong to the group of different enzyme inhibitor that inhibits the viral enzymes activity. The drugs **Rukobia**, **Descovy** and **Truvada** are found remarkable against HIV.

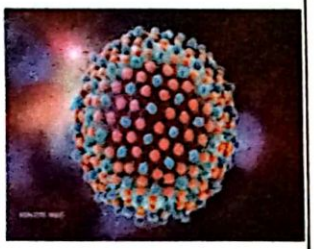
### 5.4.5. Transmission and control of HIV

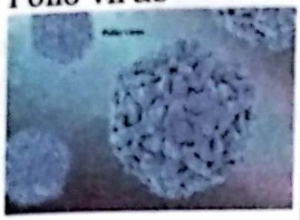
HIV spreads through contaminated blood transfusion or one to another by exposed wounds and from placenta of mother to child. It can also transmit by sexual contact in which urinogenital tract and its fluids facilitates viral transmission. Those who share or vaccinated through unsterilized syringes becomes cause of viral transmission.

The spread of HIV one should take precautionary measure before having sexual interaction, remain intact with religious Islamic preaching. Get vaccinated to prevent from opportunistic infections during AIDS although there is no vaccine to prevent or treat HIV. Sharing needles should be avoided. There is no cure for this disease.

## 5.5 VIRAL DISEASES

Table 5.1 viral diseases

| Viral disease | Causative agent | Symptoms | Transmission | Treatment and prevention |
|---|---|---|---|---|
| Hepatitis | Hepatitis virus  | Fever, pain in Belly. dark yellow urine, Fatigue, Jaundice, pain in joint, loss of appetite. | Through Fecal oral, Needle, blood, Sexual activities | Proper hand wash before and after meal, avoid to meet infected person with close contact use clean food and sanitize yourself by soap. |
| Herpes | *Herpes simplex* virus  | fever blisters around the mouth and sexual organs. A person may experience painful sores in genital region and anus, burning sensation in urination, flu and fever. | virus can enter the body through a break in skin, through mouth, reproductive organs and anus. Insanitary may lead to the spread of this disease | Use antiviral drugs on doctor's advice, avoid insanitary conditions |

| | | | | |
|---|---|---|---|---|
| Poliomy elitis | Polio virus  | The major symptom is paralysis of lower limbs while along with fever, sore throat, headache, body pain and tetany appears. | It is usually transmitted through contaminated water and food and by secretions from the nose, mouth or faeces of an infected person from fecal oral route in areas with poor sanitation then absorbed in blood and lymphatic system spread throughout the body and stays about 7 to 14 days. | disease it can only be handled prophylactically by vaccination and proper sanitary conditions. This virus may lead to death if not treated properly |
| Cotton Leaf Curl disease | *Begomovirus*   | Most common symptom is leaf curling upward or downward, veins thickening appears in leaves and quality of fibre are variably affected by leaf curl disease | This virus is transmitted through white fly pest | Use spray at every seven days and practice crop rotation. Or just cut and burn the infected plants. |

## Economic losses due to viral diseases

Viral diseases always remain a significant threat to the world economy. These are responsible to the sizable losses of agricultural products as well as livestock commodities. For example, Pakistan ranks fourth in area and production of cotton in the world. It has 9.36% of total world cotton area,

10.18% of production, 8.06% of consumption and 4.55% of total world export of raw cotton. The impact of cotton leaf curl virus on the Pakistan national economy cannot be forgotten as the country has lost Rs. 50 to 55 billion since 1992 and it is essential to maintain vigilance over the disease. Similarly, bird flu viral disease caused around 700 to 800 million Rupees. Huge loss at one time during its peak time.

## 5.6 PRIONS AND VIROIDS

### Viroids and Prions

Some entities are more simplified and smaller than viruses. These entities are called subviral particles. These include viroids and prions.

### Prions

An American biologist named Stanley B. Prusiner discover prions and received noble prize in 1997. These are infectious just protein molecule comprises of 29 amino acids with single disulfide bond. And without any nucleic acid. Prions are found in body tissues and in brain. Prions may cause Trisomy 21, Alzheimer's disease, sleeplessness (insomnia) in humans and mad cow disease in cattle.

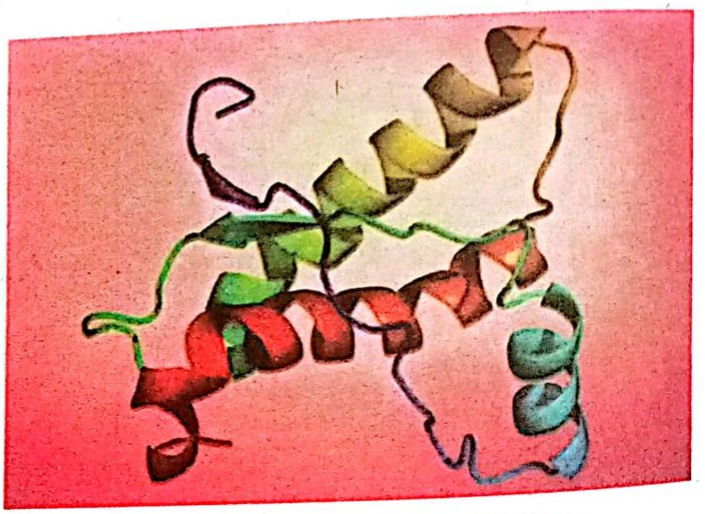


**Fig. 5.8. Structure of prion**

### Viroids

Viroids were discovered by an American plant pathologist, Theodor O. Diener, in 1971. They are simple nonenveloped single stranded RNA infectious molecules with some double stranded regions. They can be transmitted by pollen or seeds. The smallest viroid discovered so far is 220 nucleotides long while the smallest known virus causing infection are around 2000 bases in size. Viroids synthesize new RNA from its genome as template by using host cell enzyme RNA polymerase. The *Potato spindle tuber viroid* identified as first viroid and now the known species of viroids are about 33 in number. Viroids don't interrupt protein synthesis but they only replicate and produce specific RNA molecule. Viroids mainly cause plant diseases and infected plants show distorted growth. There is no evidence of human disease caused by viroids.

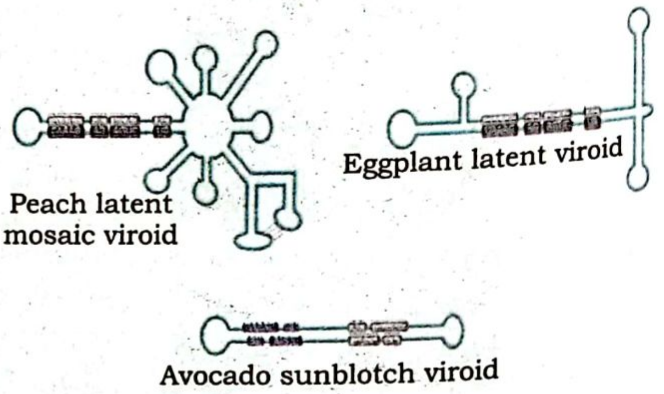



**Fig. 5.9. Different shapes of viroids**

**Table 5.2 Animal viruses their transmission and symptoms**

| Name of virus | Vector /Host | Type of nucleic Acid | Transmission | Symptoms |
|---|---|---|---|---|
| Chikungunya virus | *Aedes* Mosquito and nonhuman primates | RNA virus with a positive-sense single-stranded genome | Blood | Headache, body muscles and joints pain, Nausea, Vomiting, swollen glands, and painful eyes. |
| Dengue virus | *Aedes* mosquito human | positive-sense, single stranded RNA | Blood | vomiting. Rashes with pain Nausea, pain typically behind the eyes, and in the body |
| Ebola virus | Canid animals Bats, dogs etc. | Negative sense stranded RNA virus. | Body fluid | Hemorrhagic fever |
| Hepatitis C virus | Human infected blood | positive sense single-stranded RNA | transmission of Hepatitis C virus occurred mainly during blood transfusions | Fever, yellow skin, Fatigue. Muscle and joint pain. Nausea and loss of appetite. Stomach pain. |
| Measles virus | air borne droplets from nose and throat mucus in human | negative-sense RNA gen ome | Sneezing and coughing of infected person | fever, cough, and a runny nose, followed by a body rash |
| Corona virus | Bats | RNA viruses | Air born droplets | Laboured breathing Pressure inside the chest with pain, weakness, difficulty in speech. Low oxygen level. |

# SUMMARY

- Viruses are a major threat to human health and countries economy. Millions of people died during 1918-1919 and now a days Corona becomes havoc to human beings. Due to Corona industrial production fell by 20 per cent on average in 93 per cent of countries during 2019 to 2020.
- Viruses have their own nucleic acid with genome that determine their functionality and shows complicated assemblies of molecules, including proteins, nucleic acids, lipids, and carbohydrates as present other living cells. There is an undeniable genetic and physiological connection between viruses and the organisms they infect.
- Viruses were first discovered after the development of a porcelain filter by Charles Chamberland (1884) in Paris, called the Chamberland-Pasteur filter.
- A virus Bacteriophage means 'bacteria eater'. Bacteriophage is a group of viruses that kills bacteria.
- Viruses have nucleic acid that contain such powerful genes which can overtake and forcefully derive all the cellular metabolic machinery including enzymes, organelles to work according to the directions of viral nucleic acid.
- A virus integrates its genome with the host cell nucleic acid and control the metabolic activities it also interrupts transcription and making protein of its own kind in the host cell. Viruses also misguide the immune response and establish a chronic infection.
- Many environmental factors may affect virus survival including temperature, humidity.
- Bacteriophages have genetic material compatible to incorporate any foreign eukaryotic gene for the betterment of living standards related with health and protection not only from diseases but to enhance the potential benefit of any organism of utmost importance for humans.
- HIV destroys our body T lymphocyte cells and particularly Helper T lymphocyte cells.
- Hepatitis is a viral disease that causes inflammation and damage to the liver. There are about five different types of hepatitis viruses like A, B, C, D and E.
- Some structures are more simplified and smaller than viruses. These structures are called subviral particles. These include viroids and prions

# EXERCISE

## 1. Encircle the correct choice.

(i) Viruses evolve by using the
(a) Cellular organelles (b) Cellular enzymes
(c) Cellular energy (d) All of them

(ii) The pathogenicity of a virus depends upon
(a) the immunity of the host body
(b) the effective penetration of its genome
(c) the overall environment inside the body
(d) the overall environment outside the body

(iii) Bacteriophages escape from host cell by the activity of
(a) Lysozyme (b) Ribozyme
(c) Peroxisomes (d) Glyoxisomes

(iv) The smaller proteins are cut down and forms a new virus structure by the process called
(a) Integration (b) Transcription
(c) Budding (d) Assembly

(v) Virus that severely damage motor neurons and causes paralysis called
(a) HIV (b) Dengue
(c) Polio (d) Herpes

(vi) Proteins that cause pathogenicity in humans and animals called
(a) Prions (b) Viroids
(c) Antigen (d) Antibodies

(vii) Smaller than viruses having single stranded RNA with some double stranded regions are called
(a) Prions (b) Viroids
(c) Minus strand viruses (d) Double stranded DNA viruses

(viii) Dengue fever, encephalitis and yellow fever are caused by which group of viruses?
(a) Arbo-viruses (b) Retro-viruses
(c) Rhabdo-viruses (d) Rhino-viruses

(ix) Aedes mosquito is the vector of
(a) Dengue virus (b) Ebola virus
(c) Hepatitis virus (d) Measles virus

## 2. Write short answers of the following questions:

1. Discuss the living and nonliving status of virus
2. What do we mean by positive and negative sense virus?
3. Name the groups of viruses from Baltimore classification
4. How does bacteriophage virus infect bacteria?
5. Differentiate lytic and lysogenic life cycle of bacteriophage.
6. What is reverse transcription? How it performs by HIV in human?
7. List down any five animal and plant viruses with their vector transmission and symptom
8. List down the sequences involved in the lytic and lysogenic life cycle of bacteriophage?
9. How a virus survives without host discuss.
10. What are the symptoms of AIDS?
11. What is the prevention and control of AIDS?
12. Differentiate Prions and Viroids.

## 3. Write detailed answers of the following questions:

1. Explain the lytic life cycle of Bacteriophage with labelled diagram.
2. Explain the life cycle of HIV with labelled diagram.
3. Explain the pathogenicity and economic losses caused by viruses to the humans.

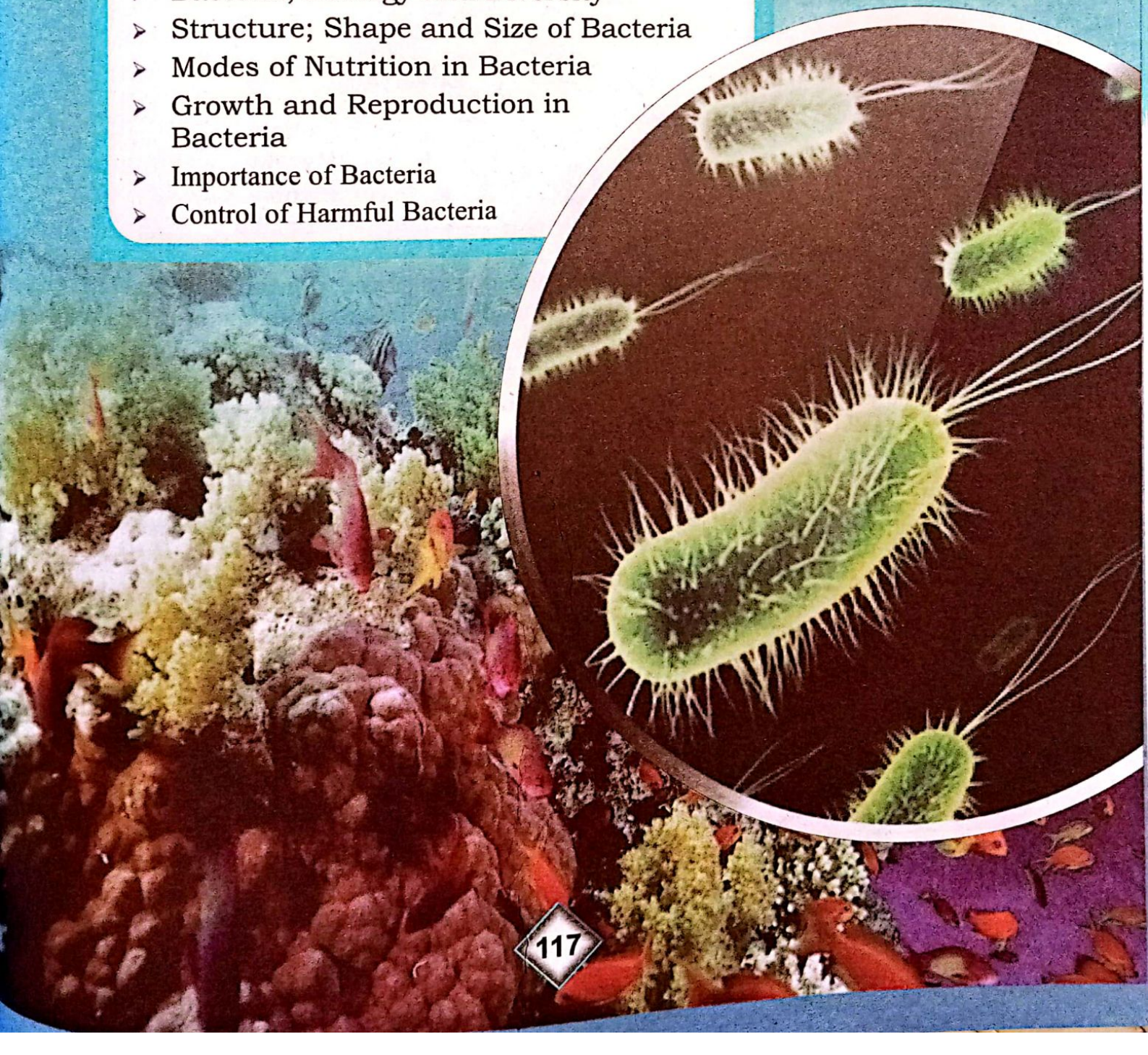
# PROKARYOTES

Chapter 6

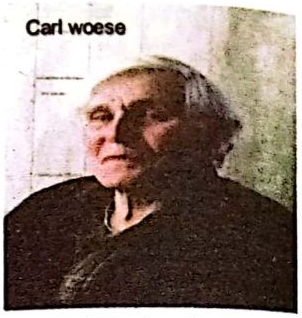
## Major Concept

**In this Unit you will learn:**

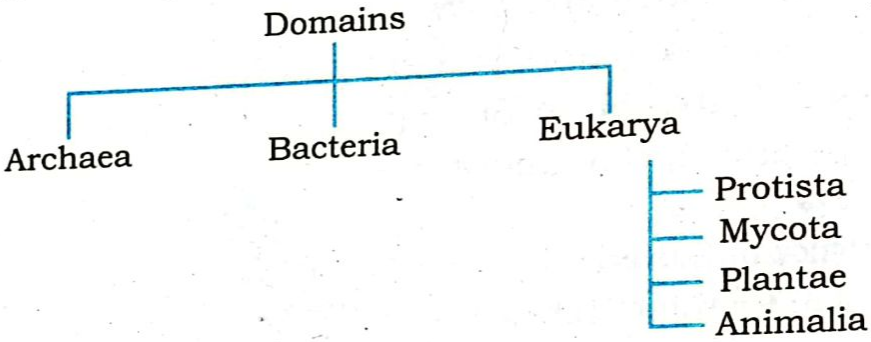
- Taxonomy of Prokaryotes
- Archaea
- Bacteria; Ecology and Diversity
- Structure; Shape and Size of Bacteria
- Modes of Nutrition in Bacteria
- Growth and Reproduction in Bacteria
- Importance of Bacteria
- Control of Harmful Bacteria



## 6.1 TAXONOMY OF PROKARYOTES




In recent past all living organisms are grouped into five kingdoms and Prokaryotes were placed into the kingdom Monera (Prokaryotae) but now the status of classification has been changed in late 90's. The pioneer work had been conducted by Carl Woese (1990) and his colleagues proposed domain system of classification based upon the differences of subcellular structure ribosomes and cell membranes. He described that life has evolved on earth along three lineages called domain which include Bacteria, Archaebacteria (Archaea) and Eukaryotes (Eukarya). This division is widely accepted throughout the world.




In view of recent classification two out of three domains' Eubacteria and Archaebacteria are prokaryotes. The domain Eubacteria comprises all bacterial organisms and recently given status as kingdom bacteria, the domain Archaea comprises the rest of the prokaryotes, and the domain Eukarya includes all eukaryotes, including organisms in the kingdoms Protista, Fungi (Mycota), Plantae and Animalia.

**Table 6.1.**

**Classification of organisms given by different scientist in different era**

| Linnaeus 1758 | Haeckel 1866 | Chatton 1925 | Copeland 1938 | Whittaker 1969 | Woese et al. 1990 |
|---|---|---|---|---|---|
| 2 kingdoms | 3 kingdoms | 2 empires | 4 kingdoms | 5 kingdoms | 3 domains |
| | Protista | Prokaryota | Monera | Monera | Bacteria |
| | | | | | Archaea |
| | | Eukaryota | Protoctista | Protista | Eukarya |
| Plantae | Plantae | | Plantae | Plantae | |
| | | | | Fungi | |
| Animalia | Animalia | | Animalia | Animalia | |

### 6.1.1. Phylogeny of Prokaryotes

Prokaryotes are the most primitive and first inhabitant on earth. Earth at that time highly exposed to radiations and probably had a very less molecular oxygen therefore prokaryotes were adapted to those conditions. The prokaryotes may have evolved from protobionts ancestors. Their early selective habitat could be the microbial mats as evidenced by the fossil presence aged 3.5 billion years ago. These mats are few centimeters thick, moist and sticky due to the secretion of extracellular matrix from Prokaryotes and found near hydrothermal vents to obtain energy and food from these vents. These mats when dried becomes stromatolite as a sedimentary structure represents the earliest fossilized record of life on earth.

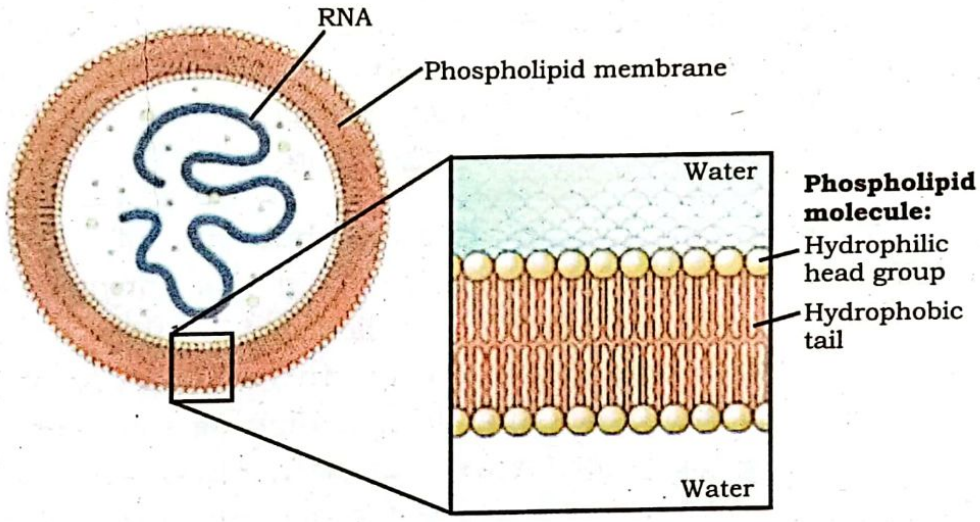



**Fig. 6.1. Protobiont:**
**Enclosure of self-replicating RNA in a phospholipid membrane. The first cell is thought to have arisen by the enclosure of self-replicating RNA and associated molecules in a membrane composed of phospholipids.**

Prokaryotes present in every habitat and each comprised of several smaller taxonomic groups. The domain Bacteria of the Prokaryote also include cyanobacteria or blue-green algae. This primitive prokaryotic alga can perform photosynthesis and are called photoautotrophs. Higher phototrophic autotrophs are thought to have evolved from this group. They have well developed pigment system and can reproduce by fragmentation. Bacteria also exist as decomposers or saprotroptus and symbionts.
Prokaryotes have tremendous ability to adapt according to the changing environment. Their genome has much role in developing this ability extending up to genetic level for example bacterial species *Escherichia coli* contains approximately 5,000 genes. On average, about one in every 200 bacteria is likely to have a mutation in at least one of the genes.

## 6.2. DOMAIN ARCHAEA

Archaea is a very diverse group in a domain system of classification. They were initially classified as Archaebacteria but this classification is obsolete now they are a separate domain. They are present in different shapes like spherical, rod, lobed, square etc. their diameter ranging 0.1 to over 15μm. Archaea are slightly different from bacteria. They don't have peptidoglycan in their cell wall as it is present in bacteria and also some metabolic activities are different from bacteria. Archea reproduce asexually by binary fission, fragmentation or budding.

Curd may contain a wide variety of bacteria like *Lactobacillus acidophilus, Lactococcus lactis,* etc., whereas yogurt contains *Streptococcus thermophilus* and *Lactobacillus bulgaricus*. Anaerobic bacteria in the oral cavity include:, *Eubacterium*, *Lactobacillus*, *Selenomonas*, *Treponema*, *etc*.

Archaea can live in different habitats of extreme condition and classified accordingly like those living in hot springs called thermophiles, high acidic conditions dwellers called acidophiles and methanogens are found in marshy areas and in gut produces biogas to obtain energy another group includes halophiles that live in high salt concentration environment as they require high salt for their growth. Although they are almost similar with bacteria in shape and size but genetically, they also have some affinity with eukaryotes like they have genes that produce enzymes particularly polymerase used in metabolic activities during translation and transcription as present in eukaryotic organisms. Archeal membrane composition is bit different from bacterial membranes marking as unique character. They have hydrocarbons attached to glycerol by ether linkage rather than ester linkages this combination is also called **archaeol** specially in methanogens while in bacterial membrane glycerol ester lipids are presents. *Example Methanococcus, Halobacterium*

They do not live as pathogens or parasites instead they develop useful associations with others as mutualists or commensals for example methanogen archea *E.coli* live in human intestine and helps in digestions, marine archean *Cenarcheaum symbiosum* lives within sponge *Axinella mexicana* as symbiont, some thermophile archea used in biotechnology due to their endurance of high temperature.

Table 6.2. Comparison of domain system classification

| Characteristics | DOMAINS | | |
|---|---|---|---|
| | Archaea | Bacteria | Eukarya |
| Cell Membrane | Ether-linked lipids, pseudopeptidoglycan | Ester-linked peptidoglycan | Ester linked lipids, various structures |
| Gene Structure | Circular chromosomes, similar translation and transcription to Eukarya | Circular chromosomes, unique translation and transcription | Multiple, linear chromosomes, similar translation and transcription to Archaea |
| Internal cell structure | No membrane-bound organelles or nucleus | No membrane-bound organelles or nucleus | Membrane-bound organelles and nucleus |
| Metabolism | Various methanogenesis unique to archaea | Various, including Photosynthesis, aerobic and anaerobic respiration, fermentation, and autotrophy | Photosynthesis and cellular respiration |
| Reproduction | Asexual reproduction, horizontal gene transfer | Asexual reproduction, horizontal gene transfer | Sexual and asexual reproduction |

## 6.3. BACTERIA ECOLOGY AND DIVERSITY

Earth is formed around 4.5 billion years ago. The evolution of this planet and its atmosphere gave rise to life, which shaped earth's subsequent development. When earth was evolved the allover environmental conditions are not so good for any living organism. Initial temperature is very high the volcanic activities releasing gasses probably created the atmosphere and the oxygen almost unavailable. The earliest undisputed evidence of life on earth dates at least from 3.5 billion years ago. Since then, life has evolved into a wide variety of forms. As evolution proceeds fossil records indicate bacterial colonization developed and acquired different areas of earth. Later on, some started making their own food using carbon dioxide from the atmosphere and energy they harvested from the sun. These initial photosynthetic organisms helped establish a stable atmosphere and produced oxygen in such quantities that eventually life forms could evolve

that needed oxygen. Soon afterward, new oxygen-breathing life forms came onto the existence.

With a population of increasingly diverse bacterial life, the stage was set for more life to form. There is compelling evidence that mitochondria and chloroplasts were once primitive bacterial cells. The Russian botanist Konstantin Mereschkowski first outlined the **theory of symbiogenesis** (Endosymbiotic) which states that some of the organelles in today's eukaryotic cells were once prokaryotic microbes. Over millions of years of evolution, mitochondria and chloroplasts have become more specialized and today they cannot live outside the cell. Mitochondria and chloroplasts have striking similarities to bacteria cells. They have their own DNA, which is separate from the DNA found in the nucleus of the cell and both organelles use their DNA to produce many proteins and enzymes required for their function. A double membrane bounding both mitochondria and chloroplasts is further evidence that each was ingested by a primitive host. The two organelles also reproduce like bacteria, replicating their own DNA and directing their own division.

Mitochondrial DNA (mtDNA) has a unique pattern of inheritance. It is passed down directly from mother to child, and it accumulates changes much more slowly than other types of DNA. Because of its unique characteristics, mtDNA has provided important clues about evolutionary history. For example, differences in mtDNA are examined to estimate how closely related one species is to another.

### 6.3.1. Bacterial habitat

Bacteria can be found in almost all the habitat on earth. They are present in soil, water, plants, animals, radioactive waste, deep in the earth's crust, arctic ice and glaciers and in hot springs. Their range extending up to 30 miles up in the atmosphere and 10,000 meters deep in water. A gram of soil typically contains about 40 million bacterial cells. A milliliter of fresh water usually holds about one million bacterial cells. The earth is estimated to hold at least 5 nonillion bacteria, and much of the earth's biomass is thought to be made up of bacteria. This distribution also ensures the evidence that bacterial colonization and endurance develops due to the extreme environment when the earth is formed. Deep in the ocean environment is total dark and both temperature and pressure are very high, bacteria living in these areas survive by oxidizing
deep inside the earth.



that needed oxygen. Soon afterward, new oxygen-breathing life forms came onto the existence.

With a population of increasingly diverse bacterial life, the stage was set for more life to form. There is compelling evidence that mitochondria and chloroplasts were once primitive bacterial cells. The Russian botanist Konstantin Mereschkowski first outlined the **theory of symbiogenesis** (Endosymbiotic) which states that some of the organelles in today's eukaryotic cells were once prokaryotic microbes. Over millions of years of evolution, mitochondria and chloroplasts have become more specialized and today they cannot live outside the cell. Mitochondria and chloroplasts have striking similarities to bacteria cells. They have their own DNA, which is separate from the DNA found in the nucleus of the cell and both organelles use their DNA to produce many proteins and enzymes required for their function. A double membrane bounding both mitochondria and chloroplasts is further evidence that each was ingested by a primitive host. The two organelles also reproduce like bacteria, replicating their own DNA and directing their own division.

Mitochondrial DNA (mtDNA) has a unique pattern of inheritance. It is passed down directly from mother to child, and it accumulates changes much more slowly than other types of DNA. Because of its unique characteristics, mtDNA has provided important clues about evolutionary history. For example, differences in mtDNA are examined to estimate how closely related one species is to another.

### 6.3.1. Bacterial habitat

Bacteria can be found in almost all the habitat on earth. They are present in soil, water, plants, animals, radioactive waste, deep in the earth's crust, arctic ice and glaciers and in hot springs. Their range extending up to 30 miles up in the atmosphere and 10,000 meters deep in water. A gram of soil typically contains about 40 million bacterial cells. A milliliter of fresh water usually holds about one million bacterial cells. The earth is estimated to hold at least 5 nonillion bacteria, and much of the earth's biomass is thought to be made up of bacteria. This distribution also ensures the evidence that bacterial colonization and endurance develops due to the extreme environment when the earth is formed. Deep in the ocean environment is total dark and both temperature and pressure are very high, bacteria living in these areas survive by oxidizing sulfur that comes from deep inside the earth.

Table No. 6.3
Types of bacteria on the basis of mode of respiration

| Aerobic bacteria | Anaerobic bacteria |
|---|---|
| Live in places where oxygen is available | Live in places where oxygen is not available |
| They produce $CO_2$ and $H_2O$ | They produce $CO_2$, ethanol and Lactic acid |
| Live in soil, water and open surfaces | Live in areas where oxygen is depleted like intestine, marshes |
| Produce more energy<br>Example *Lactobacillus, Mycobacterium* | Produce less energy<br>Example *Clostridium and E. coli* |

Like Archea different bacteria also live in different extreme environment.

### 6.3.2. Major groups of bacteria

Carl Woese studied the differences in rRNA sequences in different organisms and established the evolutionary relationships among species. On that basis domain bacteria classified into five major phylums namely Proteobacteria, Chlamydias (Gram-negative), Spirochetes, Cyanobacteria, and gram-positive bacteria.

Table 6.4 Different groups of bacteria

| | Phylum | Characters | Example |
|---|---|---|---|
| Domain Bacteria | **Protobacteria** | Free living and symbionts<br>Some are pathogenic | *Helicobacter pylori* causes stomach ulcer<br>*Salmonella* causes food poisoning |
| | **Chlamydias (Gram-Negative bacteria)** | Obligate intercellular parasite<br>Cell wall with low peptidoglycan | Chlamydia trachomatis causes sexually transmitted disease |
| | **Spirochetes** | Spiral shaped, free living anaerobes<br>Pathogenic<br>Flagella present | *Treponema pallidum* causes Syphilis |
| | **Cyanobacteria** | Known as blue green algae<br>Chlorophyll present<br>Present in aquatic environment | *Prochlorococcus* most abundant photosynthetic organism on earth |
| | **Gram-Positive bacteria** | Pathogenic and decomposers<br>Thick cell wall and without outer membrane | *Clostridium botulinum* cause botulism<br>*Bacillus anthrax* cause anthrax |

### 6.3.3. Cyanobacteria as photosynthetic bacteria

Cyanobacteria is the most prominent primitive photosynthetic organism that earth acquired in its wide range of habitats. They have remarkable ability to survive in extremely high and low temperatures. Primarily these are found in aquatic environment and established around 2.5 billion years ago. At that time when earth was suffering from high temperature and oxygen deficiency, they were contributed in providing oxygen to our atmosphere by using water during photosynthesis and using $CO_2$ might had reduced the earth temperature to some extent. Their life processes require only water, $CO_2$, inorganic substances and light. Their abilities to colonize on rock and soil, in tough environmental conditions like glaciers and near volcanos and radiation.

Cyanobacteria can survive in low $CO_2$ environment. They have RuBISCO enzyme that help to convert $CO_2$ into sugars. Filamentous cyanobacteria can fix elemental nitrogen in their specialized cells called **Heterocyst** and they are used in fertilizers as produced by *Nostoc*. Some of the cyanobacteria also produce toxic substances which contaminate water and if drink commonly cause gastroenteritis.

Cyanobacteria don't have chloroplast for being the most primitive form but the green pigments are present. Since they are the primitive one and do not represent the true photosynthetic eukaryotic cellular organization, therefore they require little amount of energy to maintain cellular activities and have the higher growth rate than other phytoplanktons when light intensities are low. They can also live within the organisms for developing mutualism and also can live. They have chlorophyll a, carotenoids and the blue pigment phycobilin while in some species, the red pigment phycoerythrin is also present. If they have not evolved on earth, it would have low level of oxygen all around and most of the life form could not been able to exists.

## 6.4. STRUCTURE OF BACTERIA

Bacteria are the prokaryotic unicellular organisms. Structurally bacterial cell has three distinct regions first appendages that include **flagella** and **pili** which helps bacteria cell in locomotion and floating respectively, secondly cell coverings consisting of **capsule** the outermost covering in some cells, cell wall and cell membrane and third is cytoplasmic region that contains the cell chromosome (DNA), **plasmid** as the extra circular molecule of DNA used

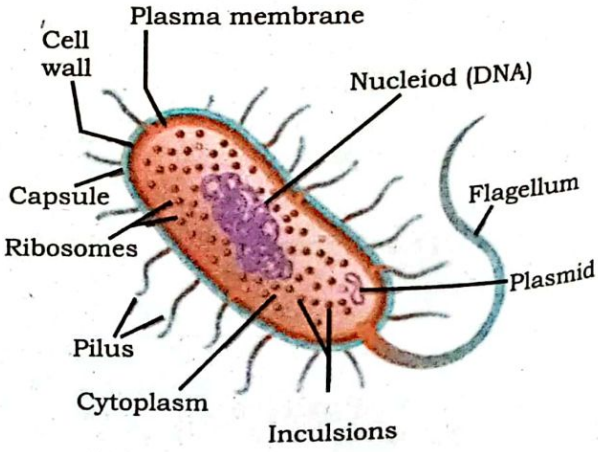



**Fig. 6.2 Bacterial structure**

in conjugation and also protect bacteria from antibiotics. Bacteria also contain **Ribosomes** for protein synthesis, **Mesosomes** the membranous invaginations which helps in DNA replication, cell division respiration and export of enzymes and various inclusions. Inclusions are considered to be nonliving components of the cell that do not perform metabolic activities and are not bounded by membranes. The most common inclusions are glycogen, lipid droplets, crystals, and pigments.

Generally bacterial cells have two protective coverings the outer **cell wall** and inner **cell membrane**. Some bacteria have a third outermost protective covering called **glycocalyx** which separates bacterial cell from its surroundings. Glycocalyx may be condensed to form **capsule** and **slime** which is soft and sticky according to the surrounding environment. Capsule form of glycocalyx relatively tightly associated with cell wall, it provides sticky or gummy nature to the cell wall, where as slime is loosely attached with cell wall and gives slimy and slippery nature to bacterial cell. which is formed by polysaccharide, polypeptide and hyaluronic acid in different species. Mostly capsules are hydrophilic and protect bacteria from desiccation. Capsule protects bacteria from ingestion of WBCs and increases the bacterial pathogenicity in host organisms. Another function of glycocalyx is to promote adhesion with each other and form biofilm, biofilm bonding become more resistant and harder to kill.

**Table 6.5.**

**showing Cell wall differences in Gram-positive and Gram-negative bacterial cell wall.**

| S.N. | Character | Gram-Positive Bacteria | Gram-Negative Bacteria |
|---|---|---|---|
| 1. | Gram Reaction | Retain crystal violet dye and stain blue or purple on Gram's staining. | Accept safranin after decolorization and stain pink or red on Gram's staining. |
| 2. | Cell wall thickness | Thick (20-80 nm) | Thin (8-10 nm) |
| 3. | Peptidoglycan Layer | Thick (multilayered) | Thin (single-layered) |
| 4. | Rigidity and Elasticity | Rigid and less elastic | Less rigid and more elastic |
| 5. | Outer Membrane | Absent | Present |
| 6. | Variety of amino acid in cell wall | Few | Several |
| 7. | Aromatic and Sulfur-containing amino acid in cell wall | Absent | Present |

| | | | |
|---|---|---|---|
| **8.** | Teichoic Acids | Mostly present | Absent |
| **9.** | Lipid and Lipoprotein Content | Low (acid-fast bacteria have lipids linked to peptidoglycan) | High (because of presence of outer membrane |
| **10.** | Cell Wall Disruption by Lysozyme | High | Low (requires pretreatment to destabilize outer membrane) |
| | Examples | *Staphylococcus*<br>*Streptococcus*<br>*Bacillus*<br>*Clostridium*<br>*Enterococcus* | *Escherichia*<br>*Salmonella*<br>*Klebsiella*<br>*Proteus*<br>*Helicobacter*<br>*Pseudomonas* |

**Bacterial cell wall**

The bacterial cell wall is made up of **murein,** which is a mixture of two conjugated molecules called lipoglycan and peptidoglycan. It is specifically present only in prokaryotes cell wall and provides the cell shape and surrounds the cytoplasmic membrane to protect. Peptidoglycan is a conjugated structure contain polymer of disaccharides. From the peptidoglycan inwards all bacterial cells are very similar. The cell wall provides important ligands for adherence and receptor sites for viruses or antibiotics. On the basis of their cell wall structure and composition. Gram-positive bacteria, due to high content of peptidoglycan in their structure (as shown in the fig.6.8) retain crystal violet when stain while Gram negative bacteria due to less peptidoglycan and outer lipopolysaccharide content fail to retain stain and washed-out during alcohol treatment of staining process.

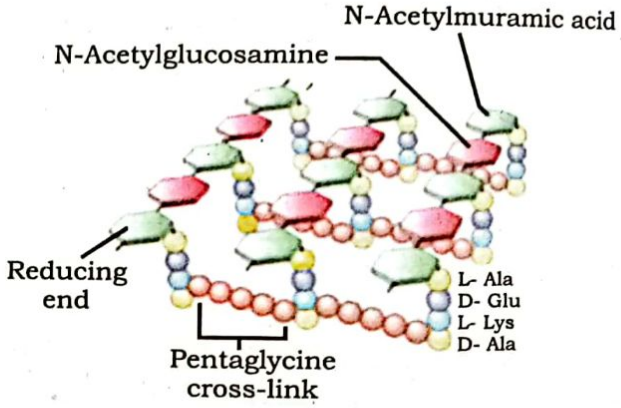



**Fig. 6.3. Structure of Peptidoglycan in bacterial cell wall**

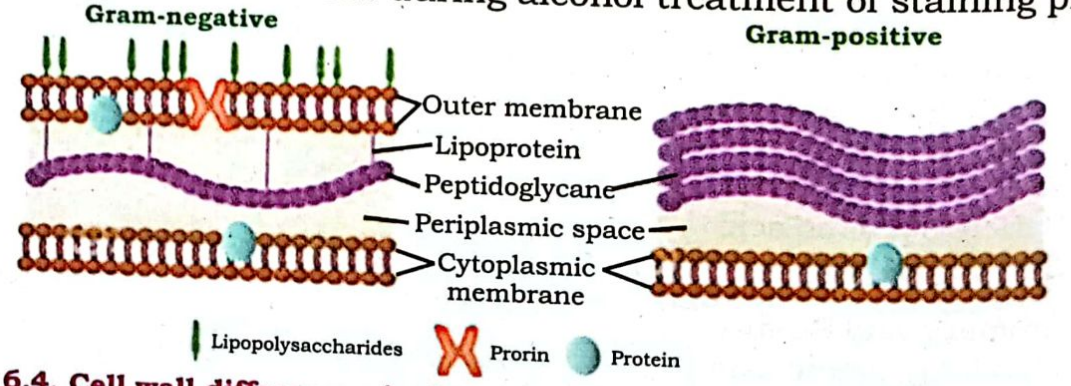



**Fig. 6.4. Cell wall differences in Gram-positive and Gram-negative bacteria.**

### 6.4.1. Shape and size of bacteria

Bacteria are found in different shapes and sizes. Bacteria are classified into five groups according to their basic shapes: spherical (cocci), rod (bacilli), spiral (spirilla), comma (vibrios) or corkscrew (spirochaetes).

1. **Cocci**: These are spherical and non-flagellated. **Cocci** exists in different arrangements like single cell, in pairs of two called **diplococci,** in groups of four called **tetrads**, in chains as **streptococci,** in clusters as **staphylococci** or in cubes consisting of eight cells as **sarcina**.
2. **Bacilli** are rod shaped maybe flagellated bacteria they exist in single form, paired form as **diplobacillus**, arranged in chains called **streptobacillus**, some are **coccobacillus** appears as short and stumpy ovoid and shaped in between coccus and bacillus. Few other are called **Palisades** long slender and their arrangement resembles with picket fence.
3. **Spirilla** (or spirillum for a single cell) are flagellated deeply curved from the middle of the body.
4. **Vibrio** are slightly curved bacteria like comma shape with flagella.
5. **Spirochetes** are long, slender, and flexible cork screw like bacteria.

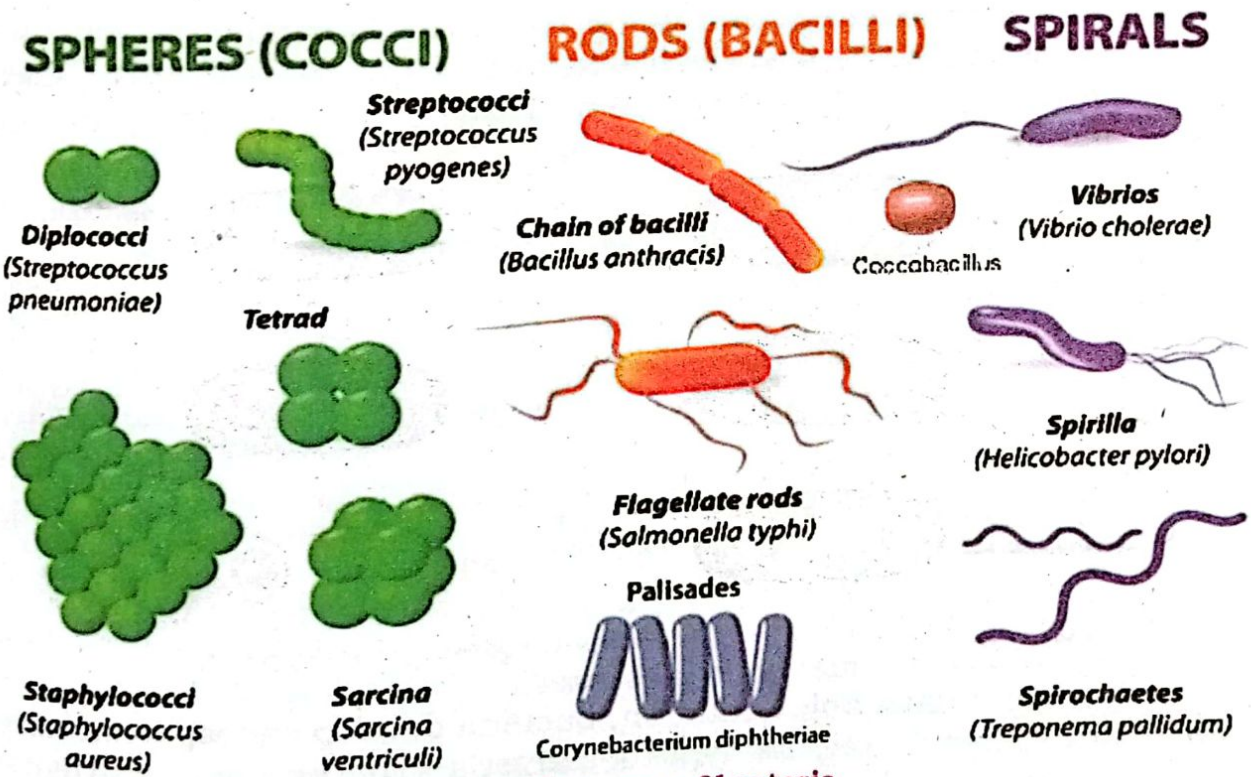



**Fig. 6.5 shapes of bacteria**

### 6.4.2. The Endospore Formation in Bacteria

Bacteria are very adaptive to the changing environment. When habitat conditions become harsh and nutrients are exhausted the development of endospore is initiated. It develops inside the bacterial cell becomes highly resistant from the environmental stresses including high temperature, ultraviolet radiations, desiccation, chemical damage, enzymatic destruction which protect bacterial genetic material. Bacteria are able to survive for a long period of time due to endospore as it is difficult to destroy.

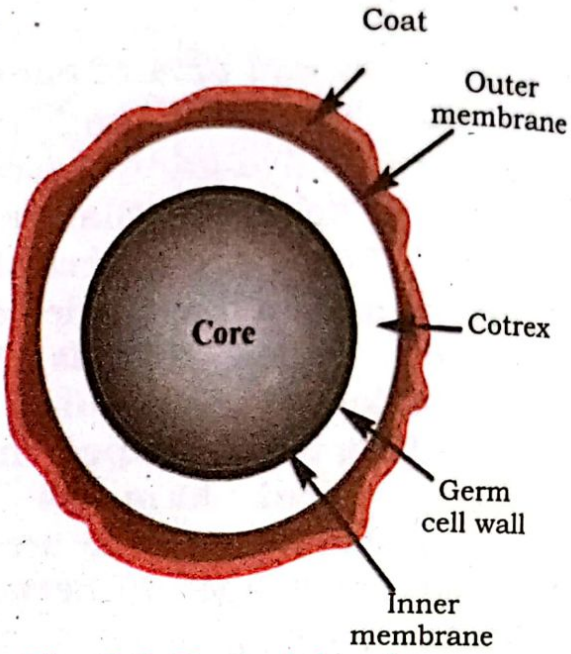



Fig. 6.6. Bacterial endospore

**Endospore development**

In certain bacteria like Clostridium and Bacillus, the cells tide over unfavourable conditions by forming endospores. During this process, a portion of the cytoplasm and a copy of the bacterial chromosome undergo dehydration and get surrounded by a three-layered covering. The remaining part of cytoplasm and cell wall degenerate. The resulting structure, called **endospore** can tolerate extreme environmental conditions and can remain viable for several years. When the environmental conditions become suitable, the endospore absorbs water, swells and the wall splits, releasing the cell inside. It develops a new cell wall and starts functioning as a typical bacterial cell.

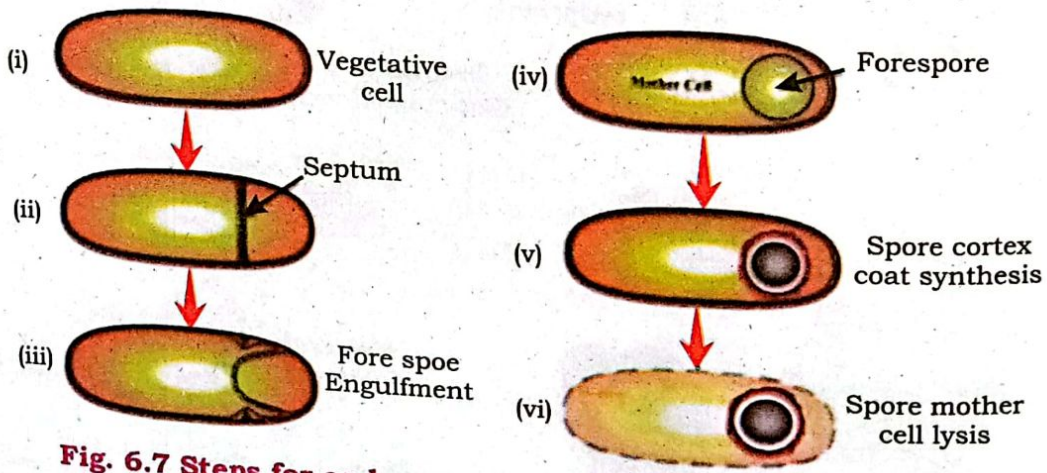



Fig. 6.7 Steps for endospore formation in bacteria

**Some other survival methods of bacteria**

During unfavorable condition, bacteria develop endospores, exospores and cysts, depends on the type of bacteria. The endospore formation is already discussed above. A group of gram +ve bacteria form spores, these bacteria form long tubules called filaments, which differentiate into thick

walled, round structure called exospore. These structures are the part of the reproductive process and formed outside the cell wall e.g. Actinomycytes.

In other type of bacteria like azobacter species, the cyst is formed. These cyst are dormant cells with thick cell wall the cytoplasm contract. The cyst formation occur by changing cell wall. These bacterial cells become resistant to desiccation and some chemical. These cells are not same resistat to temperature like endospore.

### 6.4.3. Motility in bacteria

Movement in bacteria depends on various stimuli in their surroundings like magnetic field, chemicals, light, temperature etc. due to which bacteria express magnetotactic, chemotactic, phototactic, movements respectively. Bacteria moves by its flagella in particular direction towards or away from the stimulus they detect. Flagella are present in different numbers and positions over the cell body. Sometimes bacteria floats with the help of their pili that provides buoyancy to the cell body. Generally, there are three types of movement in bacteria.

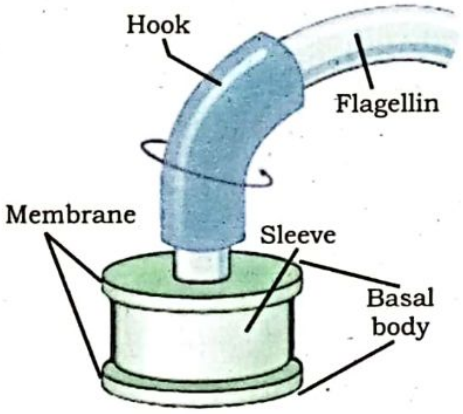



**Fig. 6.8 Direction of movement of bacterial flagella**

#### (a) Flagellar movement:

Bacterial flagella embedded with cell wall by motile and help in locomotion. Prokaryotic flagellum moves the cell by rotating from the basal body either clockwise or counter clockwise around its axis. The helical waves are generated from the base to the tip of flagellum that pushes against water and propels the bacterium.

On the basis of number of flagella bacteria are classified as:

| | | |
|---|---|---|
| Atrichous | bacteria without flagella | |
| Monotrichous | bacteria with single flagella at one pole present. | |
| Lophotrichous | bacteria with a tuft of flagella at one pole present | |
| Amphitrichous | bacteria with a tuft of flagella at each of two poles present | |
| Peritrichous | bacteria are surrounded by flagella | |

**(b) Spirochaetial movement:**

The spirochaetes show several types of movements such as flexing, spinning, free swimming and creeping as they are flexible and helical bacteria lack flagella. Just within the cell envelope they have flagella like structure which are known as periplasmic flagella or axial fibrils or endo-flagella.

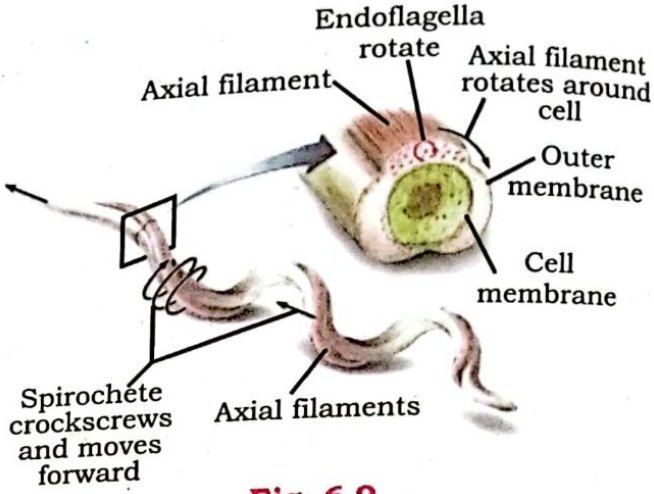



**Fig. 6.9**
**Spirochaetial movement**

**(c) Gliding movement:**

Some bacteria such as the species of cyanobacteria (e.g. Cytophaga) and mycoplasma show gliding movement when come in contact with a solid surface. It helps to find out the substratum e.g., wood, bark, shell, etc. for anchorage and reproduction. They secrete slime with the help of which they get attached to the substratum. However, no organelles are associated with the movement.

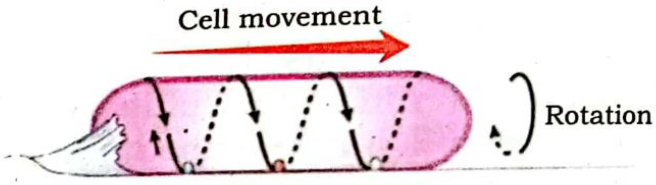



**Fig. 6.10**
**Bacterial gliding movement**

### 6.4.4. Structure of Bacterial Flagellum

Bacterial flagella are long, thin (about 20 nm), whip-like appendages that move the bacteria towards nutrients and other attractants. Flagellum is made up of protein called flagellin. Flagellum has three distinct regions the hook, the filament and the basal body. The wider region at the base of the flagellum is called a hook. It is different in structure than that of the filament. Hook connects filament to the motor portion of the flagellum called a basal body. The basal body anchored in the cytoplasmic membrane and cell wall. It contains the rotating motor, which is powered by ATP and a C ring. The C ring is a proteinaceous cup-shaped structure and attached to the cytoplasmic side of the basal body and works as the rotor of the motor.

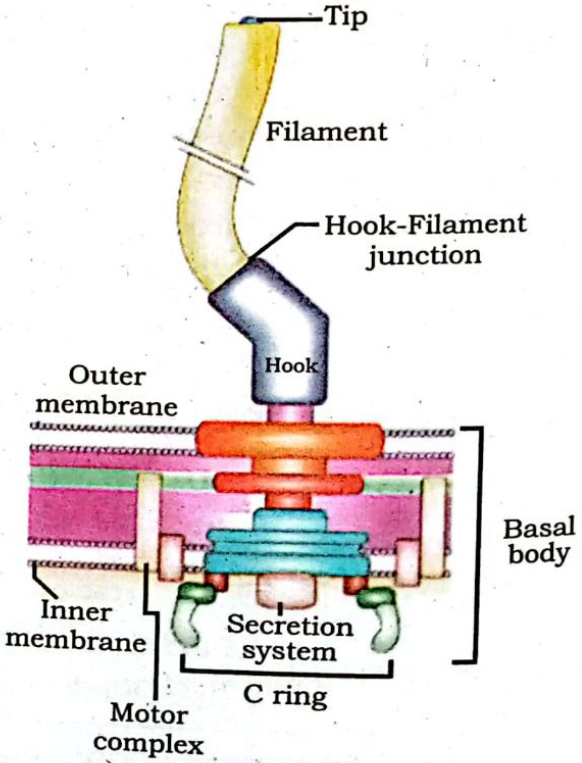



**Fig. 6.11**
**Anatomical structure of bacterial flagella**

## 6.4.5. GENOMIC ORGANIZATION OF BACTERIA

The term genome refers to the sum of an organism's genetic material. The bacterial genome or **nucleoid** is composed of a single molecule of chromosomal deoxyribonucleic acid (DNA) located in a region of bacterial cytoplasm visible under electron microscope. The bacterial chromosome is one long, single molecule of double stranded, helical, supercoiled DNA. In most bacteria, this DNA is circular. Bacterial nucleoid may contain as many as 3500 genes. Unlike the eukaryotic nucleus, the bacterial nucleoid has no nuclear membrane or nucleoli. The bacteria have only one copy of DNA, that is they have only one chromosome and only reproduce asexually, cell divide by amitosis.

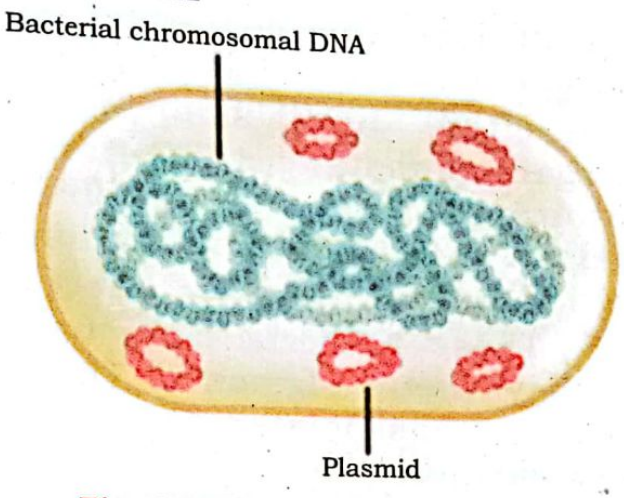
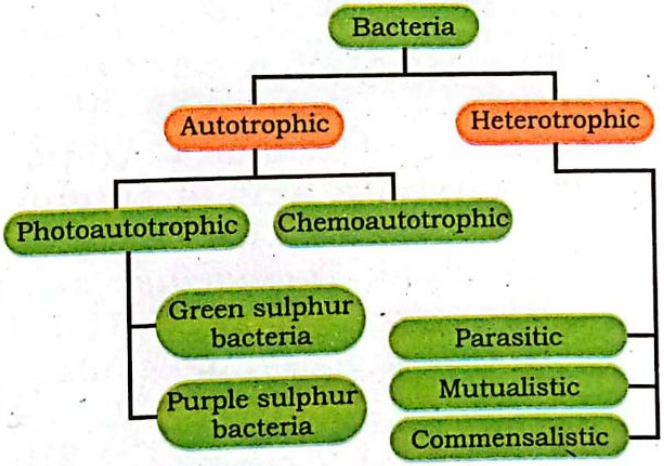


**Fig. 6.12 Bacterial Chromosome**

In addition to the bacterial chromosome, many bacteria often contain small non chromosomal extra circular DNA molecules called **plasmids**. They usually contain between 5 and 100 genes. Plasmids replicate independently of the host chromosome. They are not essential for bacterial growth under normal environmental conditions. The plasmid increases the immunity of bacterial cell. The bacterial plasmid may be use in rDNA technology is carrier of gene.

## 6.5. MODES OF NUTRITION IN BACTERIA

Bacteria require carbon and energy to synthesize their cell components by different processes. They can obtain energy and nutrients in different ways like photosynthesis, chemosynthesis, decomposing of dead organisms and wastes, establishing mutualistic and parasitic relationships. They are classified on the basis of their mode of nutrition into two types, autotrophic bacteria and heterotrophic bacteria.



### 1. Autotrophic bacteria

Autotrophic bacteria synthesize their own food from simple inorganic sources like $CO_2$. In this process, energy is obtained from either sunlight or chemically by the oxidation of some inorganic substances like iron, sulphur, nitrogen compounds, etc. Autotrophic bacteria are further divided into two types on the basis of their energy utilization.

### a. Photoautotrophic Bacteria

These bacteria have bacteriochlorophyll or chlorobium as photosynthetic pigments. These pigments are present in specific vesicles associated with bacterial membrane called **chromatophores.** These bacteria use light energy as a source and hydrogen sulphide or other $H^+$ donor as reducing agent instead of water to make carbohydrates, therefore does not release oxygen but release sulphur as by product.

$$2H_2S + CO_2 \xrightarrow[\text{bacteriochlorophyll}]{\text{Light energy}} (CH_2O)_n + 2H_2O + 2S$$

$$H^+ \text{ donor} + CO_2 \longrightarrow (CH_2O)_2 + 2H_2O + \text{Salt}$$

### b. Chemoautotrophic Bacteria

a. Chemoautotrophic bacteria prepare their food by using inorganic raw material in the absence of photosynthetic pigment.
b. In this process, chemical energy is obtained from the oxidation of certain inorganic substances such as ammonia, nitrates, ferrous ion, hydrogen sulphides, and some metallic and nonmetallic substances.
c. In this reaction, chemical bonds are broken, to release energy, which is used to drive the synthetic processes of the cell.
d. These are again divided into the following types:

#### i) Sulphur Bacteria (Sulphomonas)

These types of bacteria oxidise elemental sulphur or $H_2S$ and release sulphuric acid or sulphur.

$$2S + 2H_2O + 3O_2 \rightarrow 2H_2O + 2S + \text{Energy}$$

**Example:** *Thiobacillus denitrificans*

#### ii) Hydrogen Bacteria (Hydromonas)

In this process, molecular hydrogen is oxidized into water.

$$2H_2 + O_2 \rightarrow 2H_2O + \text{Energy}$$

$$4H_2 + CO_2 \rightarrow 2H_2O + CH_4 + \text{Energy}$$

**Example:** *Hydrogenomonas, Pseudomonas.*

iii) **Iron Bacteria (Ferromonas)**

They use chemical energy by oxidation of ferrous compounds into the ferric compounds.

$$4FeCO_3 + 6H_2O + O_2 \rightarrow 4Fe(OH)_3 + 4CO_2 + \text{Energy}$$

**Example:** *Thiobacillus, Ferrobacillus*, etc.

iv) **Methane Bacteria (Methanomonas)**

These types of bacteria get their energy from the oxidation of methane; byproducts are water and carbon dioxide.

v) **Nitrifying Bacteria (Nitrosomonas)**

Bacteria get their energy by oxidation of nitrogen compounds into nitrates.

$$2NO_2 + O_2 \rightarrow 2NO_3 + \text{Energy}$$

**Example:** *Nitrobacter, Nitrosomonas.*

vi) **Carbon Bacteria:**

These types of bacteria oxidize CO into $CO_2$.

$$2CO + O_2 \rightarrow 2CO_2 + \text{Energy}$$

**Example:** *Bacillus oligocarbophillous*

2. **Heterotrophic Bacteria**

Heterotrophic bacteria do not have photosynthetic pigments and are not capable of synthesizing their own food from organic or inorganic compounds. They are of three types:

a. **Saprotrophic Bacteria**

Saprotrophic bacteria obtain food by decaying matter (humus) and dead organisms. They secrete enzymes that break down complex organic compounds into simpler products which are then absorbed as nutrients, for example *Bacillus mycides, Azotobacter.*

b. **Parasitic Bacteria**

Parasitic bacteria live on and within the body of other living organisms and gets nutrition from them. During their living they harm their host and cause different diseases in both animals and plants hence they are called pathogenic bacteria, e.g., *Vibrio cholerae, Diplococcus pneumoniae*, etc.

c. **Mutualistic Bacteria**

Mutualistic bacteria live in close association with other living organisms so that they both benefit from each other so neither of them is harmed. Symbiotic bacteria fix free atmospheric nitrogen into nitrogenous compounds which are utilized by the plants, and in return, the plant gives nutrients and protection to the bacteria. For example, nitrogen fixing bacteria like *Rhizobium, Bacillus spp., Clostridium* that lives in the root nodules of leguminous plants as mutualists.

**6.5.1. Differentiate between the photosynthesis mechanisms in cyanobacteria and other photosynthetic bacteria.**

| Photosynthesis in cyanobacteria | Photosynthesis in bacteria |
|---|---|
| These are oxygenic prokaryotes | These are non-oxygenic bacteria |
| Utilize $H_2O$ as $H^+$ donor | Utilize $H_2O$ or organic acids as $H^+$ donor |
| Have chlorophyll as necessary pigment | Have bacteriochlorophyll |
| Have only one type of photosynthetic mechanism | Have different mode of photosynthetic mechanism according to environmental condition |

## 6.6. GROWTH AND REPRODUCTION IN BACTERIA

### 6.6.1. Growth in bacteria

Growth of bacterial cultures is defined as an increase in the number of bacteria in a population rather than in the size of individual cells. The growth of a bacterial population occurs in a geometric or exponential manner. Exponential describes a very rapid increase.

**1. Lag Phase**

The word **lag** describes a kind of slowness or delay. Immediately after providing fresh nutritive medium, the bacterial population initially remains unchanged. Although there is no apparent cell division occurring but the cells growing in volume or mass.

**2. Exponential (log) Phase**

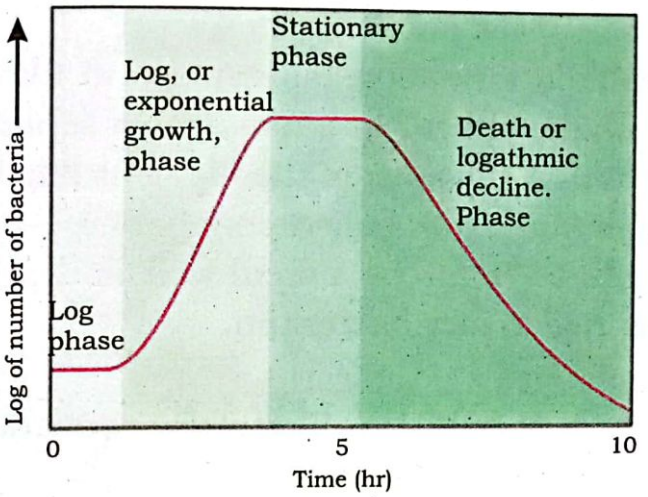
The exponential phase of growth is a pattern of balanced growth where in all the cells are dividing regularly and rapidly by binary fission. The cells divide at a constant rate depending upon the composition of the growth medium and the conditions of incubation. The growth of bacteria is very high during this phase.

**3. Stationary Phase**

The log phase of bacterial growth is followed by the stationary phase, in which the size of a population of bacteria remains constant, increase in bacterial population has simply stopped. In this phase rate of reproduction is equal to rate of death.

**4. Death Phase**

If incubation continues after the population reaches stationary phase, a death phase follows, in which the viable cell population declines. During this rate of death is higher than rate of reproduction. This phase ends at complete exhaustion of nutrients.




**Graph 6.13 Growth in bacteria**

### 6.6.2. Reproduction in Bacteria

Bacteria being prokaryotic organism reproduce by asexual methods. Sometime bacteria can perform genetic recombination. Bacterial modes of reproduction are as follows.

**Asexual reproduction in bacteria**

The following methods by which asexual reproduction in bacteria takes place. The methods are:

1. Binary Fission 2. Conidia 3. Budding.

**1. Binary Fission**

It is the most common and fastest mode of asexual reproduction in bacteria. In binary fission, single cell divides into two equal cells (Fig. 6.14). Before binary fission occurs, the cell must copy its genetic material (DNA). The double stranded DNA molecule i.e., incipient nuclei, are then distributed into two poles of the dividing cell without spindle formation, a transverse septum develops and cytoplasm is cleaved in two regions of the cell from the middle separating the two daughter cells. In many bacteria, new cell wall is synthesized. The binary fission is a rapid process and cell undergoes division at an interval of 20-30 minutes.

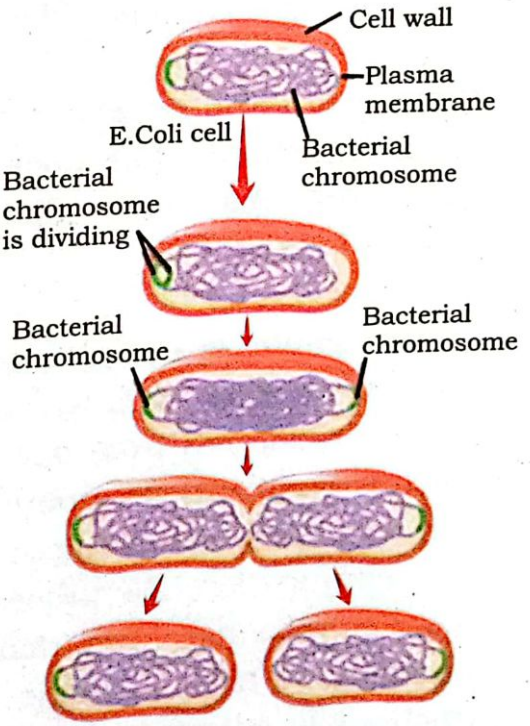



**Fig. 6.14.**
**Binary fission in *E. coli* bacteria**

**2. Conidia:**

Like fungi conidia formation takes place in filamentous bacteria like *Streptomyces* etc. conidia appear as small spores separated by the formation of a transverse septum at the apex of the filament (Fig 6.15). The part of this filament which bears conidia is called conidiophore. After maturity conidia detached as a fragment from the parent cell and germinates on suitable substratum to gives rise to new bacterium.

**3. Budding:**

Budding has been observed in some members of the Planctomycetes, Cyanobacteria etc. In budding the bacterial cell develops small swelling at one side which gradually increases in size. Simultaneously the nucleic material undergoes division, where one remains with the mother cell and other one with some cytoplasm goes to the swelling. This outgrowth is the bud, which gets separated from the mother by partition wall, e.g., *Hyphomicrobium vulgare*, *Rhodomicrobium vannielia*, etc.

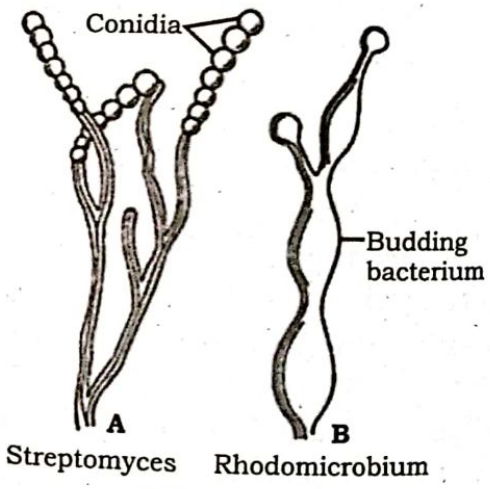



**Fig. 6.15.**
**Budding in bacteria**

### 6.6.3. Mutation and genetic recombination in bacteria

Sexual reproduction does not take place in bacteria however genetic recombinations may take place accidently and regularly which causes mutation in bacteria.

**1. Conjugation**

Conjugation is the process by which one bacterium transfers genetic material to another through direct contact. During this process, DNA plasmid is transferred from one bacterium (the donor) of a mating pair into another (the recipient) via a pilus or cytoplasmic bridge.

It is a parasexual mode of reproduction in bacteria. However, in bacterial conjugation, the process involves transfer of only a portion of the genome i.e., plasmid from donor to recipient cell unlike regular sexual reproduction. Thus, genetic transfer in bacterial conjugation is unidirectionally followed by separation of the cells and further changes in the organization or recombination of the combined genetic material within

the recipient cell. While new cell in not formed therefore it is not completely considered as sexual mode of reproduction.

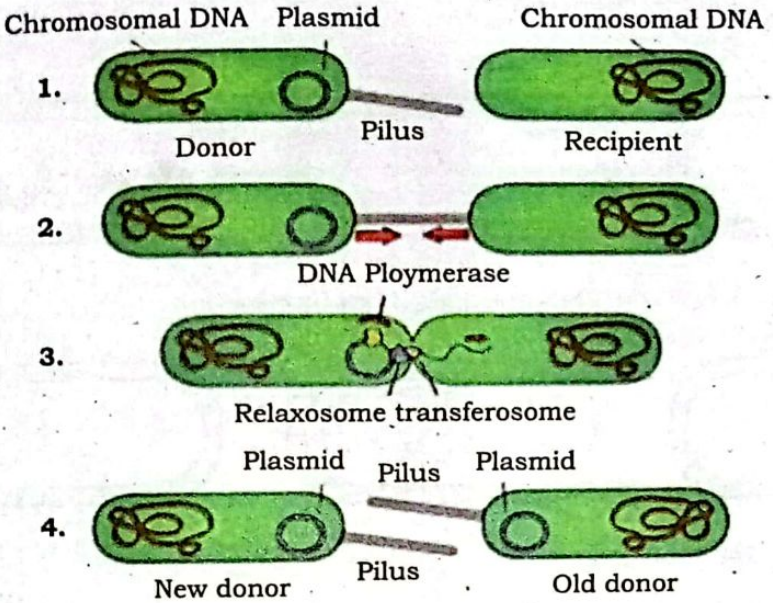



Fig. 6.16 Conjugation

## 2. Transformation

In transformation, a bacterium takes in DNA from its environment, often DNA that's been shed by other bacteria. In a laboratory, the DNA may be introduced by scientists. If the DNA is in the form of a circular DNA called a plasmid, it can be copied in the receiving cell and passed on to its descendants.

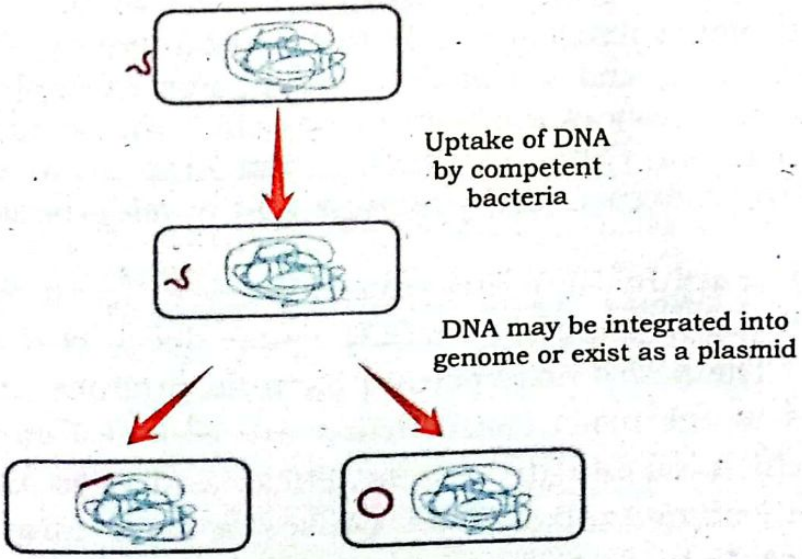



Fig. 6.17 Bacterial transformation

### 3. Transduction

A process in which genetic material is transferred by phage between two bacteria is called transduction.

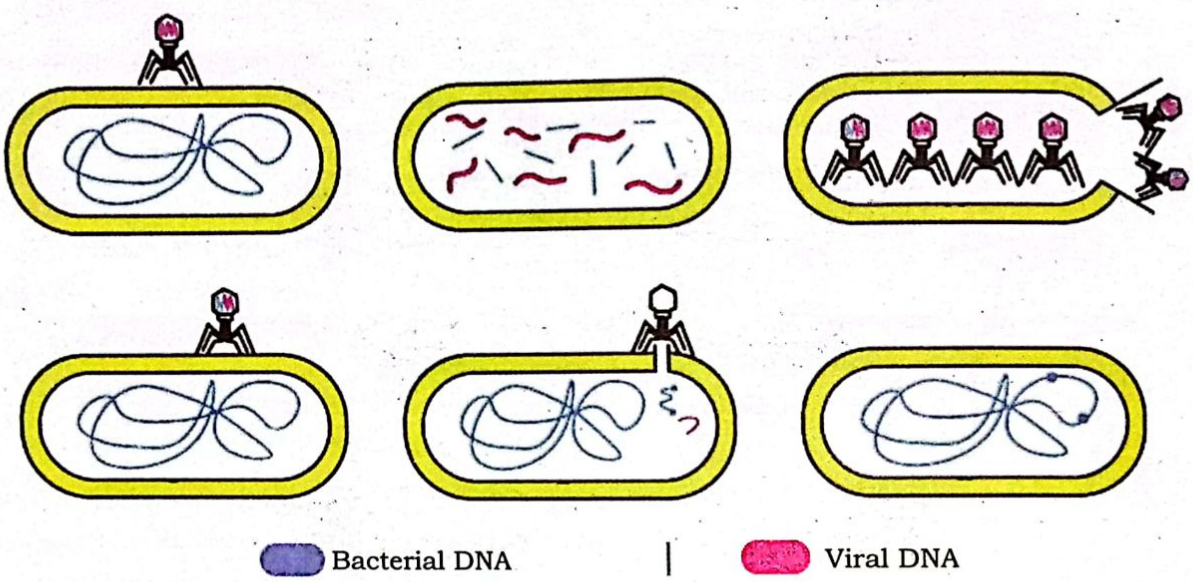



**Fig. 6.18 Bacterial transduction**

## 6.7. IMPORTANCE OF BACTERIA

Bacteria are both useful and harmful to us. Bacteria are economically important as these microorganisms are used by humans for many purposes. The beneficial uses of bacteria include the production of traditional foods such as yogurt, cheese, and vinegar. Microbes are also important in agriculture for the fertilizer production. Bacteria decompose organic matter and release minerals into the environment. *Rhizobium leguminosarum* as symbiont and perform nitrogen fixation in the roots of leguminous plants due to which plants flourish and increase productivity. Bacteria are used in genetic engineering and medical research. For example *Escherichia coli* is used for the synthesis of antibiotic amoxicillin and commercial preparation of riboflavin (vitamin $B_2$) and vitamin K. Bacterial plasmid is used in genetic engineering to produce useful products and develop beneficial characters in organism

Bacteria are harmful like causes diseases in animals and plants and spoil food. Some saprophytic bacteria cause decay of our food and make it unpalatable. The activities of certain bacteria produce powerful toxins such as ptomains in the food. These toxins are powerful enough to cause food poisoning which results in serious illness and even death. For example, bacterium *Clostridium botulinum* causes a fatal form of food-poisoning known as **botulism**. The diseases caused by bacteria in man and plants are shown in the table given below

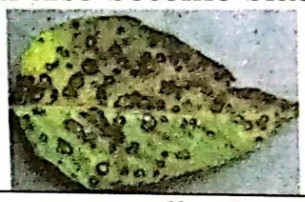
## 6.7.1. Bacterial diseases in Man

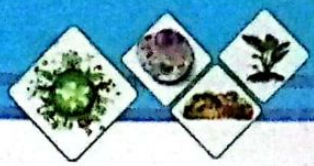
Table. 6.6. Bacterial diseases in man

| Bacterial diseases in Man | | | | |
|---|---|---|---|---|
| | **Name of disease** | **Cause** | **Signs and symptoms** | **Treatment and prevention** |
| 1. | Cholera | Bacterium *Vibrio Cholera* | Diarrhea, Nausea and vomiting, Sleepiness or lethargy, Dehydration, Muscle cramps, Electrolyte imbalance, thirst, Dry skin, dry mucous membrane, and dry mouth. | Drink rehydration solution (ORS) and take antibiotics. |
| 2. | Typhoid | bacterium *Salmonella typhi* | High grade fever and skin rash, weakness, abdominal pain, constipation, headaches. | Proper wash hands drink clean water, eat properly cooked food visit doctor if symptoms persist. |
| 3 | Tuberculosis | Bacterium *Mycobacterium tuberculosis* | cough that produces phlegm, fatigue, a fever, chills, and a loss of appetite and weight. | staying away from crowdy and congested places wearing a mask and sanitize yourself. |
| 4. | Pneumonia | Bacterium *Streptococcus pneumoniae* | coughing with blood and mucus, fever, sweating or chills, shortness of breath, chest pain, fatigue, loss of appetite, nausea or vomiting and headaches. | Properly wash hands, eat clean and properly cooked food, do exercise, quit smoking. |

## 6.7.2. Bacterial diseases in Plants

**Table. 6.7 Bacterial diseases in plants**

| Bacterial diseases in Plants | | | | |
|---|---|---|---|---|
| | **Name of disease** | **Cause** | **Signs and symptoms** | **Treatment and prevention** |
| 1. | Bacteria Leaf Spots | Bacteria *Pseudomonas* and *Xanthomonas* | Necrosis, sometimes leaf spots will grow together creating large black blotches on leaves or turning leaves completely black. Shoots, buds and flowers can also become black.  | Eradication of pathogen by using pathogen-tested seeds and propagated materials and proper spray. |
| 2. | Blights in plants by bacteria | *Erwinia amylovora,* and *Xanthomonas oryzae.* | severe yellowing, browning, spotting, withering, or dying of leaves, flowers, fruit, stems, parenchyma cells damge.  | Chemical control less effective then Biological control methods. |
| 3 | Bacterial soft rots | Bacterium *Erwinia carotovora* | plant tissue becomes macerated (soft and watery).  | Proper inspection of plant seeds, control weeds, avoid harvesting under wet conditions, Avoid bruising |
| 4. | Bacterial Wilt diseases in plants | Bacterium *Erwinia tracheiphila* | Wilt diseases caused by blocking of the vessels of host plant by masses of bacteria as a result plant wilt and dies. | Control of bacterial wilt depends on control of its insect beetle vectors. Use of insecticides. |



## 6.8. THE BACTERIAL FLORA OF HUMANS

The human body is not sterile; we become colonized by bacteria from the moment we are born. We are covered with, and contain within our intestines, approximately one hundred trillion bacteria that form the normal flora of our bodies. This normal flora helps to prevent us becoming colonized with more dangerous bacteria, which might lead to infection.

### 6.8.1 The normal flora

Normal flora are the microorganisms that live on another living organism (human or animal) or inanimate object without causing disease. In a healthy animal, the internal tissues, e.g. blood, brain, muscle, etc., are normally free of microorganisms. However, the surface tissues, i.e., skin and mucous membranes, are constantly in contact with environmental organisms and become readily colonized by various microbial species. The mixture of organisms regularly found at any anatomical site is referred to as the **normal flora**. The normal flora of humans consists of a few eucaryotic fungi and protists, but bacteria are the most numerous and obvious microbial components of the normal flora.

### 6.8.2. Significance of the normal flora

These normal floras provide us with many benefits. They prevent colonization by pathogens by competing for attachment & nutrients. They stimulate production of antibodies. Since the normal flora behave as antigens in an animal, they induce low levels of antibodies that cross react with similar antigens on pathogens, preventing infection or invasion. In large intestine some synthesize vitamins that are absorbed as nutrients by the host (e.g., vitamin K & B12). Some bacteria produce substances that inhibit pathogenic species.

## 6.9. CONTROL OF HARMFUL BACTERIA

**The chemical and physical methods used to control harmful bacteria.**

### 6.9.1. Chemical methods to control harmful bacteria

Bacterial harmful activities can be controlled by certain chemicals referred as disinfectants, antiseptics, antibiotics, and antimicrobial chemicals.

1. **Sterilization** is the process of destroying all living organisms and viruses.
2. **Disinfection** is the elimination of microorganisms, but not necessarily endospores, from inanimate objects or surfaces. An ideal disinfectant or antiseptic (chemical agent) kills microorganisms in the shortest possible time without damaging the material treated.

   There are different chemical that are used as disinfectant some are as follows:

a) **Phenol:** One of the first chemicals to be used for disinfection was phenol. First used by Joseph Lister in the 1860s, it is the standard for most other antiseptics and disinfectants.

b) **Halogens:** Among the halogen antiseptics and disinfectants are chlorine and iodine.

c) **Heavy metals:** A number of heavy metals have antimicrobial ability. For example, silver is used as silver nitrate in the eyes of newborns to guard against infection by *Neisseria gonorrhea*.

d) **Soaps and detergents:** Soaps and detergents decrease the surface tension between microorganisms and surfaces, and thereby help cleanse the surface.

e) **Aldehydes:** Two aldehydes, formaldehyde and glutaraldehyde, inactivate microbial proteins by crosslinking the functional groups in the proteins.

f) **Ethylene oxide:** Sterilization can be achieved with a chemical known as ethylene oxide (ETO). This chemical denatures proteins and destroys all microorganisms, including bacterial spores.

g) **Oxidizing agents:** Oxidizing agents such as hydrogen peroxide kill microorganisms by releasing large amounts of oxygen, which contributes to the alteration of microbial enzymes.

h) **Food preservatives:** Foods can be preserved by using a number of organic acids to maintain a low microbial population. Benzoic acid, Sorbic acid etc.

3. **The use of Antibiotics**

Antibiotics are compounds that are mostly derived from biosynthesis of other microorganisms. *Streptomyces* and *Penicillium* are two organisms which have given us antibiotics. Antibiotics act in different ways to kill microorganisms like

- Antibiotics that inhibit cell wall synthesis
- Antibiotics that inhibit protein synthesis
- Antibiotics that Inhibit Nucleic Acid Synthesis or DNA Replication
- Antibiotics that Interfere with Metabolic Pathways

### 6.9.2. Physical methods to control harmful bacteria

**Boiling:** 100 °C denatures proteins and alters membranes and destroy bacteria ex. Cooking,

**Dry-heat oven:** 170 °C for 2 hours, denature proteins and alters membranes,

**Incineration:** Exposure to flame or destroy bacteria by burning.

**Autoclave:** Heating at very high temperature like 121 °C for 15–40 minutes at 15 psi, denature proteins and alters membranes.

**Pasteurization:** 72 °C for 15 seconds 138 °C for 2 seconds (UHT), Denatures proteins and alters membranes it prevents spoilage of milk, apple juice, honey, and other ingestible liquids

**Refrigeration:** Temperature 0 °C to 7 °C, Inhibits metabolism, Preservation of food or laboratory materials.

**Freezing:** Below −2 °C, stops metabolism, may kill microbes, Long-term storage of food, laboratory cultures, or medical specimens.

**High-pressure processing:** Exposure to pressures of 100–800 MPa, denatures proteins and can cause cell lysis, Preservation of food

**Hyperbaric oxygen therapy:** Inhalation of pure oxygen at a pressure of 1–3 atm, Inhibits metabolism and growth of anaerobic microbes, Treatment of certain infections (e.g., gas gangrene).

**Simple desiccation:** Drying, Inhibits metabolism, Dried fruits, jerky. Reduce water activity: Addition of salt or water, inhibit metabolism and can cause lysis.

**Lyophilization:** Rapid freezing under vacuum, inhibits metabolism and preserve food this method is used in laboratory cultures, or reagents

**Ionizing radiation:** Exposure to X-rays or gamma rays alters molecular structures, introduces double-strand breaks into DNA.

**Membrane filtration:** use of membrane filter with 0.2-µm or smaller pore size, physically removes microbes from liquid solutions. It is used in removal of bacteria from heat-sensitive solutions like vitamins, antibiotics, and media with heat-sensitive components

**Nonionizing radiation:** Exposure to ultraviolet light Introduces thymine dimers causes mutations in bacteria used for surface sterilization of laboratory materials, water purification

**2. Write short answers of the following questions:**

1. Explain the structure of bacteria in detail with labelled diagram.
2. Explain the Autotrophic mode of nutrition in bacteria.
3. Explain the photosynthesis mechanism in bacteria.
4. Explain the economic importance of bacteria.
5. Explain the bacterial diseases in Man with their signs, symptoms, treatment and prevention.
6. Explain the bacterial diseases in plants with their signs, symptoms, treatment and prevention
7. What do you mean by bacterial growth? Describe its phases.

**3. Write detailed answers of the following questions:**

1. What are the domains of classification? Differentiate them.
2. What are protobionts? Discuss their relationship [p with prokaryotes.
3. What are the extreme conditions Archea called?
4. Differentiate between gram-positive and gram-negative bacteria.
5. Give the structure of peptidoglycan of bacterial cell wall.
6. Differentiate between transformation and transduction in bacteria.
7. Why bacteria called recycling agent in nature?
8. How bacteria increase soil fertility? Give example.
9. How cholera and typhoid spread in human population?
10. What do we mean by normal flora of bacteria?
11. List down the physical and chemical methods to control bacteria.

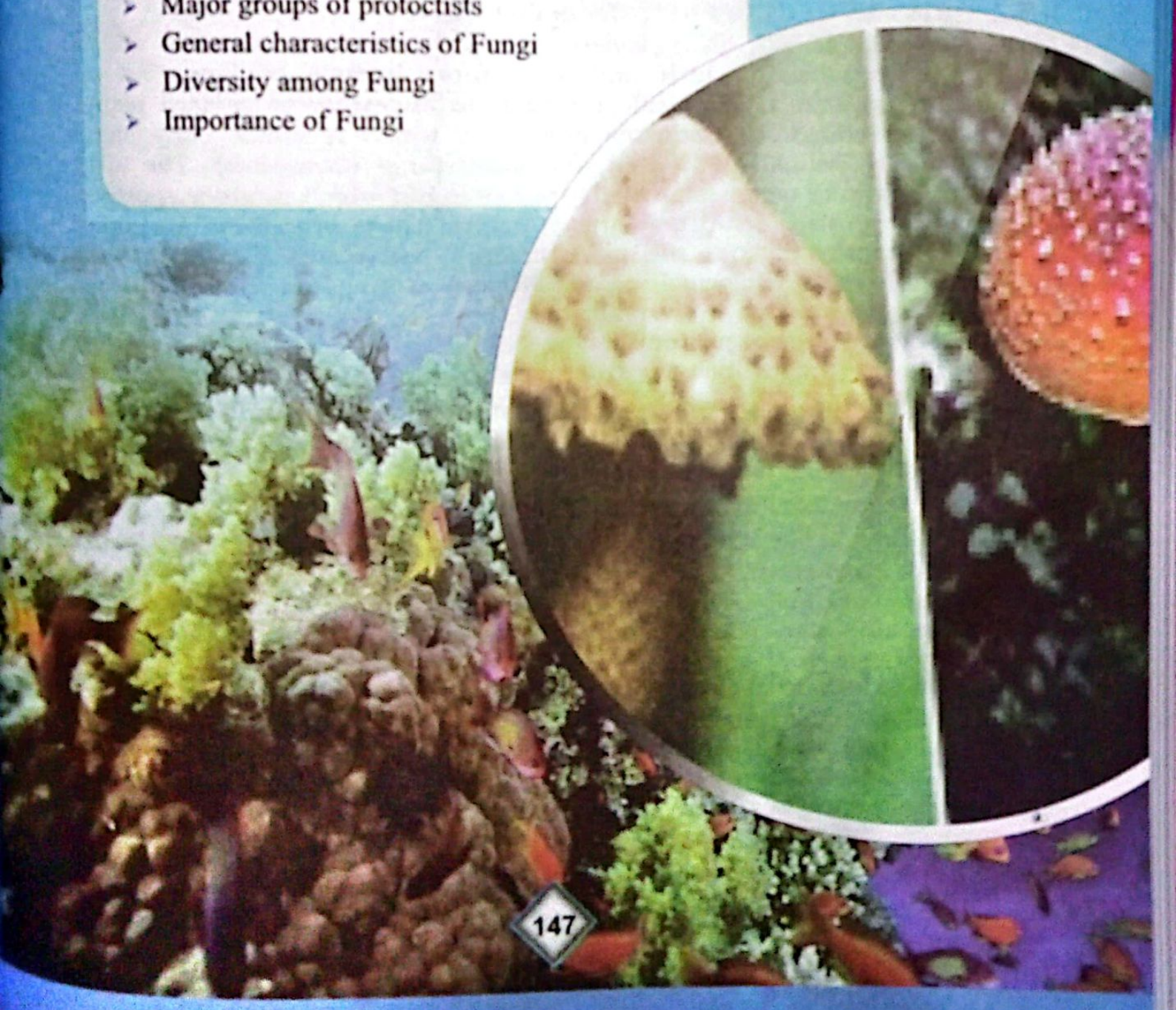
# PROTOCTISTS AND FUNGI

Chapter 7

## Major Concept

**In this Unit you will learn:**

- protoctists - The Evolutionary Relationships
- Major groups of protoctists
- General characteristics of Fungi
- Diversity among Fungi
- Importance of Fungi



## Protoctists and Fungi

### Kingdom Protoctista:

The kingdom protoctista is the most controversial and unnatural group. It includes an immense variety of organisms. It contains eukaryotes that are generally regarded as identical or similar to the ancestors of modern plants, animals and fungi. Protoctists are characterized by eukaryotic cell with simple body structure. Most protoctists are single celled, but there are number of important multicellular species also belong to this group. Protoctists may be photosynthetic, parasitic, predatory or absorptive. The Kingdom includes heterotrophic microorganisms, such as Amoeba and paramecium, and autotrophc form like algae, euglena, as well as, *Plasmodium* and *Trypanosoma,* the parasites which cause malaria and sleeping sickness respectively .

### 7.1 THE EVOLUTIONARY RELATIONSHIP:

Protista is not monophyletic group because it contains all the eukaryotic organisms which are not plants, animals or fungi but are generally regarded as identical or similar to ancestors of modern plants, animals and .fungi. It comprises organisms which resemble early plants (Algae), early animals (Protozoa) and early fungi (Oomycota) .The slime molds, a group of organisms which are motile but which produce spores in sporangia are also included in the protoctis. These organisms are linked between prokaryotic and the more modern eukaryotes like plants and animals. Therefore Biologists regard (Propetista) kingdom as a polyphletic group of organisms due to diversification.

#### 7.1.1 Major groups of protoctista:

The Protoctista includes three groups which formerly had separate taxonomic status, and which are now containing organisms of a widely different origin to be placed in one kingdom. The three groups are.

i. Plant Like Protoctista ------ Algae
ii. Fungi like Protoctista------ Primitive Fungi.
iii. Animal like Protoctista----- Protozoa

### Plant Like Protoctista ------ Algae:

Algae are photosynthetic protoctists with unicellular, colonial or simple multicellular structure. Most algae are aquatic while others may be found on moist soil, trees and rocks. However they differ from vascular plants by lacking true roots, stem and leaves but share the following plant like characteristics.

(i) The cell wall is present and have composition like plant cell wall.
(ii) Their cytoplasm usually contains one or more large vacuoles.
(iii) They contain photosynthetic pigments enclosed in plastids, of which chloroplasts are the commonest type.

(iv) Sexual reproduction is common and involves alternation of generation between haploid and diploid individuals in the life cycle of some algae.

These plant like characters of algae presumed close evolutionary link with plants.

Many different algal groups can be distinguished according to their structure, mode of life styles and by the presence of particular photosynthetic pigments or storage material. The scientific study of algae is called **Phycology**.

i. On the basis of photosynthetic pigment, algae are classified into following major groups

| Group | Common name | Major pigments | Example |
|---|---|---|---|
| 1. Chlorophyta | Green algae | Chlorophyll-a and b | Chlamydmones, ulva, volvox |
| 2. phaeophyta | Brown algae | Chlorophyll-a, c, fucoxanthin | Fucus, Laminaria |
| 3. Rhodophyta | Red algae | Chlorophyll-a, Phycobilin, Pigments, Phycocyanin and Phycoerythrin producing typical red coloured. | Porphyra |

**Ulva:**

It is a marine alga commonly called "sea-lettuce". It is found growing along the sea coasts between high and low tides. It is found attached to rocky edge of Manora and Kemari areas of Karachi coast. The body called thallus is composed of elongated wrinkled blade about 30 cms. Long It is attached to rock and other objects, in the sea by means of hold fast , consisting of long thread like cells. The thallus is very thin only two layers of cells in thickness.

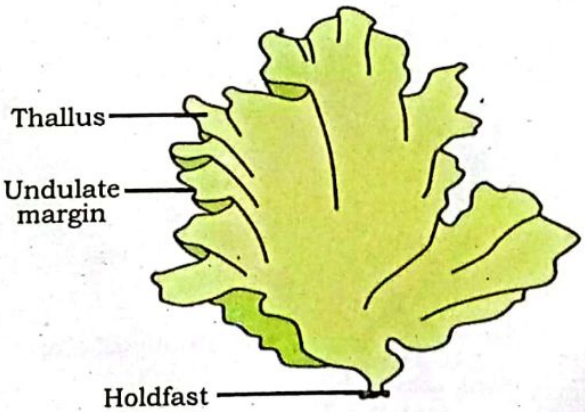



**Fig: 7.1 Morphology of Ulva**

Thallus in Ulva is of two types. The one with 26 chromosomes is called **sporophyte** and the other with 13 chromosomes is called **gametophyte**. Morphologically both gametophyte and sporophyte exactly alike hence called **isomorphic.**

**Ulva** reproduces asexually as well as sexually, alternatively.

**Asexual reproduction:**

Asexual reproduction takes place in asexual Ulva (Diploid sporophyte with 26 chromosomes or 2n) by producing quadri-flagellated zoospores . These spores are formed by meiosis in all cells of the body(thallus) except the basal cells.Eight to sixteen haploid zoospores are formed in a single parent cell. The zoospore production continues until all the cells are used and nothing remains of the thallus blade but a filmy mass of empty cell-walls liberation of zoospores usually takes place at the time when the plant is reflooded by an incoming tide. The liberated haploid zoospores after a period of swimming and rest lose their flagella and grow into gametophyte Ulva thalli.

**Sexual Reproduction:**

Sexual reproduction is **isogamous** the type of sexual reproduction takes place by the fusion of morphologically and physiologically similar gametes. The gametes are biflagellated and produced in sexual plant (haploid gametophytes with 13 chromosomes (n). These gametes are smaller than the zoospores. The fusion takes place only between two haploid gametes which are similar in structure produced by different thalli. The fusion results in the formation of quadriflagellated diploid zygote which, after a period of swimming and rest loses its flagella and secretes a wall and after repeated divisions it develops into another Ulva thallus (Sporophyte), which is similar to sexual thallus (Gametophyte) in morphology.

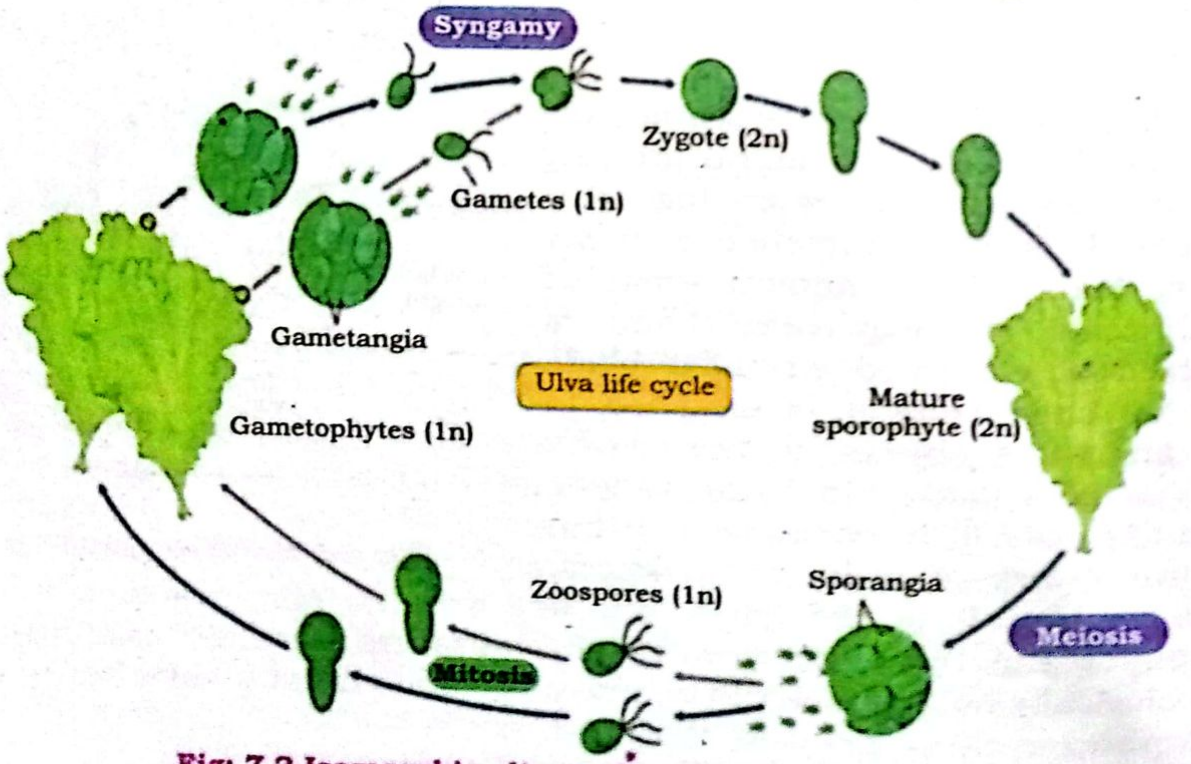



**Fig: 7.2 Isomorphic alternation of generation in Ulva**

### Alternation of Generation in Ulva:

Alternation of generation means the type of life cycle where asexual reproduction alternate with sexual reproduction. It shows there is distinct and regular isomorphic alternation of generation. The haploid gametophyte alternates with diploid sporophyte which are similar in morphology but differ in chromosome numbers.

Green algae are a diverse group that have some of the same characteristics as plant. The haplontic life cycle is typical but Ulva has a life cycle that has 2 distinct generations, like that of plants.

### 7.1.2 Fungi like Protoctista:

These organisms superficially resemble to fungi. The body called **mycelium** consists of network of hyphae. Many of them have centrioles and cell wall having cellulose. They are heterotrophic absorptive feeders. They also reproduce by spores. Most of the members of this group are non motile but few develop movement at some stages in their lives.

Major groups of fungi like protoctista are slime molds and water molds.

### Slime Mold:- ( Myxomycota)

(Motile like animals and produce spores like fungi)

Slime molds are amoeboid protoctists that produce fruiting bodies, i.e. sorocarps as a part of their life history. They were often classified with fungi because they absorb nutrients directly from the environment.

The term slime mold refers to the habit of the most conspicuous part of life the cycle, which is a small slimy mass.

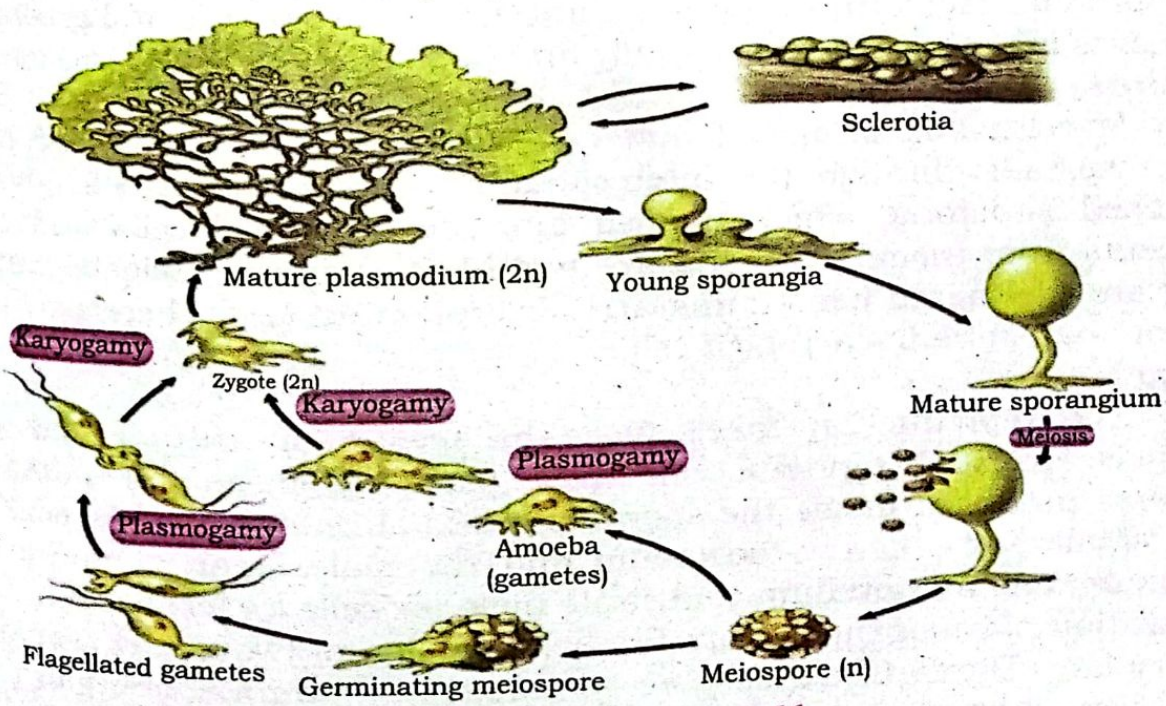
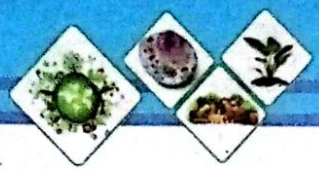



**Fig: 7.3 Life cycle of slime mold**



A slime mold is a strange and truly wonderful thing, its structure and behavior have raised many questions. At one stage in their life cycle, some species of slime molds are creeping masses of living substance. The movement of this living thing bring to mind a giant amoeba. This amoeboid stage of slime mold is called plasmodium. The Plasmodium consists of cytoplasm in which are embedded many nuclei, food vacuoles, and undigested food particles. Plasmodium move along the forest floor on to dead leaves absorbed sunlight. In this dry, often warm environment a miraculous metamorphosis takes place. In a matter of hours, the plasmodium changes into clusters of fruiting bodies called sporangia. Part of each sporangium called capsule produces a large number of microscopic, asexual reproductive cells called spores.

If we observe only the plasmodium we would certainly called slime mold an animal. If fruiting bodies and spores were the only the parts we could see, we would call the organism a plant.

**Water Molds:** (Oomycetes)

Oomycetes are so named for their distinctive oogonium, the female reproductive structure.

Oomycetes are close relatives of the fungi. Their hyphae are aseptate, coenocytic. Oomycetes are different from fungi, however, in that cell walls are cellulosic rather than chitinous.

**Phytophthora infestans:**

It is an example of water mold. It is a pathogenic organism causing late blight of potato and characterized by decay stem and potato tuber. The phytophthora mycelium stays over winters in potato tubers and grows up to the leaves in spring. Blight is usually first noticed in the leaves in August.

**Structure of mycelium:**

Mycelium is branched and consist of aseptate coenocytic hyphae which spreads through the intercellular spaces of the leaves, giving off branched haustoria, which pushed into the mesophyll cells and absorb nutrients from them. Haustoria are typical structure of obligate parasites. They are specialized penetrating and absorption devices. There may be one or more haustoria in each host cell.

**Reproduction:**

The reproduction takes place by means of asexual and sexual methods. Asexual reproduction takes place by means of biflagellated zoopores produced inside the sporangia. Sexual reproduction is oogamous. The female sex organ is oogonium and the male organ is antheridium. Oogonium and antheridium contribute their sex cells for fertilization. During fertilization plasmogamy occurs first while fusion of two nuclei (Karyogamy) is very late. The fertilized oospore germinates to form a sporangium at the tip of germ tube.

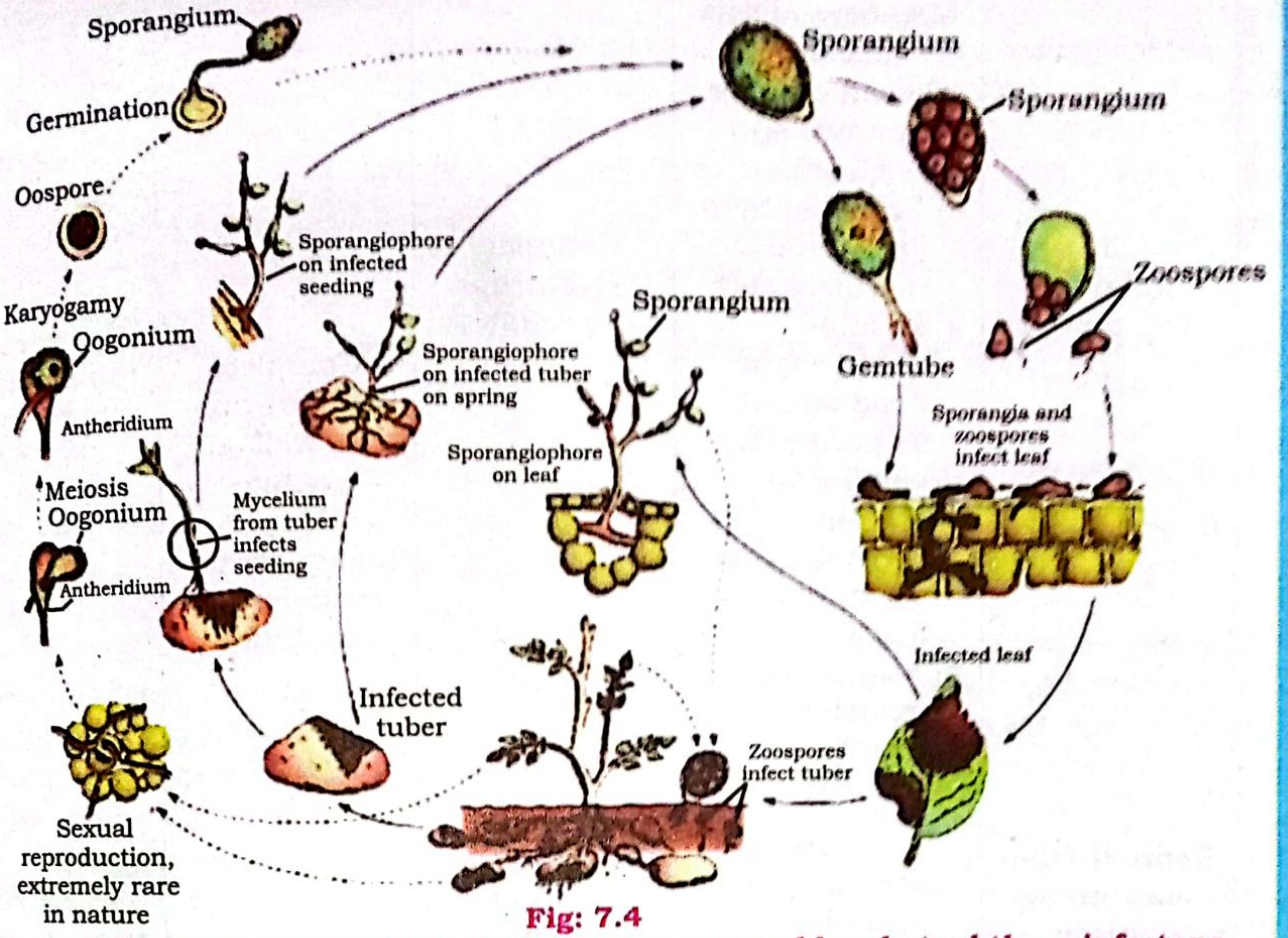



**Fig: 7.4**

**Disease cycle of late blight of potato and tomato caused by phytophthora infestans**

### 7.1.3 Animal like Protoctista ----- Protozoa:

Protozoans form a large group of protoctista. They are unicellular animal like organisms with ingestive heterotrophic nutrition. They are found in all environments where water is present .Most are free living and there are various methods of locomotion

Members of this group of protozoa are divided into five classes which differ in their means of locomotion.

i. Class Sarcodina (Rhizopoda)
ii. Class Flagellata (Mastigophora)
iii. Class Ciliata (Ciliophora)
iv. Class Suctoria
v. Class Sporozoa

| Class Sarcodina (Rhizopoda) | Class Flagellata (Mastigophora) | Class Ciliata (Ciliophora) | Class Suctoria | Class Sporozoa |
|---|---|---|---|---|
| Have pseudopodia a locomotory structure | Member of this class have one or more flagella as locomotory structure. | Have cilia as locomotory structure | Have cilia at early stage of life but become sedenatory at adult stage | No locomotory structure at any stage of life |

| | | | | |
|---|---|---|---|---|
| Parasite and holozoic cytoplasm | Members of this class may classify further into two sub classes<br>a) Englenophyta<br>Fresh and marine water<br>Mainly phototrophs<br>Food stored as paramylon (similar to starch)<br>Reproduction-asexual e.g. Euglena.<br>b) Sub class zoomastigonia<br>Mostly parasite | Complete heterotroph i.e. predatory | Complete heterotroph as well as predator<br>Have cytoplasmic tenticles for predation | Majority are intra cellular parasites |
| Reproduction asexual by binary fission<br>Sexual by gametic fussion | Reproduction, asexual and sexual. e.g. | Reproduction asexual by binary fission<br>Sexual by conjugation reproduction | Reproduction asexual by binary fission<br>Sexual reproduction by conjugation | Reproduction asexual by spores and fission<br>Sexual reproduction by syngamy |
| Have one nucleus | Member of flagellate contain one nucleus in their cell. | Have two nuclei i.e. macro and micronuclei | Have two nuclei like ciliates e.g. Acineta | Have one nucleus |
| Marine sarcodinian have exoskeleton which form layers in the bottom of sea called "Ooze" Amoeba | Trypanosoma cause African sleeping sickness diseases | Have flexible pellicle e.g. paramecium | Have flexible pellicle e.g. paramecium | Contractile vacuole are absent e.g. plasmodium, monocystist |

### 7.1.4 Importance of Protoctista:

Protoctistans have great biological importance and significance to humans.

**Pathogenic protoctista:**

Many members of protoctista cause several diseases in man as well as in plants. i.e. *Plasmodium* cause malaria, *Entameoba histolytica* causes amoebic dysentery. *Trypanosomes* cause sleeping sickness and *Leishmania* causes. Leishmaniasis (an infection of white blood cells).

*Phytophthora infestans* is a plant pathogen causes a disease known as late blight of Potato.

**Fertilizer:**

Seeweed is sometimes used as fertilizer in various parts of world. Liquid extracts of brown see weeds are a valuable source of Potassium and trace elements and use for fertilizer in various region of the world.

**Alternative source of food:**

Chlorella is considered alternate source of energy. The world's of fisheries depend on algae production. The red sea weed is cooked and made laver bread in some parts of world. Brown algae is harvested for food in several parts of the world.

**Environment's Friend:**

During photosynthesis algae remove huge amount of carbon dioxide annually from the atmosphere and supply oxygen continuously to the atmosphere

**Biotechnology:**

An imprortant alga – *Dunaliella salina* accumulates large amount of an orange red cerotenoid , β,β carotene which is used to colour products such as margarine,noodles and soft drink and as a vitamin supplement beacause it is readily converted to vitamin A. β,β carotene may also help to prevent lung cancer.

Fuel deficiency will become great threat in future, green algae may also be a future source of alternative feuls. *Botryococus braunii* produces long chain hydrocarbon similar to crude oil.

## 7.3 FUNGI

The fungi are a large successful group of organisms more than hundred thousand species are found. They range in size from the unicellular yeast to the large toad stool, Puffballs and occupy a very wide range of habitate, both aquatic and terrestrial. Fungi grow best in moist habitate. The study of fungi is called **mycology**.

### 7.3.1 General Characterstics:

Fungi are multicellular (except yeast) eukeryotic, non chlorophyllous, absorptive heterotrophs. They may be saprotrophs , parasites , mutulists and predators.

The body of fungus is called **myeclium** generally grows as filamentous **hyphae**. Hyphae may be septate i.e having cross walls (septa) e.g Pencillium or aseptate i.e lacking cross walls, coenocytic e.g Mucor .Hyphae may packed together and organized to from complex reproductive structures in mushroom, puffballs, Morels etc.

They have rigid cell wall containing chitin as the fibrillar material. Most fungal cells are haploid and multinucleate. Multinucleate vegatative cells are called homokaryons if the nuclei are same and heterokaryons if the nuclei are different. Another unusual nuclear condition is common in fungi is dikaryon when karyogamy is delayed, sometimes indefinitely, forming a cell, containing a pair of sexually compatible nuclei.

Different group of fungi produce different types of haploid sexual spores such as **basidio-spore** and **asco spores** subsequent upon meiosis in zygote.

Diploid zygote nuclei forms during sexual reproduction. They have a characteristics mitosis called **nuclear mitosis** during which nuclear membrane does not break and spindle is formed within nuclei.

Fungi are absorptive heterotrophs. Digestion, if necessary is performed by the fungus secreting enzyme out of its body on to its food. They can be saprotrophs (decomposers), parasites, mutualists and predators. Saprotrophs obtain their food from dead organic matter by their modified hyphae called **rhizoids**. Parasitic fungi depend on living host for nutritional requirements. They obtain food from host through special hyphae called **haustoria**. Parasitic fungi may be facultative which can grow on their living host as well as on artificial media or may be obligates which can grow only on their living host. Some fungi are predators, trap other living host and use them as food. Mutualistic fungi live with other organisms.

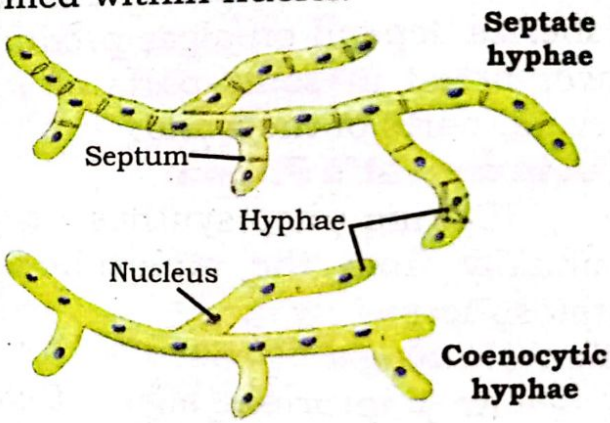



**Fig: 7.5**
**Septate and Aseptate coenocytic mycelium**

Most fungi can reproduce asexually as well as sexually (except imperfect fungi where sexual reproduction has not been observed)

Asexual reproduction takes place by spores, conidia fragmentation and budding. During sexual production fusion of haploid nuclei and meiosis are common in all fungi. If carbohydrate is stored, it is usually a glycogen not starch previously fungi were regarded as plants as they resemble plants in having cell-wall lacking centrioles and being non motile. But fungi resemble with animals also, they lack chlorophyll and feed hetrotrophically, lack cellulose in their cell wall and contain chitin. It means that fungi are neither complete plants nor animals. Their DNA studies also confirm that

they are different from other organisms, therefore fungi are classified in separate kingdom. Pencilium, Mucor and Rhizopus are known as mold.

The most widely accepted view is that the kingdom fungi represents a monophyletic lineage related to animals with which they shared a choanoflagellate like ancestor

Activity:-

- keep moist bread under a bell jar for four or five days at a moderate temperature the fungus appears and gradually spread.
- Observe hyphae under microscope. Collect different mushrooms from field and study their structures.

## 7.4 DIVERSITY AMONG FUNGI:

There are four major divisions of fungi on the basis of sexual reproduction or sexual spores.

1. Division Zygomycota
2. Division Basidiomycota
3. Division Ascomycota
4. Division Deuteromycota

First three groups are distinguished primarily by their sexual reproductive structures , while in deuteromycota the sexual stage has not been observed.

| Division Zygomycota | Division Basidiomycota | Division Ascomycota | Division Deuteromycota |
|---|---|---|---|
| Commonly called zygote fungi | Commonly called club fungi | Commonly called sac fungi | Called fungi imperfecti |
| Produce sexual spores in zygospore | Produce sexual spores in basidium and spores are called basidospores | Produce sexual spores in ascus called ascospores | Fail to produce sexual spores therefore called fungi imperfecti. |
| Mycelium are made up non-septate hyphae i.e. Coenocytic | Septate hyphae | Septate hyphae | Either septate on non-septate hyphae |
| Asexual reproduction takes place by sporangiospores and fragmentation | Takes place by conidiospores and fragmentation | Takes place by conidiospores fragmentation and budding | Takes place by sporangiospores or conidiospores and fragmentation |
| Proper gametangia do not develop | Proper gametangia develop i.e. male gametangia are antheridia | Proper gametangia develops i.e. male gametangia antheridia Female gametangia | No gametangia |

| | | | |
|---|---|---|---|
| | While female gametangium are oogonia | ascogonia have beak like structure called trichogyne, | |
| Sexual reproduction takes place by conjugation | By plasmogamy and karyogamy | By plasmogamy and karyogamy | No |
| Secondary mycelium or fruiting body donot develop | After plasmogamy each dikaryotic cells divide to form a hyphae, which develop into secondary mycelium or fruiting called basidiocarp | After plasmogamy each dikaryotic cells divide to form a hyphae, which develop into fruiting body called Ascocarp | No |
| No fruiting body | Only one type of fruiting body | Three types of fruiting bodies are formed i.e. cleistothecium, apothecium and perithecium | No |
| As a result of karyogamy diploid zygotes are formed in a resistant body called zygospore which is formed as a result of conjugation | Some cells of fruiting body perform karyogamy and develops into diploid cells which enlarge to form basidium | Some cells of fruiting body perform karyogamy and develops into diploid cells, enlarge to form ascus | No |
| The dormaint zygospore develop into promycelium which contain sporangium | Each basidium produce four finger like protection called strigmeta produce four basidiospore, each basidium | Each ascus produce eight ascospore first meiotic than mitotic cell division occur. | Only gametic recombination can takes place as sexual reproduction i.e. parasexuality |
| e.g. poread mold mucor | e.g. mushroom, toad stool, bracket fungi, puff balls, button mushroom (*Agaricus compestris*) | e.g yeast, mildew, cup fungi, traffles, important cellulose degrades of ecosystem | e.g *Penicillium notatum* different sp: of *aspergillus* |

### 7.4.5 Life Cycle of Mucor (zygomycota):

**Occurrence and habitat:**

Mucor is the commonest of saprophytic fungi, called "molds". Mucor is coprophilous and may be prepared by keeping damp cow or horse dung under a bell- jar for few days. Mucor is however, also very widely distributed in the humus of the soil. In nature, Mucor emits a "musty or moldy" smell.

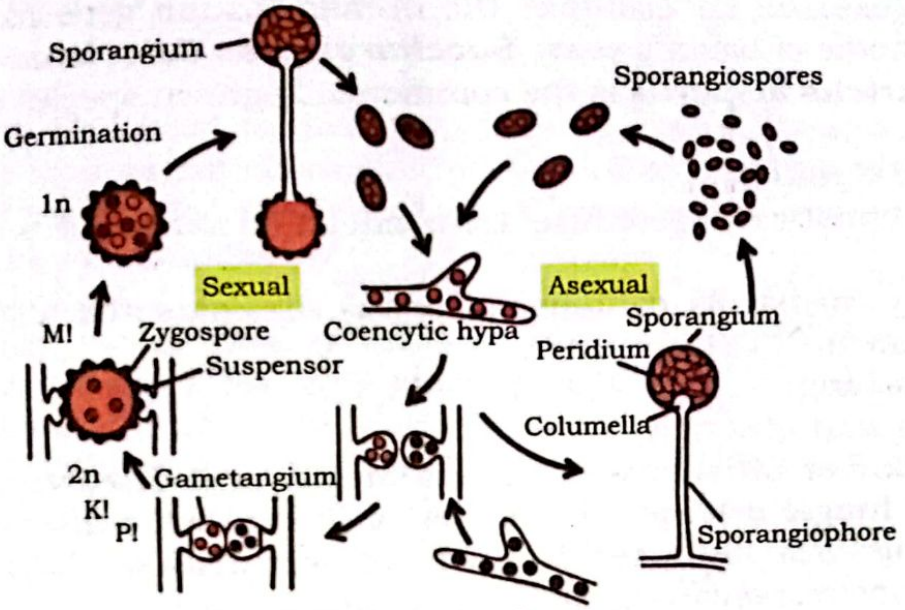



Fig: 7.6 Life cycle of mucor

**Structure:**

**Mycelium**

The mycelium of Mucor consists of long, aseptale coenocytic hyphae.

**Types of hyphae:**

The mycelium consists of three types of hyphae.

1. **Rhizoidal hyphae:**

Hyphae penetrate into the tissue of the substratum . They serve as the fixitive and absorptive which are essential for nourishment.

## 7.5 IMPOTANCE OF FUNGI:

Fungi are important to human as foods, decomposers, plant and animal pathogens, producing antibiotics, in biological control and in biotechnology.

> Because of lichen's efficiency in absorbing mineral, they are important contributors to nutrient cycle .This efficiency also makes them sensitive to pollution.

### 7.5.1 Eating and drinking fungi:

Edible mushrooms, are useful source of easily digestible proteins, vitamins and minerals e.g Agaricus bisporus ,padistren mushroom , oyster mushroom.

Fungi are vital for a whole range of fermentation industries. Soybeans are fermented by ***Aspergillus oryza*** to make soy sauce.

Fungi take part in the basic process of cheese making, the yeasts, ***Saccharomyces cerevisiae*** ferment sugars to alcohol and carbon dioxide and is exploited commercially in making wines, beer and bread.

Over the past few decades yeasts have become increasingly important in genetic research for example, the human insulin gene has been spliced into the genome of baker's yeast ***Saccharomyces Cerevisiae*** and insulin for use by ***Agaricus bisporus*** is the commercially grown species of mushroom.

### 7.5.2 Food Spoilage:

Saprophytic fungi cause tremendous amounts of spoilage of food stuff.

Many toadstools contain poisonous alkaloids the affect the human nervous system.

**Pathogenic fungi**

**Human/Animal diseases:**

A number of important human and animal diseases are caused by pathogenic fungal disease . The cause of the cosmetic diseases of the skin such as ringworm .Athlete's foot also an skin disease. Fungal spores may trigger allergic responses in sensitive people

Histoplasmotysis is a serious infection of lungs caused by inhaling spores of fungus.

A Few species are able to cause systemic infections of bone tissues and some anaerobic fungi cause fatal lung diseases

***Candida albicans*** the cause of oral and vaginal thrush. Aspergillosis, (ear, lungs, disease), and moniliasis (Skin, mouth, gums disease) are also caused by fungus. Many toad stool contains poisonous alkaloid that affect the human nervous system.

**Plant diseases:**

Fungi are responsible of various plant diseases. Fungi destroy many agricultural crops, fruits, wheat e.g downy and powdery mildews etc. Apple, grapes, cherries and roses are affected by powdery mildews.
Most cereals crops like wheat and corn are susceptible to fungal diseases call smuts and rusts.

**Decomposers:**

Saprotrophic fungi act as decomposers in ecosystem. Many feed on dead organism and decaying material in the soil and help to recycle nutrients such as Phosphate and sulphates which taken up by plants.

**Spoilage:**

Many Fungi spoil leather, wool, books, timber, cotton etc.

**Antibiotics:**

Many important antibiotics are extracted from fungi. Fungi have explored a new field, in medicine by producing antibiotics like penicillin ,chloromycetin, neomycin terraymycin etc .Penicillin is effective against most types of bacteria which cause diphtheria, pneumonia, meningitis syphilis and gonorrhea.

**Biological control:**

Fungi are also used in the biological control of weeds and pests. Some soil fungi trap nematodes using sticky branches or rings of hyphae. The activity of these predatory fungi could reduce the severity of plant diseases caused by nematodes.

**Fungi and biotechnology:**

Fungi are model eukaryotes for biotechnological research and application. Being eukaryotes they have the potential to be engineered to produce large amount of useful biochemicals.

Many Fungi have the ability to convert low- value waste into useful compounds such as vitamins , hormones and antibiotics

**Genetic Research:**

Many fungi are used in genetic research. Neurospora commonly known as orange bread mold and yeasts are extensively used as an important organism for eukaryotic genetic research, including genetic recombination and gene regulation.

**Fungal mutualism:**

As heterotrophs, fungi depend for their existence on other organism, with which they have developed intimate often interdependent, relationships. The level of interdependence saprophytic decomposers involved in the nutrient recycling

**Mycorhizae:**

In mycorhizae , the fungal hyphae help in the direct absorption of phosphorus , zinc , copper, and other nutrients , from the soil into the roots of vascular plants. Such plants show better growth than those without this association.

**Lichens:**

It is a mutualistic symbiotic association between fungi and certain photoautotrophs either green algae or a cyanobacterium, or sometimes both. Most of the visible part of lichens consists of fungus while alga partner is present within the fungal hyphae. Fungus protects the algal partner from strong light and desiccation and itself gets food through the courtesy of algae. They are ecologically important as bioindicator of air pollution.

# SUMMARY

- Protoctista are eukaryotic not belonging to the plants, animals or fungal kingdoms. The three main kingdoms of eukaryotes probably arose from Protoctista ancestors.
- Protoctista can be unicellular , colonial or muticellular.
- Due to diversification biologists regard Protista kingdom as polyphyletic group of organisms.
- The first eukaryotic organisms were probably similar to modern day Protoctista
- Plant like Protoctista are algae e.g Chlorella, Ulva. Fungi like Protoctista are slime mold and water mold oomycetes (Phytophthora). Phytophthora is a pathgenic organism causing late blight of potato
- Animal like Protoctista include all protozoans
- Plasmodium is the cause of maleria.
- Protoctista have great bilogical importance and significance to human
- Fungi include non-chlorophylous , multicellular (except yeast) organisms having chitinous cell wall.
- The body of fungi called mycelium grows as filaments called hyphae.
- Fungi are absorptive heterotrophs , secreting enzymes that digest their food externally.
- All fungal nuclei are haploid except transient diploid zygote that form during sexual reproduction.
- They have a characterstic mitosis called nuclear mitosis during which nuclear membrane does not break and spindle is formed within nucleus.
- There are four major divisions of fungi i-e, zygomycota, Basidiomycota, Ascomycota, Deuteromycota.
- Most fungi are reproduce asexually as well as sexually (except imperfect fungi in which sexual reproduction has not been observed)
- Asexual reproduction takes place by spores, conidia, fragmentation and budding.
- During sexual reproduction fusion of haploid nuclei and meiosis are common to all
- Mucor and Rhizopus are known as molds
- Fungi are important to human as food , decomposers, plant and animal pathogens , antibiotics some of some , in biological control and in biotechnology.

# EXERCISE

**1. Encircle the correct choice**

(i) Which of the following is true about the Kingdom Protoctista
- (a) All organisms are prokaryotes
- (b) All organisms are eukaryotes
- (c) All organisms are autotrophic
- (d) All organisms are heterotrophic

(ii) All members of green algae have the pigment combination
- (a) Chlorophylls a and b
- (b) Chlorophylls a and c
- (c) Chlorophyll a and Phycobilins
- (d) Chlorophylls a , b and c

(iii) The major grouping of protozoa is based upon their
- (a) Feeding habits
- (b) Mode of reproduction
- (c) Mode of Nutrition
- (d) Mode of locomotion

(iv) Protoctista having isomorphic alternation of generation
- (a) Chlorella
- (b) Ulva
- (c) Euglena
- (d) Phytophthora

(v) The amoeboid stage of slime mold is
- (a) Plasmodium
- (b) Fruiting bodies
- (c) Euglena
- (d) Merozoites

(vi) Trypanosomes and Leishmanias are disease causing
- (a) Viruses
- (b) Bacteria
- (c) Protoctists
- (d) Fungi

(vii) Ulva is commonly called
- (a) Bacteria
- (b) Virus
- (c) Mushroom
- (d) Sea lettuce

(viii) The study of fungi is called
- (a) Zoology
- (b) Microbiology
- (c) Botany
- (d) Mycology

(ix) The most important cellulose degraders in ecosystem are
- (a) Ascomycota
- (b) Zygomycota
- (c) Basidiomycota
- (d) Deutromycota

**2. Write short answers of the following questions:**

1. Why is the kingdom Protoctista considered to be an artificial taxon?
2. Why we say that ulva has isomorphic alternation of generation?
3. Why asexual and sexual ulva plants are called as sporophyte and gametophyte?
4. Protoctista are the link between prokaryotes and the more modern eukaryotic like plants and animals explain why?
5. Name various classes of Protozoa and how each of their members move?
6. Describes some of the unusual features of nuclear behavior in fungi?
7. What features allow fungi to survive in all environment where life is possible?

**3. Write detailed answers of the following questions:**

1. Write down general characteristics of Protoctista and diversity among Protoctista?
2. Describe structure and reproduction in Ulva?
3. Give diagnostic features of four classes of fungi?
4. Write an essay on economic importance of fungi?

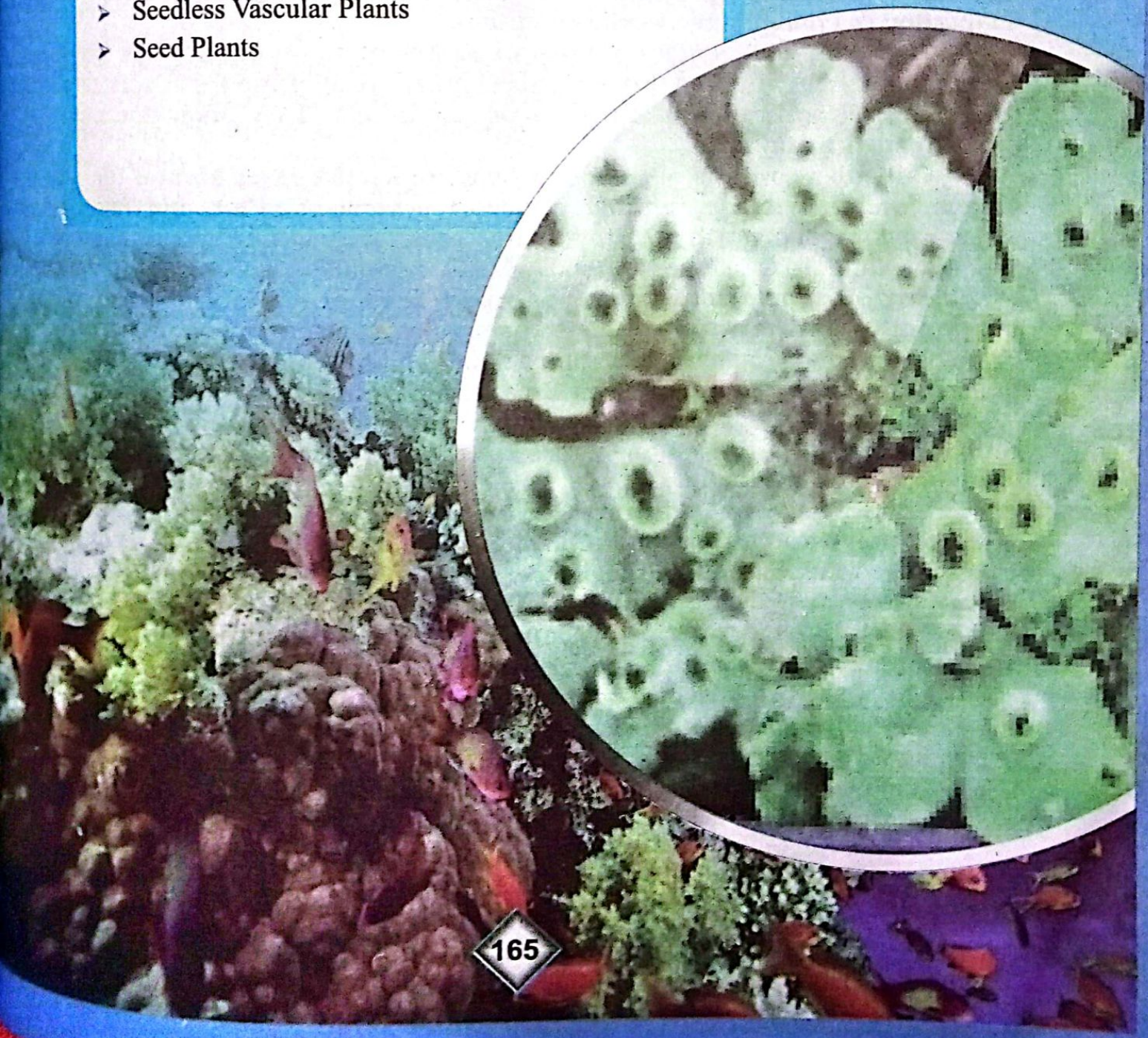
# DIVERSITY AMONG PLANTS

Chapter 8

## Major Concept

**In this Unit you will learn:**

- Evolutionary Relations in Plants
- Non-Vascular Plants
- Seedless Vascular Plants
- Seed Plants



**Diversity among Plants**

Plants are multicellular eukaryotes with Photosynthetic nutrition. Cell typically have cellulose wall, sap vacuole, plastids and several photosynthetic pigments which always include chlorophyll-a. They have tendency to develop embryo and have heteromorphic alternation of generation. Sexual and asexual both types of reproduction are reported in plants.

## 8.1 THE EVOLUTIONARY RELATION IN PLANTS:

Although life probably began on earth about 3.5 billion years ago. The earliest plants have become the first organisms adapted for life on land. In the beginning the plants were restricted only to aquatic habitat but gradually they adapted to terrestrial habitat.

The evolutionary history of the plants kingdom is a story of adaptation to changing terrestrial condition.

There are wide variety of plants species exists on earth. They live in every type of habitat .They have colonized great areas of the earth surface in practically all sorts of soil and climatic conditions. They show enormous diversity in size and form.

Cuticular covering of the plant body, protective layer around the sex organs, evolution of an internal transport system of xylem and Phloem, specialised organs, such as leaves and roots and woody tissue allowed vascular plants to attain greater body size than smaller non-vascular plants, which rely on simple diffusion for transport of water and nutrients are the important characteristics in the transition of plant from water to land. Transport of male gametes in pollen to the female reproductive organ. The pollen grain dispersed by wind or animals rather than by water.

Although the earliest vascular plants were relatively small and probably, confined to swampy areas, after that a rapid diversification of plants occurred gradually.

"Plants may be defined as multicellular eukaryotes that are photosynthetic autotrophs (chlorophyllous) with cell wall primarily made up of cellulose , exhibiting heteromorphic alternation of generation and zygote retained to become develops into embryo".

### 8.1.1 General Characterstics of Plants:

- Plants are multicellular eukaryotes.
- They are Photosynthetic autotrophs and contain photosynthetic pigments specially chlorophyll, which enable the plants to convert light energy into food (chemical energy).
- Rigid cell wall of plant cell primarily made up of cellulose
- Life cycle of show heteromorphic alternation of generation.
- Zygote retained and develops into embryo

- Plant cuticle, composed of insoluble lipid polymers and waxes , barries to prevent diffusion of water to the drier atmosphere and also filters a substantail component of UV radiation form sunlight.

Some others characteristics included are:

Plants produce some secondary products like sporopollenin and lignin. Sporopollenin tougher than lignin composed chiefly of carotenoids . It protects them from attack by grazing organism and microganism . It also make spores of land Plants tough and flexible and resistant to biodegradation. Lignin is important to provide strength to upright terrestrial plants.

In terrestrial environment gases enter through small pores in the plant surface. Stomata are present in modern hornworts, mosses stomata and lenticel and vascular plants as well as simple, ancient fossil plants such as Rhynia.

### 8.1.2 Vascular supply and lignin-Transport support:

The vascular transport of plants consists of xylem and Phloem for the transport of water and mineral ions and for the transport of sugar respectively. Another product Lignin provide strength to upright terrestrial tissues.

### 8.1.3 Alternation of generation and sexual reproduction:

Alternation of generation is the type of life cycle where asexually reproducing generation alternate with sexually reproducing generation. It is an adaptation There are two alternating generation in plants life cycle. The gametophyte generation which is haploid produces male and female gametes by mitosis. Male and female gametes fuse to form zygote which grows into the diploid sporophyte generation. The diploid sporophyte produces spores by meiosis which are dispersed and germinate into new haploid gametophytes. In land plants, haploid and diploid generations are markedly heteromorphic, these gametophyte and sporophyte differ in size and shape.

## 8.2 NON-VASCULAR AND VASCULAR PLANTS

### Non-Vascular Plants:

The non-vascular plants are the group of plants without specialized conducting tissues (xylem and phloem) for transporting water and nutrients. The gametophyte is the dominant stage of life cycle in these plants.

They need moist habitat to reproduce because flagellated sperm must swim through water drops, e.g. Liverwort, hornwort and mosses.

### 8.2.1 Bryophytes:

Bryophytes are the simplest non vascular land plants, first appeared before 450 million years ago. In bryophytes, strengthening and conducting tissue absent or poorly developed. It Includes Liver worts (Class Hepaticae), Horn worts (Class Anthocerotae) and mosses (Class Musci)

Bryophytes are small photosynthetic free-living gametophytes that lack vascular tissue. Sexual reproduction requires water for sperm to swim from an antheridium to an egg in an archegonium. The sporophyte grows on the gametophyte and is dependent on it for nutrition.

**General Characterstics:**

These are non-vascular plants, where xylem and phloem are absent.

i. Plants showing alternation of generation with dominant gametophytes having amphibious nature
ii. Gametophytes are the conspicuous, chlorophyllous, photosynthetic autotrophs having thalloid body or differentiated in rhizoids, Pseudo-stem and pseudo leaves.
iii. Male gametes (Antherozoid or spermatozoids) are produced in antheridium (male gametangia, female gametangia). while female gametes (non-motile egg cell) is produced in archegonium.
iv. Sporophytes are semi-parasite on gametophytes having a body differentiated into foot, seta and capsule. Spores are produced by the sporophytes from spore mother cell in capsule by meiosis.
v. They live mainly in damp, shady places.
vi. Bryophytes are amphibious in nature, need water to reproduce. Their sperms are flagellated and swim from antheridium to archegonium to fertilize the egg when archegonia mature and produce smell. The male gametes mature earlier than female gametes this property is called protoandry.
vii. Bryophytes lack the lignin fortified tissues required to support tall plants on land.

### 8.2.2 Life cycle of moss:

**Life cycle of Bryophyte (Moss)**

All bryophytes show heteromorphic alternation of generation with gametophytes as dominant generation including *Funaria hygrometrica* (a moss). The gametophyte is hapliod consisting of rhizoids, pseudostem and pseudo leaves.

The sex organs called **antheridia** (male) and **archegonia** (female) develop at the tips of pseudo stem which are always **dioecious** having either male or female sex organs. There is **protoandry** because antheridia mature earlier and liberate their anthrozoids, which start swimming with the help of their flagella in dew or rainwater .When archegonia mature, they have single ovum in the **venter** and few neck canal cells in the neck. Swimming sperms are attracted by scent of sugar cane secreted by mature archegonium but a single antherozoid fuses with the ovum to form **diploid** (2n) **oospore** (zygote). This is retained within archegonium and form an **embryo** (2n). This embryo undergo repeated mitotic-divisions to form sporogonium (a sporophyte) which is diploid. It consists of foot, seta and

capsule. Within capsule spore mother cells are present. Each spore mother cell divides by meiosis to form four haploid spores. Each spore when drop at proper substratum germinates into a filamentous body called **protonema,** later on gametophyte (haploid) develops from protonema to complete life cycle.

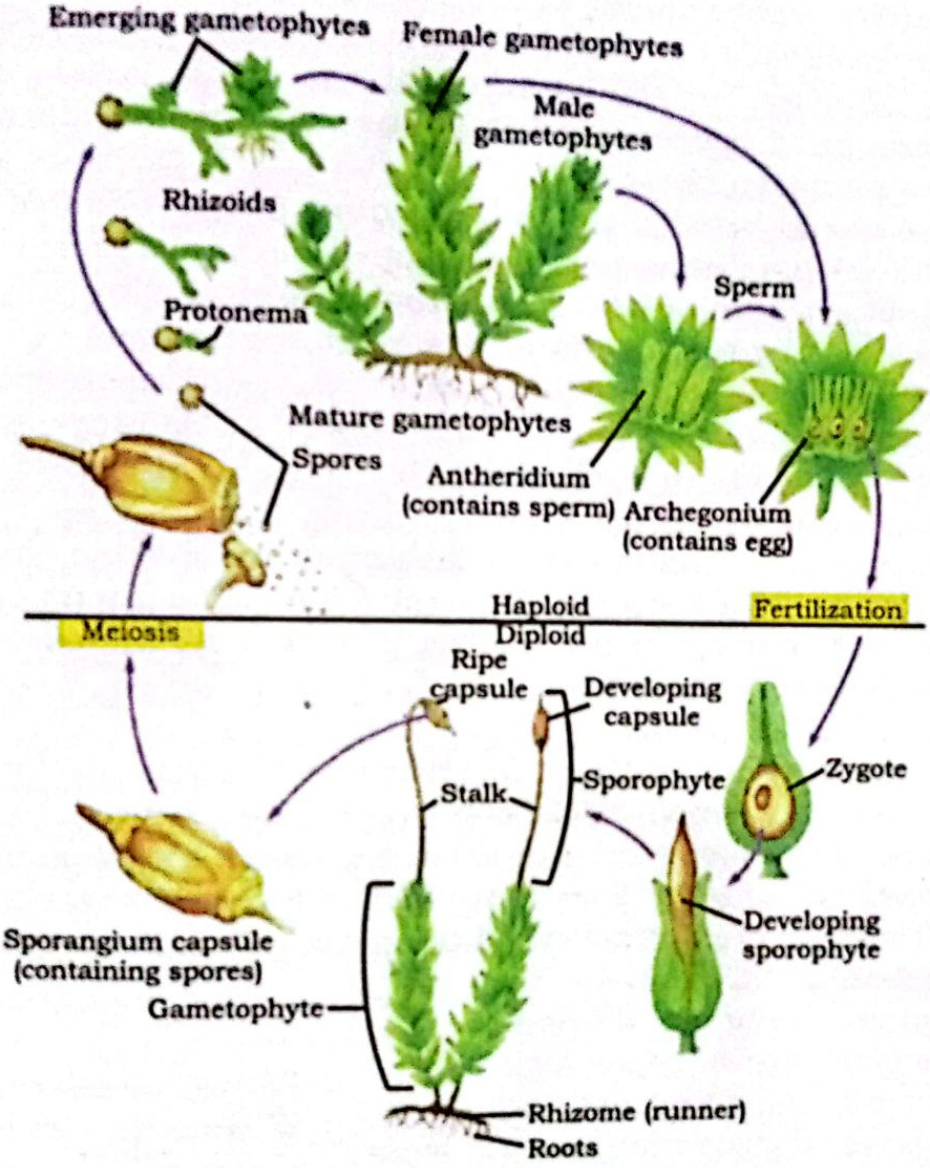
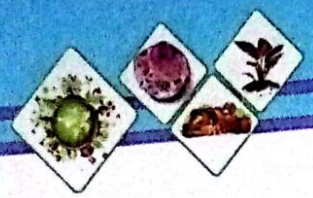



Fig 8.1: Life cycle of Moss

### 8.2.3 Adaptations to land habitat:

The first evidence that plants had invaded the land form the sea is found in fossils. All the biologists agree that the land plants and animals evolved from aquatic ancestors. The conquest of the land must have been a long and difficult process. The plants had to become adopted by developing new structures.

Life of aquatic organisms is an easy life. Water is necessary for the growth of all living things and there is little danger in the sea of any lack of



water. Carbon containing compounds, so essentail for autotrophs are present abundantly in solution. These autotrophs in turn provide a continuous supply of oxygen for all the living oraganisms in the sea. The temperature in the seas does not fluctuate as much as temperature on land. Hence, the aquatic environment is more uniform and better supplied with some of the necessities of life than in the rigorous land environment.

When plants invaded the land from the sea. They faced many problem such as obtaining and conserving water, absorbing carbon dioxide from the atmosphere for photosynthesis.

To solve these problems, land invading plants adopted themselves first to amphibious-habitat and later developed a complete terrestrial form of life. The amphibious form of land plants includes all the bryophytes. We will consider the following adaptive characters exhibited by them.

1. Rhizoids for water absorption
2. Conservation of water
3. Absorption of $CO_2$
4. Heterogamy
5. Protection of reproductive cells
6. Formation of embryos

**1. Rhizoids for water absorption:**

The study of Marchantia thallus and other bryophytes show that they have rhizoids for water absorption. These are long, filmentous extensions of the cell of the lower surface of the thallus. They greatly increase the surface for absorption of water from the soil.

**2. Conservation of water:**

To conserve water within the body thallus of all bryophytes is multilayered and very small surface area directly exposed to reduce the drying effects of the atmosphere. Moreover, the outer and uppermost layer of cells is covered with cuticle. It is non-cellular layer of wax-like substance called cutin. This is very efficient in reducing the rate of evaporation.

**3. Absorption of $CO_2$:**

Land plants need an efficient means for the exchange of gases with the environment in contrast to aquatic plants which exchange gases dissolved in water. The upper surface of the thallus is provided with a number of aerating pores. Each pore leads inside into an air-chamber. These chambers have filamentous branching photosynthetic cells. Air having $CO_2$ enters through the pores and $CO_2$ from air absorb by these photosynthetic cells and diffuses into the cytoplasm.

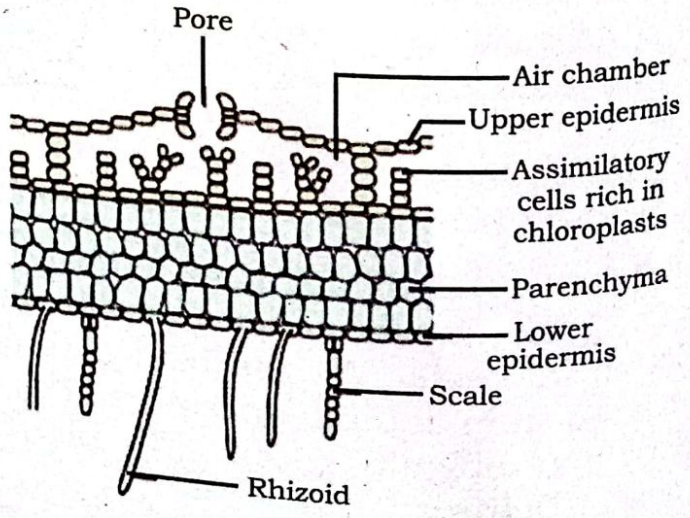



**Fig 8.2 Marchantia thallus**

**4. Heterogamy:**

Heterogamy is the most successful kind of reproduction that has evolved in bryophytes. It is defined as production of two different types of gametes. One is male (motile) and the other is female (non-motile) full of stored food.

**5. Protection of reproductive cells:**

The land environment requires special protection for the reproductive cells. In amphibious plants reproductive cells are very well protected. The male gamete (sperm) and female gamete (ovum) are produced in multicellular reproductive sex organs called **antheridia** and **archegonia** respectively. Moreover, these organs are also surrounded by hair like structures called **paraphyses** which help to prevent drying of the sex organs.

**6. Formation of embryos:**

Embryo formation in amphibious plant is of universal occurrence. The fertilized egg called oospore (zygote) is formed inside the archegonium. An embryo develops from the oospore as it divides still inside the protective coverings of the archegonia. Thus the coverings formed by the female organ protect the growing embryo from drying out and from mechanical injury.

### 8.2.4 Advantages of Bryophytes:

Bryophytes play important role in maintaining the ecosystem. They initiate soil formation, maintain soil moisture, and in recycling of nutrients in forest ecosystem. They are bio indicators of heavy metals in air pollution.

From ancient time in many parts of the world bryophytes used as medicines for example Liverworts (*Marchantia*) used for the treatment of liver disorder, another member of bryophytes *Polytrichum* used for curing diseases such as fever, homeostatic and traumatic injuries to pneumonia and lymphocytic leukemia. Insecticidal activities of bryophytes are also reported.

## 8.3 VASCULAR PLANTS:

Vascular plants characterized by the presence of vascular tissue. Vascular tissue is made up of Xylem and phloem. Vascular tissue has two important properties. First these tissues are concerned with translocation of water and nutrients throughout the plant body. Xylem carries mainly water and mineral salts, whereas Phloem carries mainly organic solutes in solution, such as sugar. Secondly plant bodies can be supported because Xylem contains lignified cells of great strength and rigidity. Another lignified tissue, sclerenchyma also develops in vascular plants and supplements the mechanical role of xylem. The dominant generation of living vascular plants is the sporophyte existing as free-living plant. The gametophyte is smaller in size, bear smaller sex organs. It may be monoecious (Bisexual) or dioecious (Unisexual), short lived, and degenerates once the sporophyte is established.

Vascular plants are categorized in two major groups.

- Seedless plants---- Fern allies (Psilopsida, Lycopsida and Sphenopsida) and ferns.
- Seeded plants (Spermatophyte) ---- Gymnosperms and Angiosperms.

### 8.3.1 Seedless Vascular Plant( Pteridophytes):

Seedless vascular plant include fern allies and ferns.

**Fern allies:**

The term " Fern allies" refers to a loose assemblage of spore producing vascular plants that are classified in three group.

(i) Sub division Psilopsida e.g Psilotum and tmesipteris.
(ii) Sub division Lycopsida e.g Lycopodium and Selaginella
(iii) Sub division Sphenopsida e.g Equisetum

**(i) Sub division Psilopsida (Whisk ferns) living fossils:**

This is the most primitive group of living vascular plants includes two genera Psilotum, Tmesipteris. The Psilopsida was considered as living fossil because of its apparent similarities to the fossil plant Rhynia. Psilotum is the only living vascular plant where leaves and roots are absent.

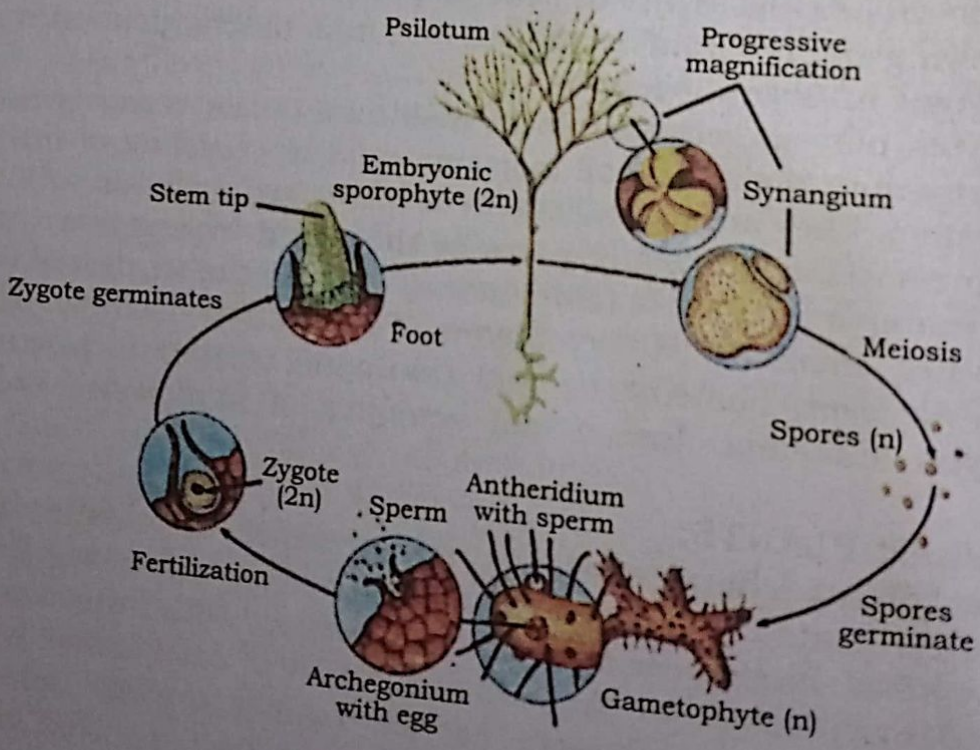



**Fig 8.3 Life cycle of psilotum**

The Psilopsida sporophytes are simple dichotomously branching small Plants. They lack true leaves but produce small out growths of stem (enations). The aerial stems are green and carry out photosynthesis. Sporangia develop at the tips of some of the aerial branches. Within the sporangia meiosis produces haploid spores from spore mother cells. These

spores are morphologically similar therefore called homospory. Each spore germinates into gametophytes of Psilopsida which is also called prothallus. It has one or more dichotomous branches. It bears numerous unicellular rhizoids .It is monocious .The male sex organ antheridium and female sex organ archegonium are produced near the growing apex.

**(ii) Sub division Lycopsida:**

They are commonly called as club mosses most of which are tropical. They are the first plants to have evolved true roots. It is generally supposed that these roots arose from branches of the ancestral of algae that penetrated the soil and branched underground. The sporophyte consists of dichotomously branched shoots that bear simple spike like leaves. Sporangia are located in leaf axil either along normal portions of stem or condensed into cones, strobilus. These sporangia containing leaves are called sporophyll. The lycopodium are homosporous having one type of spores develop monoecious gametophytes that bears both male and female sex organs. *Selaginella kraussiana* is a common green house plant. Selaginella exhibits heterospory i.e., it produces spores of two distinct kinds large haploid spores germinate to produce female gametophytes, which archegonia development on it and small microspores which develop into male gametophytes, antheridium on it. These gametophytes are dioecious.

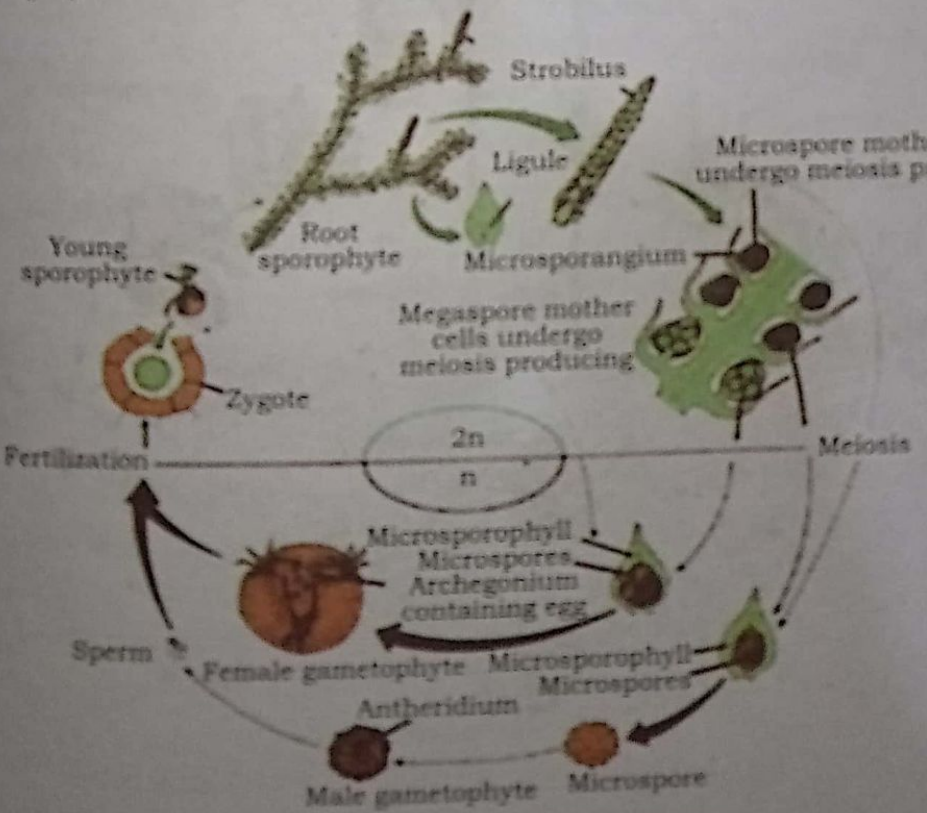



**Fig 8.4 Life cycle of Selaginella**

### (iii) Sub division Sphenopsida (Horse tails):

Horsetail grow abundantly in the swamps of carboniferous times. Today the phylum consists of only one living genera *Equisetum*. It consists of a creeping underground rhizome that produces upright stems. Stems are green and photosynthetic. Small leaves are borne in sheeth like whorls at nodes in the stem. Sporangia are produced in small strobili borne terminally on either normal vegetative or specialized reproductive shoots. Following meiosis, spores are produced. Spores are unusual. The outer layer of spore wall form four sporopollenin thread called elators their movement assists in spore dispersal. When a spore lands in a damp place, the elator coil up and spore germinates. A tiny gametophyte about the size of a few millimeters up to 3 centimeter is produced.

Gametophyte is dorsiventral. Unicellular rhizoid are arised from the basal cells. Gametophyte is basically bisexual. It bears both male sex organ (antheridia) and female sex organ (archegonia).

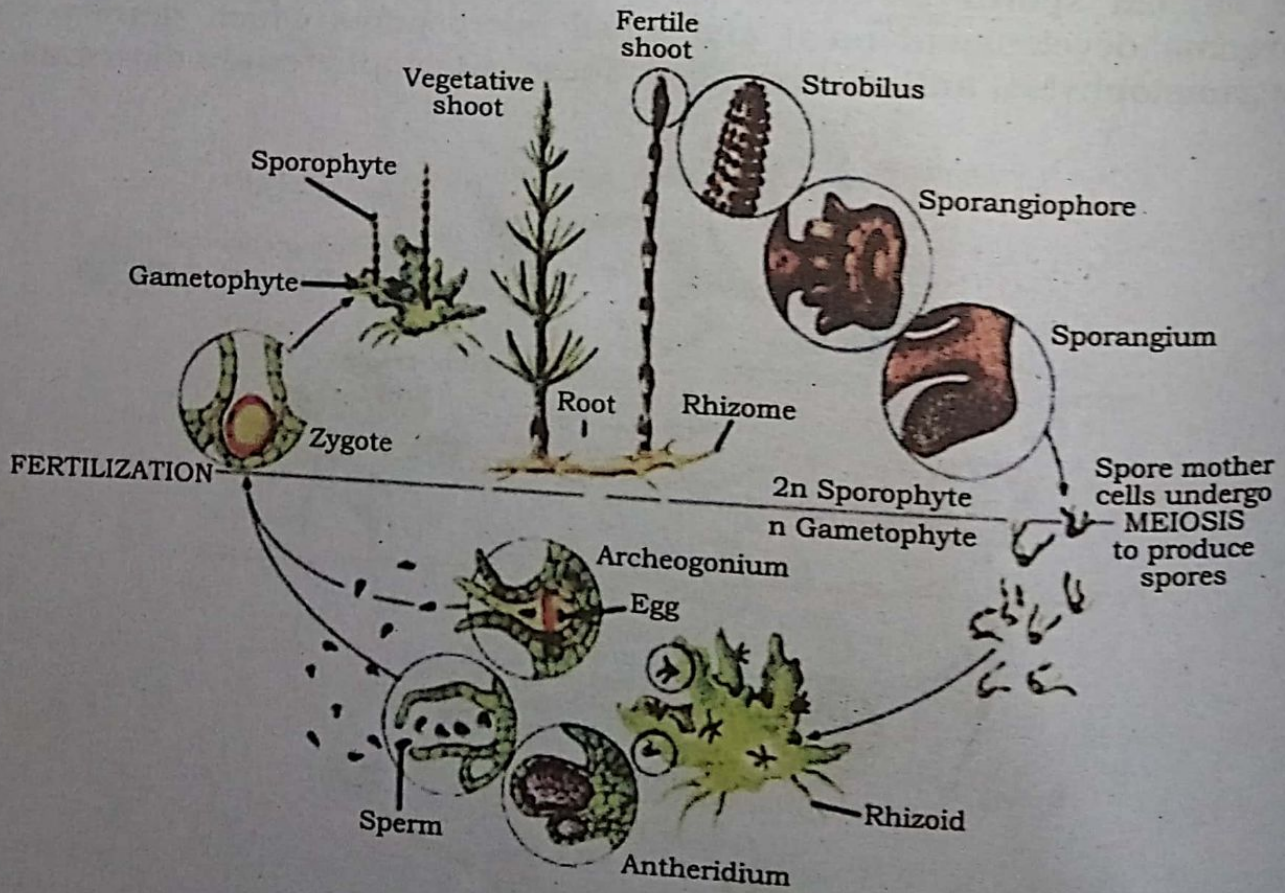



**Fig 8.5 Life cycle of Equisetum**

**(iv) Sub division Filicinophyta (Ferns):**

Ferns are the most diverse and conspicuous of the spore – producing vascular plants. Most of these are found in tropical regions but many species grow abundantly in damp habitat in temperate regions. They range in size from small, delicate filmy ferns and floating aquatic to tall trees.

Ferns shows heteromorphic alternation of generation in which the sporophyte is dominant. The sporophyte generation possesses true roots, stems and leaves. Vascular tissue (Xylem and Phloem) present in the sporophyte. Leaves relatively large and called fronds. Spores produced in sporangia which are usually in clusters called sorus.

Gametophyte is reduced to a small, simple prothallus. The prothallus contains male reproductive organ antheridia and female reproductive organ archegonia. e.g. *Dryopteris*.

### 8.3.3 Evolution of the leaf:

The leaf is the most important organ of a green plant because of its photosynthetic activity. There are two types of leaves in vascular plants.

(a) One veined leaf (microphyllous)

(b) Many veined leaf (megaphyllous)

It is very interesting to trace the origin of leaf in the green plants.

**Evolution of One Veined Leaf:**

**Enation Theory:**

The evolution of one-veined leaf (microphyllous) can be explained by assuming that a thorn like outgrowth (Enation) emerged on the surface of the naked stem. With an increase in size of the out growth, the vascular tissues were also formed for the supply of water, food and support to the leaf.

**Reduction Theory:**

Another possibility is that a single veined leaf originated by a reduction in size of the part of the leafless branching system of the primitive vascular plant. This is how the leaf of lycopodium (club mosses) and equisetum (horse tail) came into existence.

**Evolution of Many Veined Leaf:**

**Webed Theory:**

Many veined leaf (megaphyllous) originated much later. These are the evolutionary modifications of the forked branching system in the primitive plant. The first step in the evolution of this leaf was the restriction of forked

branches to a single plane. The branching system became flat . The next step in the evolution was filling the space between the branching and the vascular tissues. The leaf so formed looked like the web foot of a duck

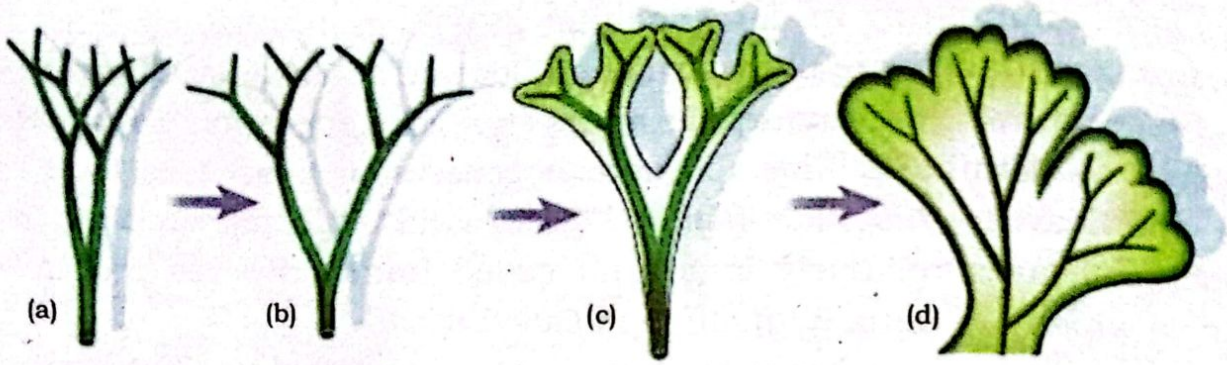



**Fig: 8.6 Evolution of leaf**

### 8.3.3 Life cycle of a fern:

The life cycle of fern (Adiantum) or Dryopteris shows heteromorphic alternation of generation in which sporophytic phase is dominant. All ferns are homosporous, producing single types of spores.

**Sporophytic Phase:**

The sporophyte (2n) which is diploid, consists of adventitious roots, underground stem a rhizome and pinnately compound leaves.

During asexual reproduction the leaves give rise to rounded bodies on its undersides which are called sori (singular sorus) .The sori are green but when ripe they become dark brown. The leaves which bears sori are called sporophylls. Each sorus is the group of sporangia.

Sporangium consists of a stalk called **sporangiophore** and a biconvex capsule consisting of **annulus** and **stomium.** The annular cells are thickened whereas stomial cells are thin-walled. Within sporangium spore mother cells are present. Each spore mother cell divides by meiosis to from four haploid spores. The spores are liberated through stomium.

Each spore on germination gives rise to miniature bisexual (monoecious) gametophyte called **prothallus**.

**Gametophytic Phase:**

The gametophyte of fern is called prothallus. The prothallus is independent autotrophic, heart shaped, dorsoventrally flattened lying prostrate on same wet substratum. It is fixed soil with the help of rhizoids which absorb water and nutrients. The prothallus is monoecious having archegonia and antheridia on the same prothallus

Archegonium consists of venter with an ovum and a neck and secrete malic acid by degenerating neck canal cells at maturity. Each antherdium produces a number of antheroziod (sperms). A number of sperms, by making chemotactic movement in water reach to the archegonium. Only one

sperm fuses with ovum to form oospore (zygote) which is dilpoid. Young sporophyte develops from the oospore. In the meantime prothallus degenerate in this way life cycle is completed.

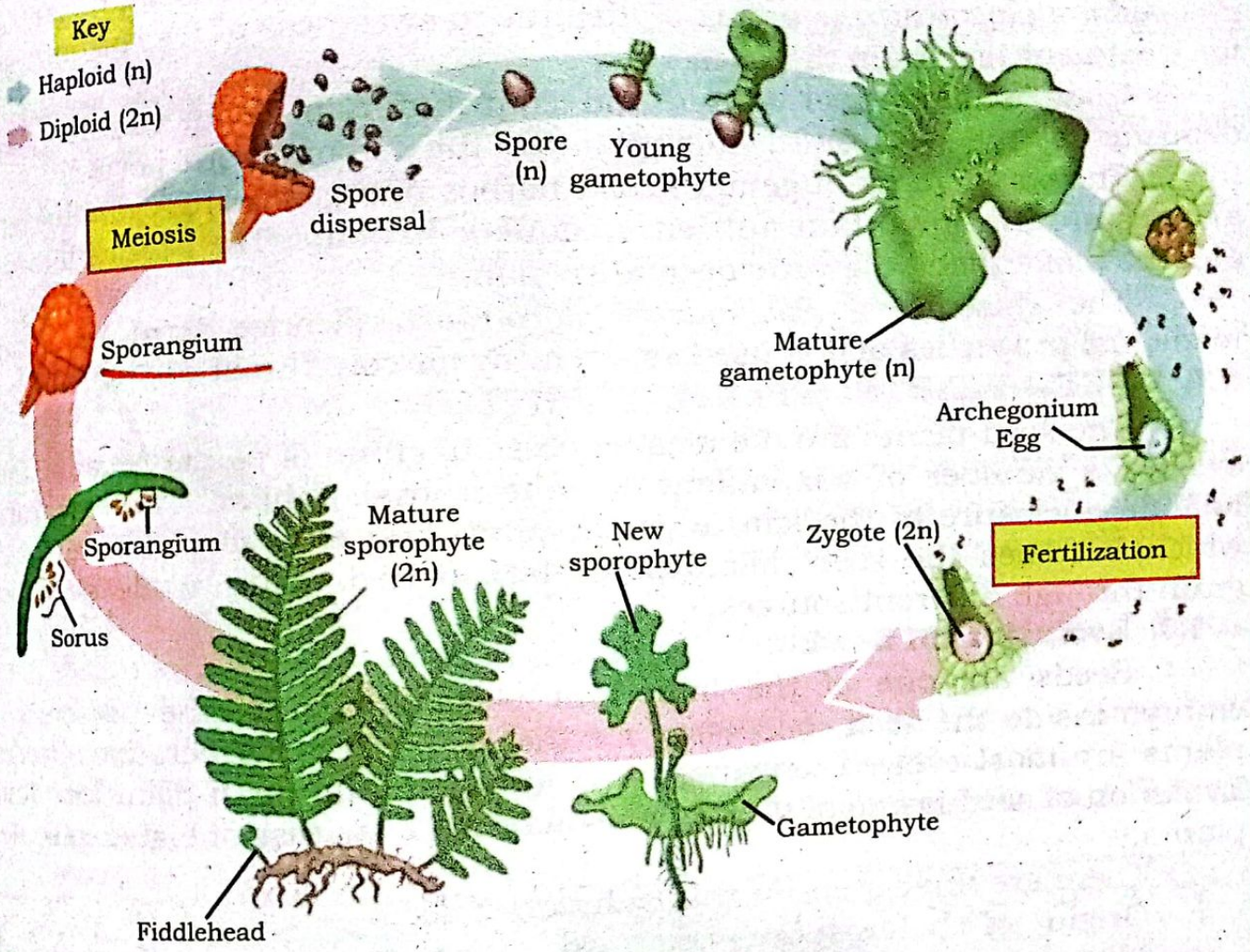



**Fig: 8.7 Life cycle of fern**

### 8.3.4 Vascular Plants as successful land Plants:

The vascular plants have evolved a number of adaptations to the terrestrial environment that have enabled them to invade all the most inhositable land habitat. During this process they diverged sufficiently from one another. The four fundamental adaptations of vascular plants ( with a few minor exceptions)make them more successful land plants.

i. A protective layer of sterile jacket cells around the gametangia.
ii. Multicellular embroyo retained within the archegonia.
iii. Cuticles on the aerial parts to prevent evaporation of water.
iv. Xylem for conduction of water and, dissolved minerals as well as providej support.

Many other such adaptations, absent in the earliest vascular plants, appear in most advanced member of the division.

### 8.3.5 Importance of Seedless Vascular Plants:

Seedless plants have historically played a role in human life. Man get many advantages including food, shelter, fuel and medicine and decoration.

They had been used as food e.g. Pteris, Ceratopteris and Marsilea. *Polypodium glycorrhiza* is a part of diet due to sweetness of it's rhizome, and for treatment to certain diseases.

Coal, a major fuel source and contributor to global warming, was deposited by the seedless vascular plants of the carboniferous period.

The water ferns of genus Azolla harbor nitrogen fixing cyanobacteria and restore this important nutrient to aquatic habitats. The beautiful fronds of ferns make them a favorite decorative plants.

The rhizome of *Polypodium glycorrihiza* (licorice fern) also have medicinal properties and is used as a remedy for sore throat.

## 8.4 SEED PLANTS: (SPERMATOPHYTES)

The seed plants are the most successful group of plants because they evolved a number of adaptations to a terrestrial habitat. These features include enclosure of the female gametophyte and embryo within an ovule which becomes the seed. Microspores transported to the ovule as pollen grain through different sources.

### 8.4.1 Evolution Of Seed:

Seeds are one of the important parts of plants, the presence of embryo inside the seed, necessary for the continuity of generation. Seeded plants are most evolved, advanced and successful group of plant kingdom. Evolution of seed is one of the key reasons for the success of higher vascular plants.

There are three steps in the evolution of seed.

i. Origin of heterospory i.e., two types of spores are produced. Microspores grows into sperm forming gametophyte (male gametphyte) and megaspore grows into egg forming gametophyte (female gametphyte).
ii. Development of integument, an enveloping structure for the protection of megasporangia to form ovule.
iii. Retention of the mature megaspores in the sporangia to develop female gametophyte

The development of seed has given the vascular plants better adaptation to their environment.

### 8.4.2 Groups of Seeded Plants: (Spermatophytes)

The seed plants have traditionally been divided into two groups

1. The Gymnospermae
2. The Angiospermae

## The Gymnospermae:

They are the successful group of plants of worldwide distribution, accounting for about one third of the world's Forest

## General Characterstics of Gymnosperms:

- They have naked seeds because ovules are not covered by ovary i.e. ovary absent.
- They are trees or shrubs mostly ever green with needle like leaves with xerophytic adaptations.
- They are cold resistant and found in colder parts of the world.
- The tree is the sporophyte generation heterosporous producing two types of spores. The best-known group of gymnosperm is the conifers. In conifers ovules ( later seeds) are located on the surface of specialized scale leaves called ovuleiferous scales .These are arranged in cones. Male and female cones are produced on the same tree.
- Most conifers bear their micro and megasporangiate structure in cones
- Gametophyte generation reduced , the functional megaspore develops to form miniature female gametophyte which is permanently lodged within megasporangium(Ovule)
- Microsporangia (Containing pollen) are borne on microphylls ( Fertile leaves) .
- Vascular tissue containing Xylem tracheids and Phloem sieve cells while Xylem vessels and phloem companion cells are absent.
- Female gametophyte consists of two to five archegonia each having single ovum.

*Coast red* grow to more than 100m. The trunk of the general sherman tree is estimated to weight 625000 kg.
The largest trees in the world, *Sequoia gigantea* of south western united states belonging to the gymnosperms.
They are cold resistant and found in colder regions.

- Each microspore develops into another miniature male gametophyte consisting of stalk nucleus tube nucleus , two male gametes and two prothalial cells within an elongated pollen tube.
- Pollen grains of conifers are wind dispersed.
- Fertilization takes place within sporophyte.
- After fertilization, megasporangium gives rise to seed.
- Seed undergoes epigeal germination to form new sporophyte plant. e.g. Pinus, the familiar tree, fir, larch, cedar redwood, Yew.

Conifers are the most diverse and wide spread of the living non flowering seed plants. They are all woody plants many of which are important soft wood timber tree.

**Uses of Gymnosperms:**

- Conifers are commercially important, conifer wood is valuable commercial resource world wides. Pines, spruce firs and other conifers are a major source of softwood timber used in house construction, the timber can be pulped to make paper or compressed to make chipboard, the basic material for modern furniture.
- In addition, Pines are a source of resins, turpentine and pine oil.
- The plants are widely used as ornamentals and largely spotted in gardens and parks e.g Cycas, Thuja, Juniperus, Ginkgo.
- The famous dry fruits locally called chilghoza (*Pinus gerardiana*) belongs to pine tree.
- Ephedrine a drug obtained from Ephedra is used in various respiratory disorder particularly in asthma.

### 8.4.3 The Angiosperms:

The flowering Plants, or angiosperms have their seeds enclosed in fruit because ovules are covered by ovary They are dominate vascular plants of modern flora, adapted to a great range of habitats from the tropics to polar regions, including frets and salt water.

The smallest plants are free floating aquatic duck weeds which is highly reduced and not even differentiated into leaf and stem. The tallest flowering plant is the mountain ash tree.

One of the most important features of angiosperm a part from the enclosed seed is the presence of flowers as reproductive structure instead of cones.

Flowers are unique to angiosperms and have become adapted to attracts insects or other pollinators, for example by the development of large brightly coloured petals, nectaries and scent glands.

Flowering plants are classified into two major groups the monocotyledonae and the dicotyledonae.

**Difference between Monocotyledonae and Dicotyledonae:**

| Monocotyledonae | Dicotyledonae |
|---|---|
| **Seeds**<br>Plants produce only one cotyledon (Scutellum) containing seed. | Plants produce two cotyledon (seed leaves) containing seed. |
| **Leaf**<br>Veins are parallel. | Net like pattern of veins (Reticulate Venation). |
| Dorsal and ventral surfaces are same. (Monofacial leaf) | Dorsal and ventral surfaces are different (bifacial leaf) |
| **Stem**<br>Stem is mostly unbranched, vascular bundles scattered, vascular cambium. Cambium usually absent so no secondary growth to (exceptions occur e.g palms) | Stem is mostly branched, vascular bundles arranged in a ring. ring usually present giving rise secondary growth. |

| | |
|---|---|
| **Root**<br>Adventitious roots from the base of the stem take over from the primary root, giving rise to a fibrous root system | Roots are mostly branched tap roots. |
| **Flower**<br>There are three whorls in flowers. No distinct petals and sepals. These structures are combined to form "Perianth Segment" e.g Grasses, Iris, Onion, Maize, Palms | There are mainly four or five whorls. Usually distinct petals and sepals e.g Pea, Rose Plant, Daisy, Acacias, Nerium. |

### 8.4.4 Life cycle of flowering Plants:

Flowering plants show heteromorphic alternation of generation . The haploid gametophyte alternates with diploid sporophyte . The gametophyte generation is reduced the main plant body is sporophyte.

In the life cycle of plant, meiosis produces female and male haploid spores, each of which undergoes cell division by mitosis to produce a multicellular haploid stage, the female or male gametophyte. These gametophyte produces haploid gametes by mitotic division. Two gametes fuse to form a diploid zygot which then undergoes mitotic divisions to produce the diploid life stage, the sporophyte.

**Sporophyte generation:**

**Asexual reproduction in Angiosperm:**

The main plant body is sporophyte that consist of root, Stem, leaves and flowers. Root, stem and leaves are considered as vegetative parts while flower is the reproductive part. Flower is a compressed reproductive shoot with four whorls of modified (floral) leaves called sepals, petals microsporophyll (stamen) and megasporophyll (carpel). Microsporophyll (stamen) is male reproductive structure and megasporophyll (carpel) is female reproductive structure.

**Microsporophylls (Stamens):**

Microspores which later develops into pollen grains are produced by **microsporophyll** or **stamens**, each stamen consist of sac like anther and a stalk called filament, usually the anther have four chambers called **pollen sac** or **microsporangia**, contain numerous microspores mother cells.

Each microspore mother cell produces four microspores by meiosis so each pollen sac has numerous microspores, develop into pollen grains and disperse from here for pollination.

**Megasporophylls (Carpels):**

Megasporophyll now called carpel produce ovum in ovary. Each carpel consist of three parts, stigma, style and ovary, within ovary one or more ovules (megasporangium) develop. The main body of ovule is called

nucellus which is protected by two layers of protective sheaths of cell called **integuments**. A small pore is present on it, the **micropyle**, with these it contains one megaspore mother cell which produce four megaspores on maturation. Out of four megaspores only one megaspore will be functional to develop into **female gametophyte**. The female gametophyte develops inside ovule called **embryo sac**.

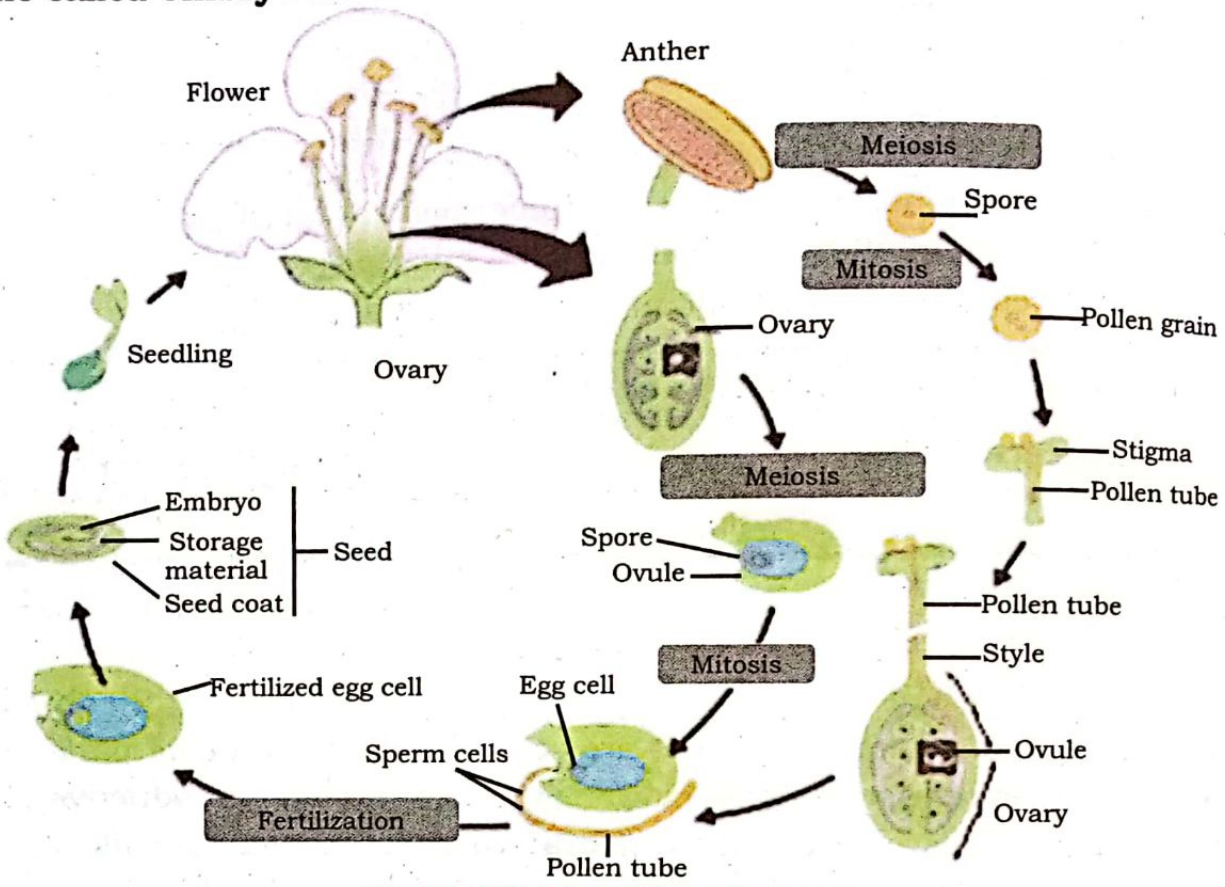
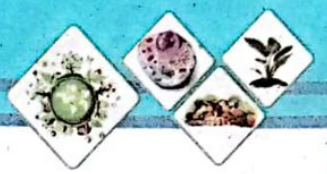



**Fig 8.8 Life cycle of Angiosperms**

## Development of female gametophyte:

Megasporangium (Ovule) within ovary contains mega spore mother cells which undergoes reduction division to form four haploid megaspores. Three of them disintegrate and only one survive, which after successive mitotic division develop into seven-cell (eight nucleated) structure called female gametophyte or embryo sac. Out of seven three cells found toward chalaza and called **antipodal cells**, three cells found toward microphyle called egg apparatus, two of which termed **synergid cells** and one comparatively large cell is **egg cell** and one central cell with two nuclei called polarnuclei which after fusion called secondary nuclei or definitive nuclei. All the cells except **secondary nuclei** are haploid. This multicellular structure of ovule is termed **embryo sac** which constitutes the female gametophyte of angiosperm, male and female gametophyte dependent on sporophyte.



**Double fertilization:**

After pollination, pollen grains transfer and settle on the stigma of carpel, The pollen tube grows through the tissue of the stigma and style than enters the ovary with tube nucleus at its tip. When the tip of the pollen tube reaches on ovule, it enters the micropyle and then discharges the two sperm cells into the female gametophyte (embryo sac). One sperm fertilizes the egg cell to form zygote (2n) which further develops into an embryo sporophyte. By the time fertilization occurs the two polar nuclei of the female gametophyte have combined to form a diploid fusion nucleus with which the second sperm unites to form a triploid nucleus structure. This nucleus undergoes a series of division and a triploid cell, called endosperm is formed. The endosperms function in the food for the embryo.

Food storage organ provide food to embryo at the time of germination. Double fertilization is a special type of fertilization which occurs only in angiospermic plants. During this process a sperm fuses with the ovum to form oospore. The other sperm fuses with secondary nucleus to form triploid endosperm nucleus.

After fertilization the ovule matures and develop into seed while ovary develops into the fruit. The fruit not only helps to protects the seeds from desiccation during the early development, but often also facilitates their dispersal by various means.

| Activity:<br>Arrange a field trip and collet Cassia, Brassica, Achyranthus, Marcus,Helianthus flowers. Identify different type of inflorescence. |
|---|
| Collect flower of Rose, Cassia fistula, Solanum nigrum and Avena sativa. Describe their flowers |

### 8.4.5 Angiosperms as successful group of land Plants:

The life cycle of angiosperm shows that angiosperms are so well adapted to life on land. Their major advantage over other plants is related to their reproduction. Here they are better adapted in three important ways.

1. The gametophyte generation is very reduced. It is always protected inside sporophyte tissue, on which it is totally dependent .In mosses and liverwort where the gametophyte is conspicuous ,while in seedless vascular plants it is a free-living prothallus. The gametophyte is susceptible to drying out.
2. Fertilization is not dependent on water as it is in other plant groups, where sperms swim to the ovum .The male gametes of seed plants are non-motile and are carried within pollen grains that are suited for dispersal by wind, insects,water and animals. Finally transfer of male gametes after pollination takes place by means of pollen tubes. The ova being enclosed within ovules.

3. Conifers and flowering plants produce seeds. Development of seeds is made possible by the retention of ovules and their contents on the parents sporophyte

### 8.4.6 Inflorescence:

It is mode of branching of floral axis having a group of flower, or it may be defined as arrangement of group of flowers on a floral axis. There are two types of inflorescence recemose and cymose. In recemose inflorescence, main axis called **penduncle** continues to grow. The flower develop in **acropetal succession** and opening of flower is centripetal. Whereas in cymose inflorescence, main axis soon stops growing. The flower develop in basipetal succession and opening of flower is centrifugal.

**Kinds of recemose inflorescence:**

**Peduncle elongated:**

**Receme** is an inflorescence in which flowers are pedicellate and bisexual e.g., Gold mohar whereas in **spike**, the flowers are sessile and bisexual (amaranthus) **Catkin** is another kind of inflorescence in which flowers are sessile and unisexual (Mulberry) whereas in **spadix**, flowers are covered over by one or many large bracts called **spathes** (e.g Banana)

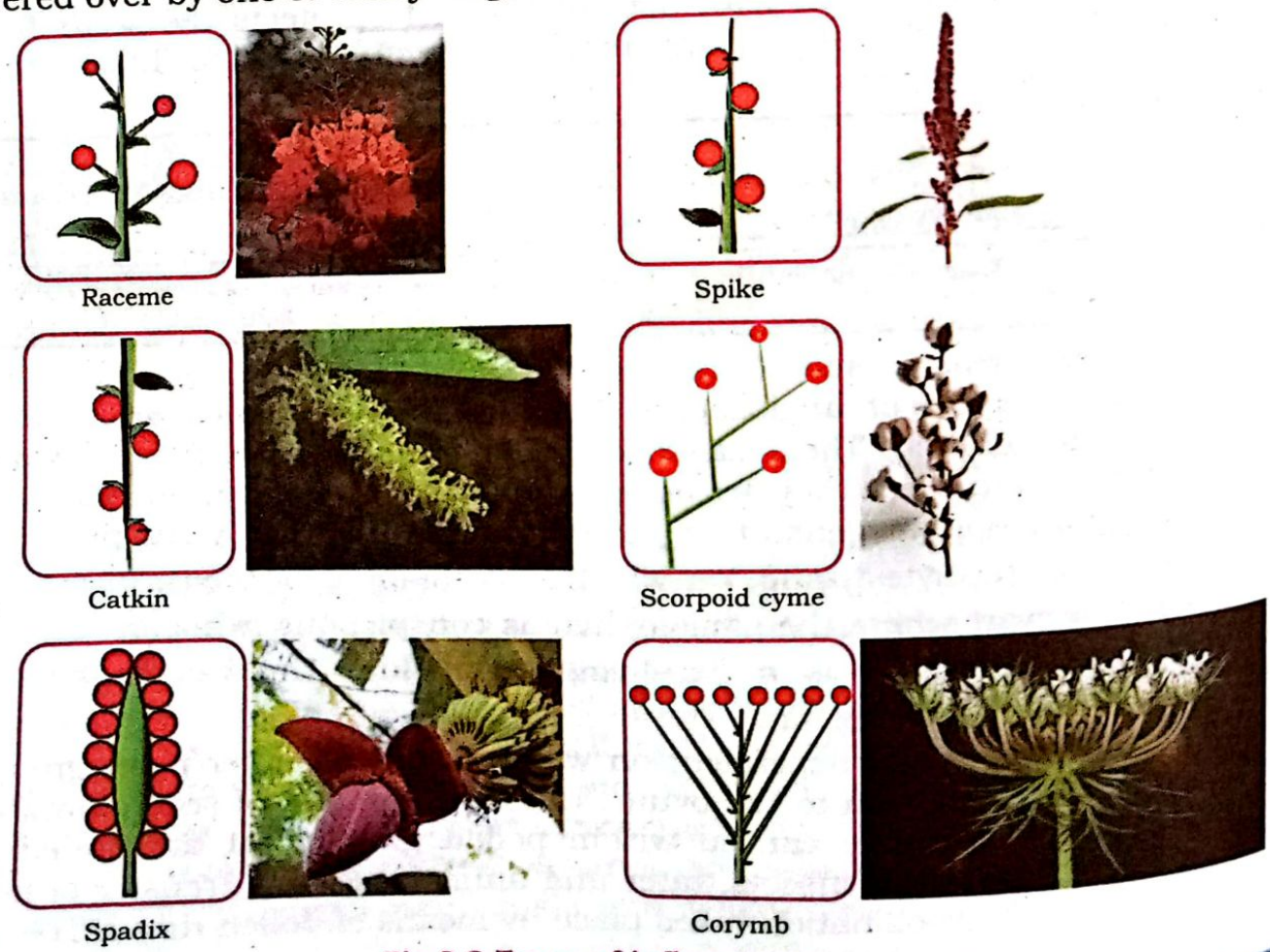



**Fig 8.9 Types of inflorescence**

**Peduncle shortened:**

**Corymb** is an inflorescence in which flowers have pedicels of unequal length lower flowers having large pedicels and upper ones having small (e.g. Iberis) when pedicels are of same length and arise from common point, the type is known as **umbel** (corianders)

**Peduncle flattened:**

**Head (capitulum)** flattened peduncle has a mass of small sessile flowers (florets) with one or more whorls of bracts at the base forming an involucre. The florets are commonly of two kinds namely ray florets (marginal) strap shaped and disc- florets (Central tubular ones) e.g sunflower, zinnia, marigold etc.

**Spikelet Inflorescence:**

It is kind of recemose inflorescence. There are three bracts at its base called **glumes**. The lower two without flowers are called empty lemma, there is small bracteoles called **Palea**. Flowers, covered by their respective lemma and palea. This type of inflorescence is characteristic feature of family Poaceae.

**Kinds of cymose inflorescence:**

**Uniporous ( Monochasial) cyme:**

Main axis soon ends into a flower and produces only one lateral branch at a time ending in a flower. The succeeding lateral branches again follow the same mode of producing flower. If the succeeding branches are produced on alternate sides, it is called **scorpioid cyme** ( cotton , forget-me-not) . Whereas, if the succeeding branches are produced on same side, it is called **helicoid cyme** (sundew).

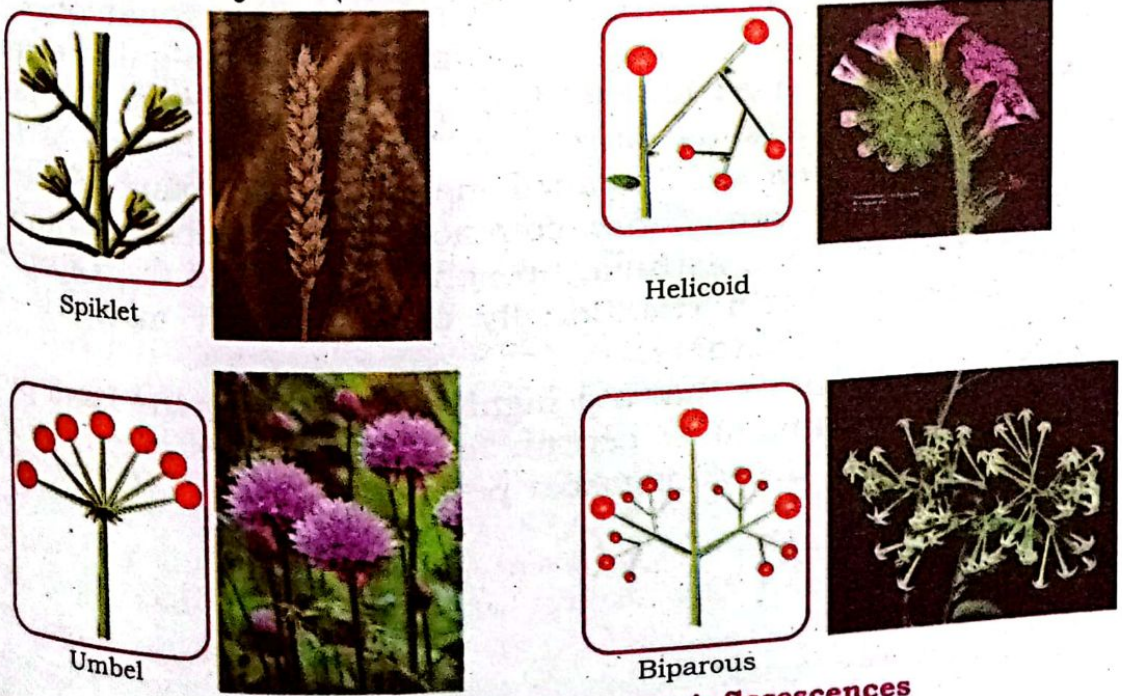
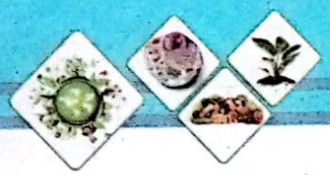



**Fig 8.10 Types of cymose inflorescences**





**Biparous (dichasial) Cyme:**

Main axis soon terminate into a flower and produces two flower . This mode is followed by each succeeding flower ( Pink night- jasmine).

### 8.4.7 Significance/benefits of angiosperms for humans:

Angiosperms are very important to human. They have number of uses as food; specially cereals from the grass family. Among most economically important grains are corn (Zeamays), barley (Hordium), oats (Avena), wheat (Triticum) and rice (Aryza).

**Vegetables:**

There is a variety of vegetables, different in forms and nutritional content, and are grown for one or more of their parts the flowers, shoots, leaves or the underground parts. E.g., Potato, tomato, eggplant and chilli pepper from the potato family (Solanaceae), legumes and beans (Fabaceae), pumpkin, melon and gourd from the squash family (Cucurbitaceae), cabbage, cauliflower, radish and mustard seeds from mustard family (Brassicaceae).

**Fruits:**

A large number of fruits belongs to rose family (Rosaceae), e.g. Almonds, apples, apricots, cherries, peaches, pears, raspberries and strawberries. Citrus fruits from family Rutaceae, bananas from family Mucaceae and Papaya from family Caricaceae.

**Medical/Pharmaceutical plants:**

Flowering plants have great pharmaceutical and medical value. Citrus fruits are source of vitamin C, aspirin from bark of willows, narcotics such as opium from opium poppy, quinone from cinchona. Arq-e-gulab extracted from rose (*Rosa indica*) is used as eye drop and for soothing. The pulp of amaltas (*Cassia fistula*) acts as purgative. *Atropa belladonna* of family Solanaceae, *Solanum nigrum* locally called mako used as pain reliever and anti-inflammatory. *Ocimum tenuiflorum* commonly called tulsi used in many herbal medicines to help treat asthma, bronchitis, cold and flu. *Glycyrrhiza glabra* locally called mulhethi traditionally used to treat many diseases particularly in respiratory disorders.

Angiosperm compounds that are highly toxic to humans have proved to be effective in the treatment of certain forms of cancer, such as acute leukemia (vincristine from the Madagascar periwint).

## SUMMARY

- Plants are multicellular eukaryotes with photosynthetic nutrition.
- The story of plant revolution is mainly of gradually improving adaption to life on earth.
- Plants show heteromorphic alternation of generation and zygote retained and develops into embryo.
- Bryophytes are small, photosynthetic, free-living gametophytes that lacks vascular tissues.
- Heterogamy is the most successful kind of reproduction that has evolved in bryophytes.
- All the biologists agree that the land plants and animals evolved from aquatic ancestors.
- Land invading plants adapted themselves first to amphibious habits and then developed a complex terrestrial form of life.
- Vascular plants characterized by the presence of vascular tissues i.e. Xylem and Phloem. The dominant generation of living vascular plant is the sporophytes, existing as free-living plants.
- Ferns are the most diverse and conspicuous of the spore-producing vascular plants with about 12000 living species.
- The gametophyte of Pteridophyte (Ferns) is called Prothallus, The Prothallus is independent, autotrophic, heart shaped, dorsoventrally flatland lying prostrate on wet substratum.
- The seed plants have been by for the most successful in fully exploiting the terrestrial environment. They first appeared in the late Devonian, and in the carboniferous they soon replaced the lycopsids and sphenopsids as the dominant land plants, a position they still hold today.
- The seed plants have traditionally divided into two groups. 1. The Gymnospermae 2. The Angiospermae. Gymnospermae have naked seeds because ovules are not covered by ovary while Angiospermae have their seeds enclosed in fruits because ovules are covered by ovary.
- Double fertilization is the specific type of fertilization which occurs only in angiospermic plants. During this process a sperm fuses with the ovum to form ouspore (zygote). The other sperm fuses with secondary nucleus to form triploid endosperm nucleus.
- Flower may be described as compressed reproductive shoot with four whorls of modified (floral) leaves called sepals, petals, stamens and carpels; and which after pollination and fertilization produces seeds within fruits.
- Inflorescence is made of branching of floral axis having a group of flower. The inflorescence may be recemose or cymose.

# EXERCISE

## 1. Encircle the correct choice

(i) The rapid diversification of plants occurred in the period:
(a) Silurian (b) Devonian
(c) Carboniferous (d) Paleozoic

(ii) Spores of land plants tough, flexible and resistant to biodegradation by:
(a) Lignin (b) Chitin
(c) Waxes (d) Sporopollenin

(iii) Hepaticae, Anthocerotae and Moss are the classes of:
(a) Angiosperms (b) Gymnosperms
(c) Tracheophytes (d) Bryophytes

(iv) The most successful kind of reproduction is:
(a) Heterogamy (b) Oogamy
(c) Anisogamy (d) Isogamy

(v) The dominant generation of living vascular plants existing as free-living plants is:
(a) Sporophyte (b) Gametophyte
(c) Tracheophyte (d) Pteridophyte

(vi) The most primitive living vascular plants is:
(a) Lycophyta (b) Sphenophyta
(c) Psilophyta (d) Filicinophyta

(vii) The gametophyte of Fern is called:
(a) Archegonium (b) Antheridium
(c) Cones (d) Prothallus

(viii) Double fertilization is the characteristic feature of:
(a) Bryophytes (b) Gymnosperms
(c) Angiosperms (d) Ferns

(ix) Resins, turpentine and pine oil are obtained from:
(a) Rose (b) Onion
(c) Pins (d) Banana

(x) In banana tree, flowers are covered over by one or many large brackets called:
(a) Spathes (b) Spadix
(c) Capitulum (d) Palea

**2. Write short answers of the following questions:**

1. How life cycle of plants shows alternation of generations?
2. Why bryophytes are called non vascular plants?
3. How plants cope when invaded the land from the sea?
4. Why heterogamy is important for plants?
5. Why flower is called a reproductive part of plant?
6. Why fertilization in angiosperm is called double fertilization?
7. How seeds are evolved?
8. Why gymnosperms have naked seeds but not angiosperms?

**3. Write detailed answers of the following questions:**

1. Define plants. Discuss evolutionary relation in plants.
2. Write down general characteristics of plants.
3. Describe lifecycle of Moss with diagram.
4. Why vascular plants are considered more successful land plants?
5. How leaves are evolved?

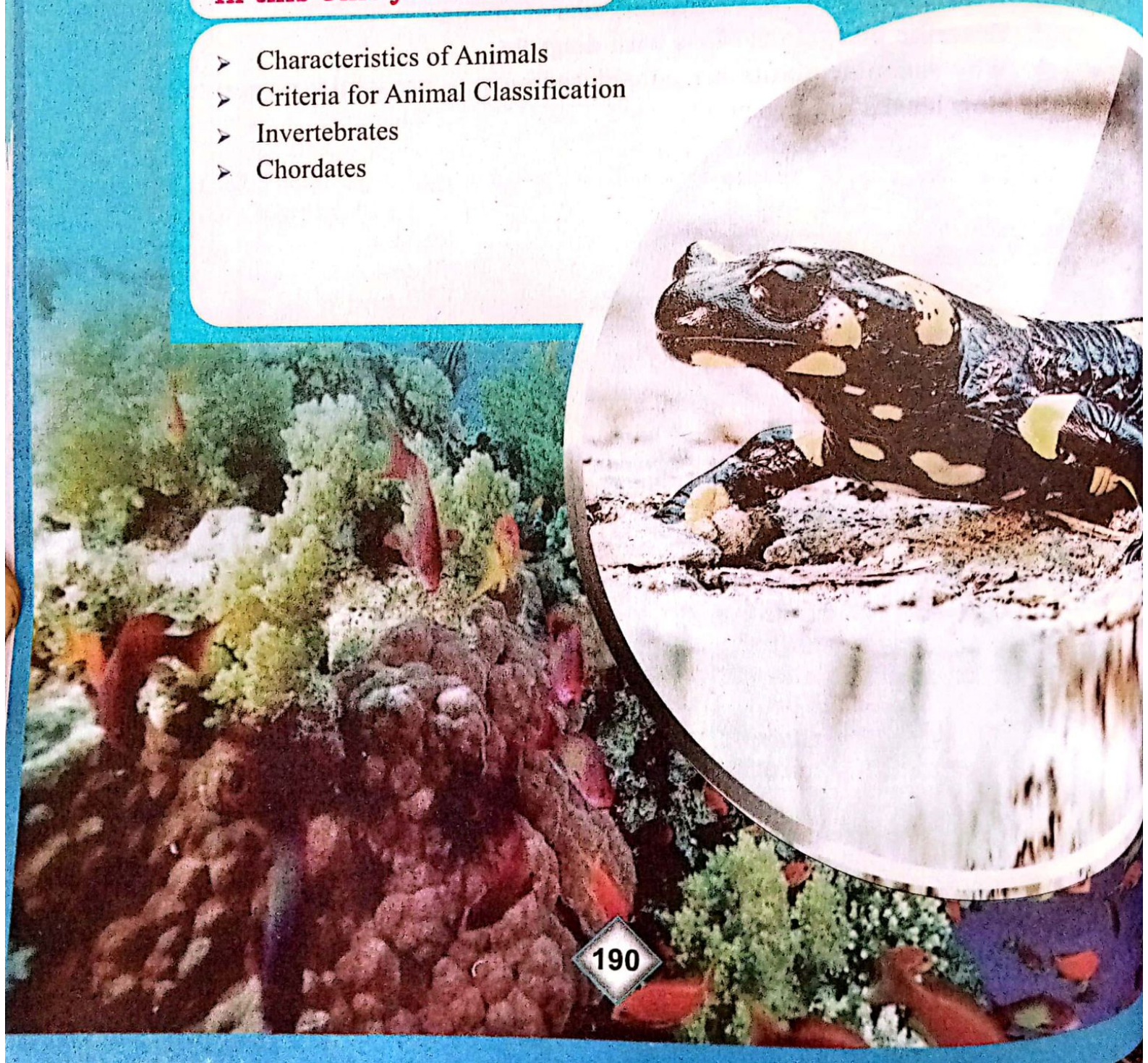
# DIVERSITY AMONG ANIMALS

Chapter 9

## Major Concept

**In this Unit you will learn:**

- Characteristics of Animals
- Criteria for Animal Classification
- Invertebrates
- Chordates



## Diversity Among Animals

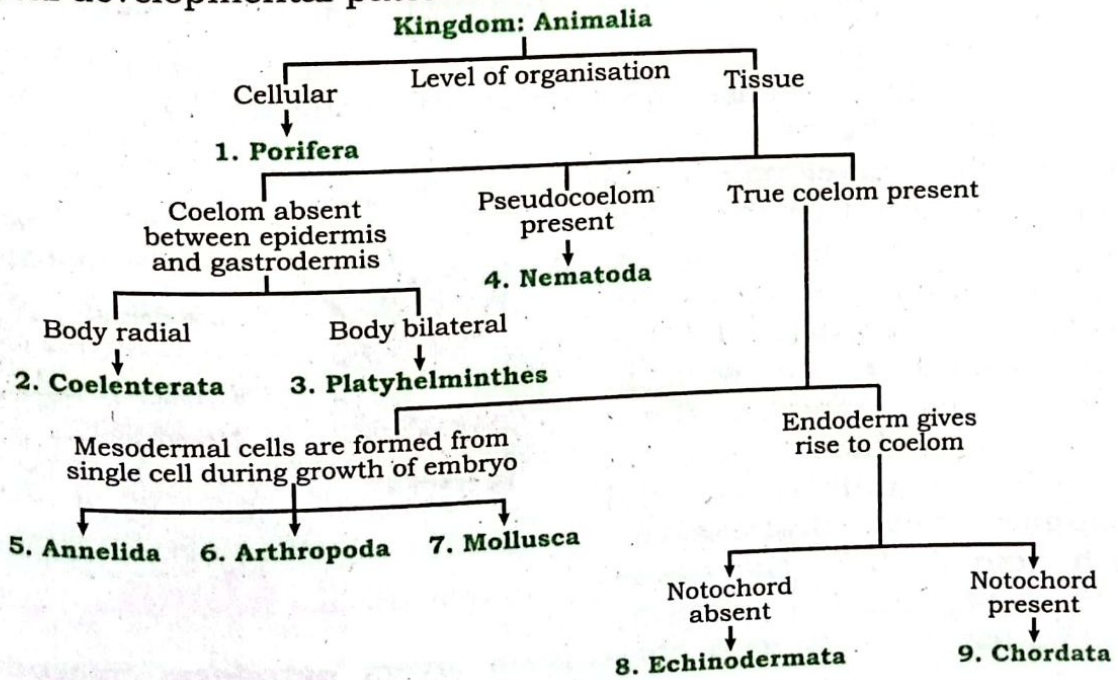
The term animal derived from Latin word "anima" means breath or soul. Animals are incredibly diverse in structure they range from simple parazoan that can only be seen with a microscope to blue whales, which weigh in upto 150 tons and 40m long. A good definition of an animal is not as easy as it might first appear. There are exceptions to nearly every criterion for distinguishing an animal from other life forms. However, when taken together, the following characteristics of animals will serve our purposes.

## 9.1 CHARACTERISTICS OF ANIMALS

Animals are multicellular, heterotrophic (ingestive) eukaryotes that can reproduce sexually. Although animal species exhibits a tremendous diversity of reproductive styles, all are capable of sexual reproduction. Lack cell wall, motile and able to make responses to external stimuli.

## 9.2 CRITERIA OF ANIMAL CLASSIFICATION

The kingdom animalia is divided into 33 groups called phyla. But we will consider in depth only nine major phyla. These major phyla are Porifera, Cnidaria, Platyhelminthes, Aschelminthes, Annelida, Mollusca, Arthropoda, Echinodermata and chordata whereas rest of the groups are minor phyla. This classification or grouping of animals is called taxonomy or systematics. It is carried out primarily on the basis of their evolutionary relationships. Clues to these relationships are found in (i) Comparative morphology and (ii) internal architecture which includes presence and absence of tissues, number of tissue layers, symmetry and the embryological developmental pattern of their coelom and blastopore.



### 9.2.1 Classification based on presence and absence of tissues

All animal are multicellular and their cells are eukaryotic, these cells are joined together into tissues, tissues into organs and organs system into organism. One phylum Porifera is grouped in a separate sub-kingdom **Parazoa**, because its members lack true tissues. Rest of the eight phyla consisting sub-kingdom eumetazoa (true metazoans) have tissues organized into organs (in lower groups) and organs into systems (in higher forms).

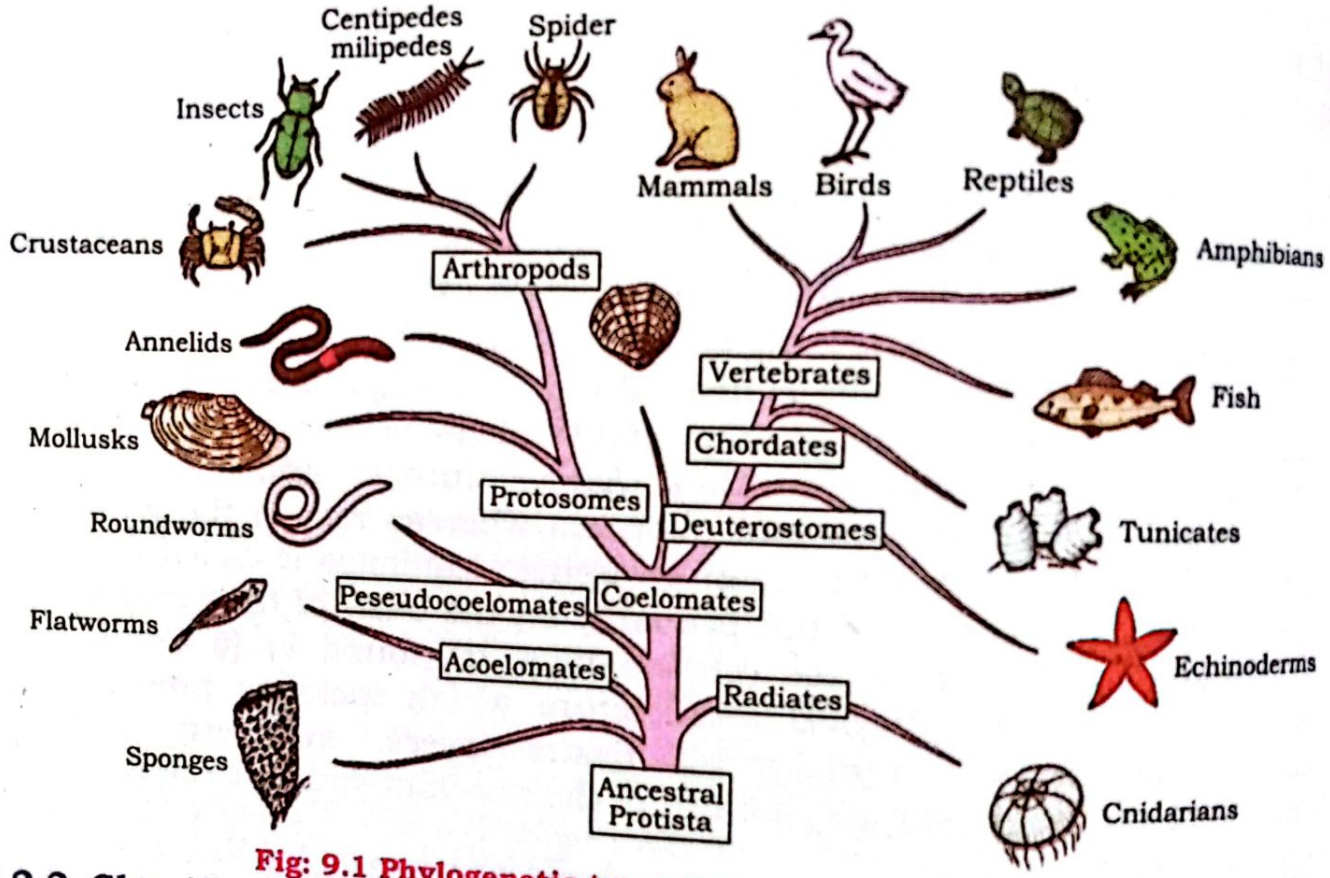



**Fig: 9.1 Phylogenetic tree of the animal kingdom**

### 9.2.2 Classification based on number of tissue layers

One of the main events during the development of animals is the establishment of germ layers or tissue layers. From which all other structures are derived. Although a total of three germ layers is seen in most animal embryos. Some animals only have two germ layers: **ectoderm** and **endoderm** called **diploblastic**, such animals have the tissue level of organization example; cnidarians. Animals with three germ layers **ectoderm**, **mesoderm** and

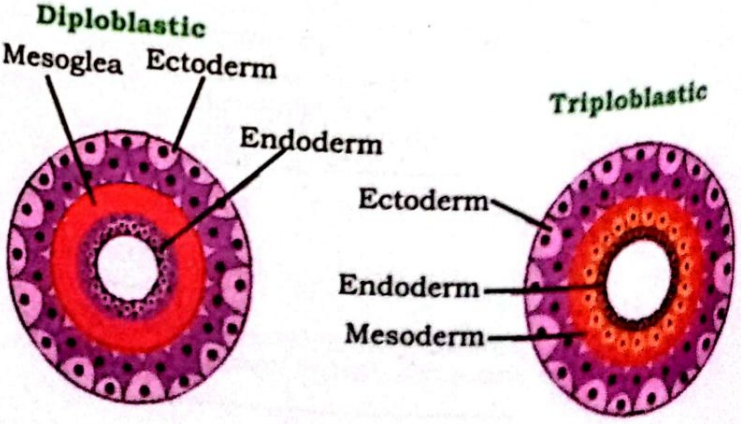



**Fig: 9.2**
**Diploblastic and Triploblastic organization**

**endoderm** called **triploblastic** such animals have organ and system level of organization. Example: Platyhelminthes to chordata.

### 9.2.3 Classification based on symmetry

The simplest animals, the sponges have many representatives whose bodies are irregular, and variable in shape so called asymmetrical. The eumetazoans are divided into two major groups on the basis of body symmetry. Members of phylum cnidaria have **radial symmetry** and group called **Radiata**. A radial animal has a top and bottom, or an oral and aboral side, but no head end and rear end and no left and right. The other major groups of eumetazoa are **bilateral symmetry**. A bilateral animal has not only a dorsal (top) side and ventral (bottom) side, but also an anterior (head) end and a posterior (tail) end and a left and right side. Animals of this group collectively called the **bilateria**.

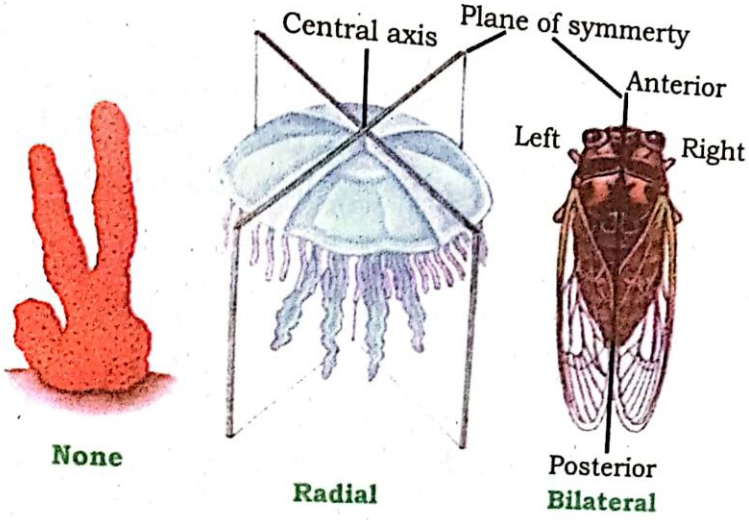



Fig: 9.3 Symmetry in animals

### 9.2.4 Classification based on coelom

The bilaterally symmetrical animals are classified into three groups on the basis of body cavity or coelom. **Acoelomate;** simple animals such as flatworms lack any internal space or coelom between their body wall and their gut. **Pseudocoelomates**; animal such as round worms (aschelminthes) have a cavity through it is incompletely lined with mesoderm. There is a layer of mesoderm beneath the body wall but not around gut. **Coelomates**; animals from annelids to chordates have a true body cavity or coelom that is completely lined with

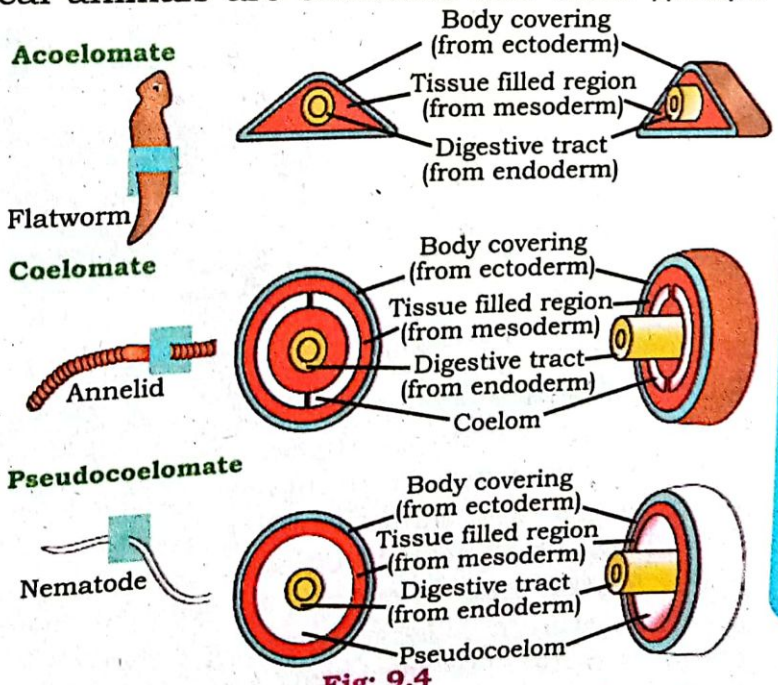



Fig: 9.4
Acoelomate, pseudocoelomate and coelomate

mesoderm. Coelomates are either protostomes or deuterostomes, when the blastopore (the site of invagination during development) is associated with mouth the animal is a **protostome** (Annelids, Molluscs and Arthropods). When the blastopore is associated with the anus and a second opening becomes the mouth, the animal is a **deuterostome** (Echinodermates, hemichordates and chordates).

A total of 1.3 million species of animals are placed in one of two major categories; **vertebrates**, those with a backbone, or vertebral column, and **invertebrates**, these lacking backbone. The invertebrates include 97% of all the animal species on earth.

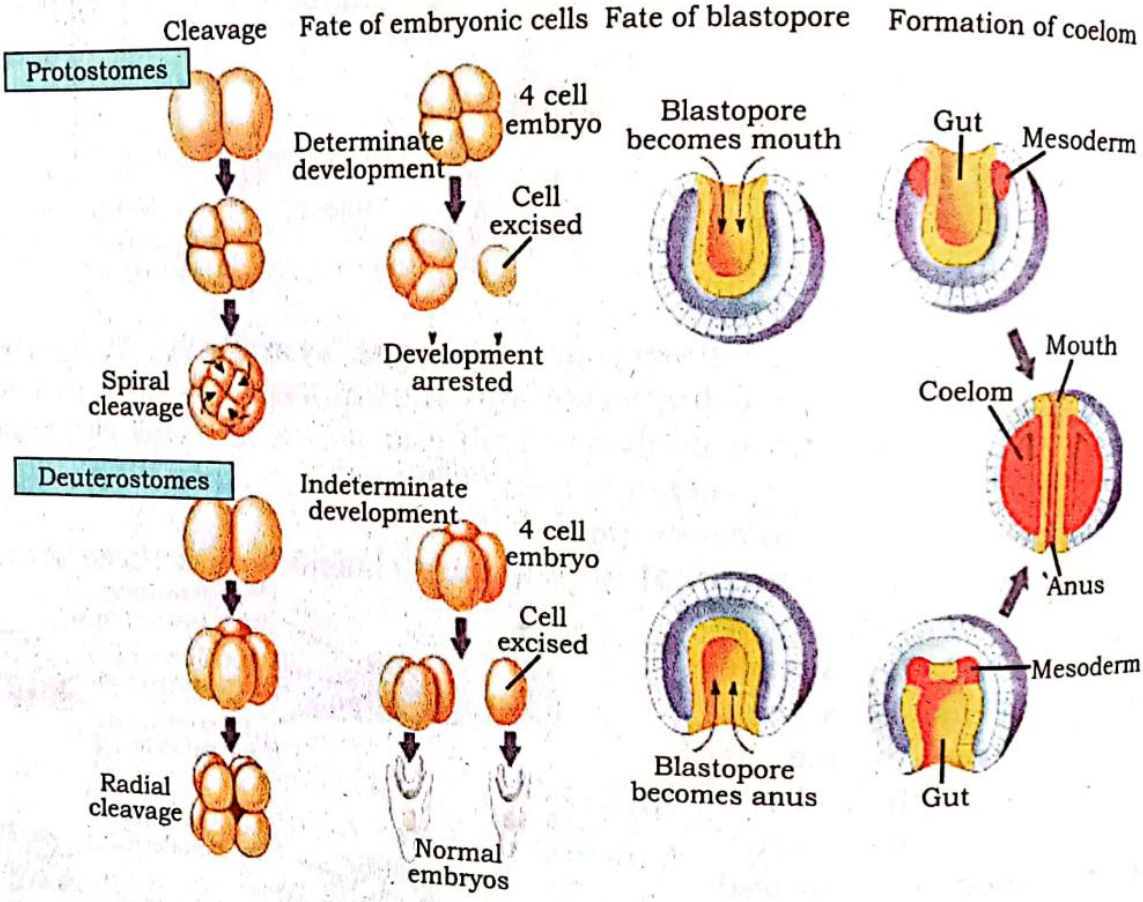



**Fig: 9.5 Protostomes and Deuterostomes**

## 9.3 PHYLUM PORIFERA (PORE BEARING)

### General characters of phylum porifera

Sponges are the simplest animals lacking true tissues and organs. All sponges are aquatic filter feeders. The body of a simple sponge resembles a sac perforated with pores (holes). Water is drawn through the pores (**ostia**) into a central cavity the **spongocoel** then flows out of the sponge through a large opening called the **osculum**. The body of sponge consists of two layers of cells separated by a gelatinous mesenchyme. Outer is made up of flattened epithelial cells called **pinacocytes**, inner layer is

made up of flagellated cells called **choanocytes** or **collar cells**. Sponges may grow to over a meter in height and have an internal skeleton, which is composed of **spicules**, provides support for the body, the spicules may be formed from calcium carbonate, silica and protein. The bath sponge now rarely used which have proteinaceous endoskeleton.

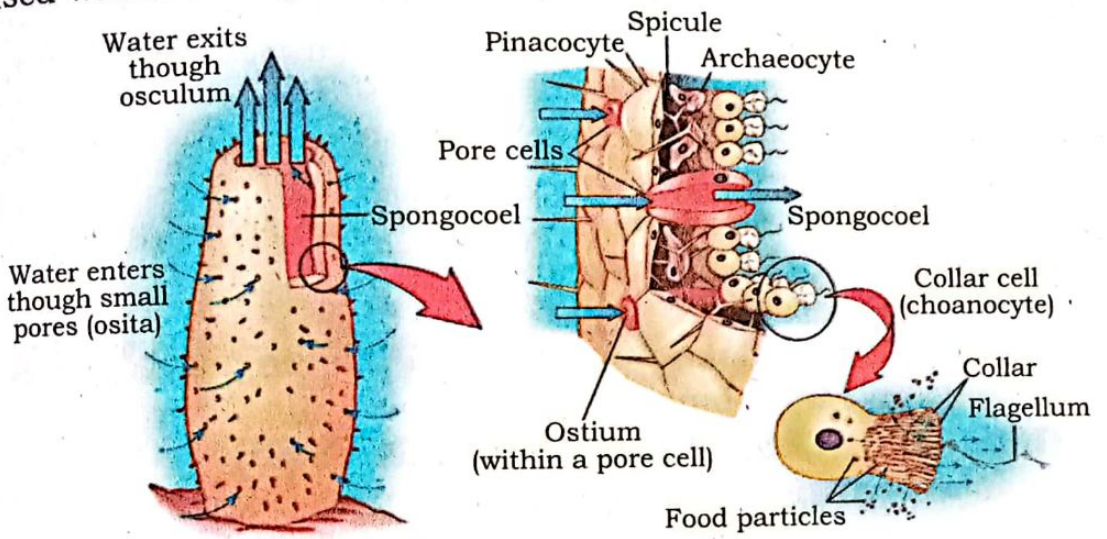



**Fig: 9.6 Sponge cellular structure**

Most sponges are hermaphrodite whereas in few members sexes are separate. Sponges can reproduce asexually by **fragmentation** or by **budding** or **gemmules**. During sexual reproduction eggs and sperm formed by **amoebocytes**. The sperm are carried out by water current to neighbouring sponges where fertilization takes place. The fertilized egg develops into a multicellular free-swimming larva which settles to the bottom and grows into an adult. Common sponges; *Sycon* (Fig: 9.7-a), *Euplectella* (Fig: 9.7-b) and *Spongilla* (Fig: 9.7-c)

**Fig: 9.7: (a) Sycon**

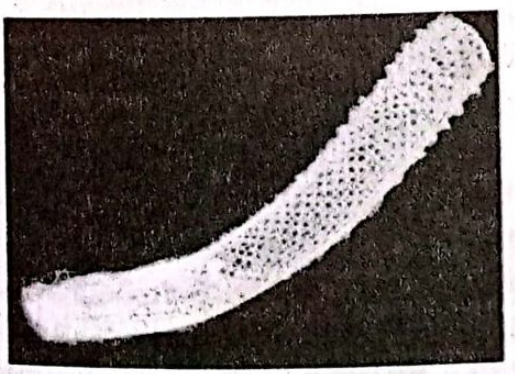


**Fig: 9.7: (b) Euplectella**

**Fig: 9.7: (c) Spongilla**

**Extra reading material**

Sponges are master filter. They can filter an amount of water 100,000 times their size each day. That means a basketball-sized sponge could filter an entire residential pool in one day. Sponges often use chemicals to deter predators from eating them. Scientists have discovered that some of these chemicals may have potential to treat cancer and HIV.

### 9.3.1 Evolutionary Adaptations in sponges

Sponges evolve from colonial flagellated protoctists that lived over 700 million years ago, these protoctists were probably related to choanoflagellates.

**Digestion:** The simplest form of digestion is found in sponges, which lack digestive tract. In sponges digestion is entirely intracellular.

**Respiration:** Respiratory system is not found in sponges. Diffusion is sufficient for gases exchange.

**Excretion:** Diffusion helps in excretion hence there is no special organ for the removal of nitrogenous waste.

**Transport**: Diffusion is sufficient for transport within sponges.

**Nervous system:** Sponges lack nerve cells.

### 9.3.2 Importance of sponges

Sponges with fibrous skeleton are used for the purpose of bathing, polishing, washing and scrubbing.

## 9.4 PHYLUM CNIDARIA (WITH NEMATOCYTES)

### General characters of phylum cnidaria

The cnidarians are clearly a step above the sponges in complexity, their cells are organized into distinct tissues, including contractile tissues that act like muscle. Cnidarians all are aquatic majority of them are marine whereas few live in fresh water. They are radially symmetrical and diploblastic their body wall encloses a hollow cavity the **gastro-vascular cavity** or **coelenteron** hence the named coelentrata. All cnidarians are **carnivorous**, they paralyse or kill their prey with the help of special stinging cells called **cnidocytes** hence the name cnidaria. They have two distinct body forms polyp and medusa. **Polyps** are cylindrical with mouth and tentacles upward, **Medusa** on the other hand umbrella shaped whose mouth and tentacles downward. Cnidarian can reproduce by both asexual and sexual methods, asexual reproduction takes place by budding and regeneration whereas sexual reproduction involves the fusion of sperms and eggs released into the water, the fertilized egg developed into free swimming larva.

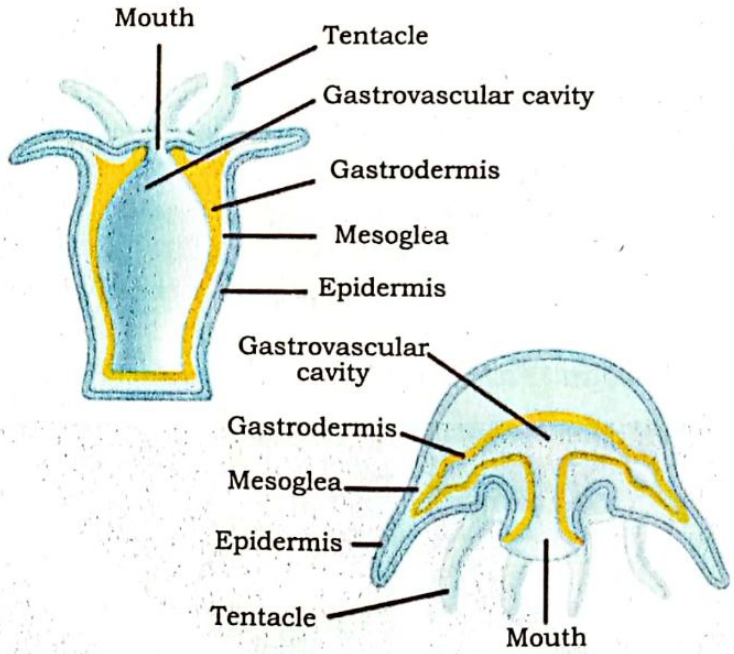



**Fig: 9.8: Polyp and medusae**

Common cnidarians: *Hydra* (Fig: 9.9-a), Jelly fish (Fig: 9.9-b), and Sea anemone (Fig: 9.9-c).

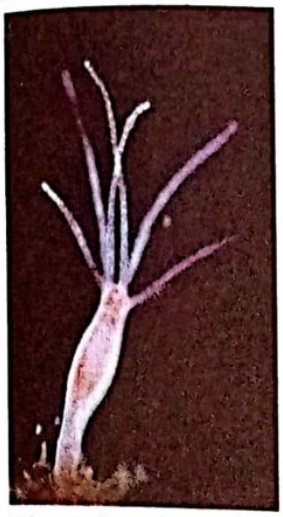


Fig: 9.9: (a) Hydra

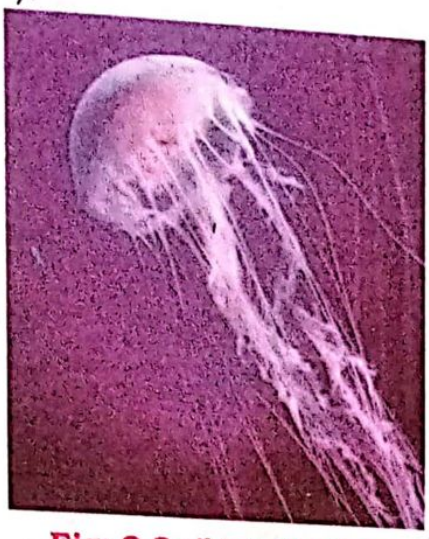


Fig: 9.9: (b) Jelly fish

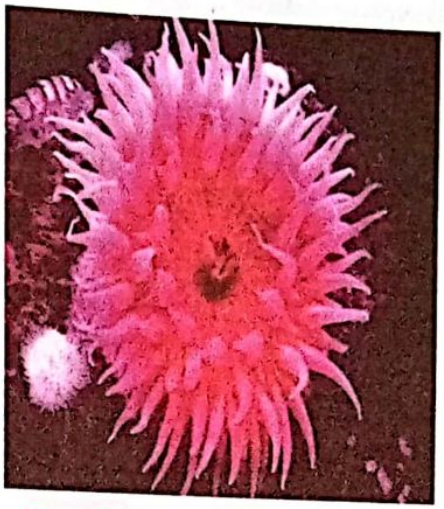


Fig: 9.9: (c) Sea Anemone

### 9.4.1. Evolutionary adaptations of cnidaria

Cnidarian evolved along one of the three evolutionary lines from the protoctista

**Digestion:** Digestive system consisting of a sac called gastro-vascular cavity with a single opening mouth help in both ingestion and egestion.

**Respiration:** There is no respiratory system both ectodermal and endodermal cell exchange gases with water.

**Excretion:** There is no excretory system, diffusion is only responsible for removal of nitrogenous waste.

**Transport:** Gastro vascular cavity help in transport of nutrients throughout the body.

**Nervous system:** The nerve cells are organized into tissue called a nerve-network or diffuse type nervous system.

**Extra reading material**

Some cnidarians are the longest animals in the world, one of them that can stretch as long as 40m is the *Praya dubia*.

Jelly fish are made up of more than 95% water and they have no brains, blood or nervous system. Jelly fish can have up to 800 tentacles.

### 9.4.2. Importance of Cnidaria

Coral reefs which are usually restricted to warm shallow water provide a heaven to large number of marine species. Jewelry and other decorative items are carved from red corals. **Red corals** named **MARJAN** are used by Hakeem in preparing eastern medicine.

## 9.5 PHYLUM PLATYHELMINTHES (FLAT WORMS)

### General characters of phylum cnidaria

Flat worms are so named because their bodies are thin between the dorsal and ventral surfaces (flattened dorsoventrally). They range in size from nearly microscopic free living to 20 m long tapeworms. They are **acoelomate**, **bilaterally symmetrical**, **triploblastic** animals with organs

and organ system. Some flat worms have a head with a pair of **eye spots** that detect light, free living flat worm move with the help of cilia present on the ventral epidermis. Flatworms can reproduce by both asexual and sexual methods. Free living form reproduces asexually through regeneration. All forms can reproduce sexually and most are hermaphrodite (monoecious).

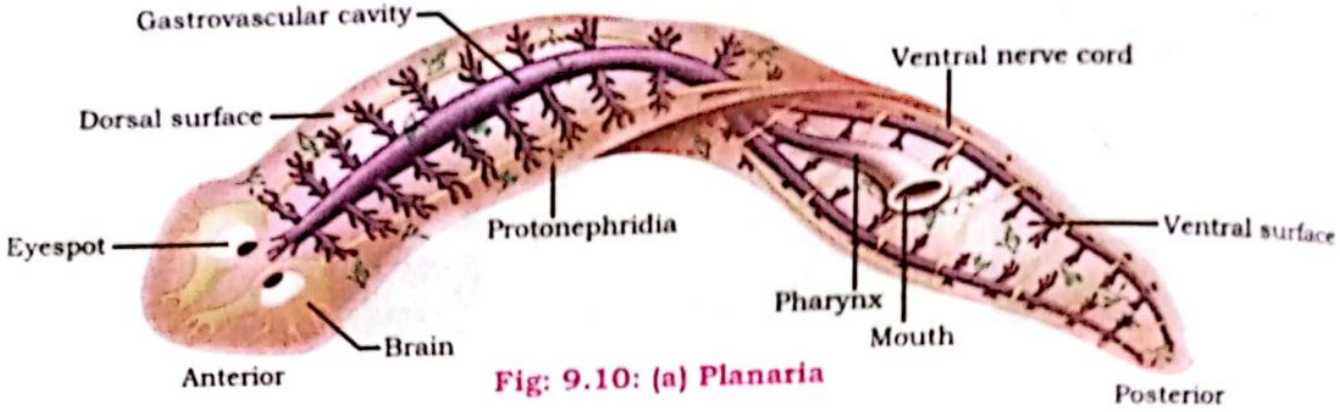



Fig: 9.10: (a) Planaria

Common Platyhelminthes: Planaria (*Dugesia*) (Fig: 9.10-a), Liver fluke (*Fasciola hepatica*) (Fig: 9.10-b) and tapeworm (*Taenia saginata*)

Fig: 9.10: (b) Liver fluke

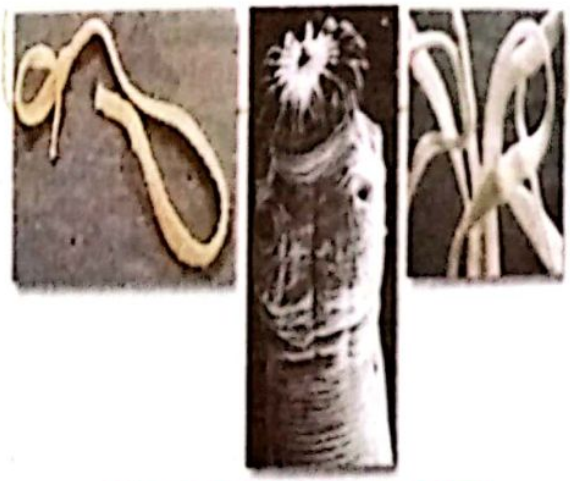


Fig: 9.10: (c) Tape worm

### 9.5.1. Evolutionary adaptations in Platyhelminthes

Flatworms do not look anything like cnidarians, the two share some features that have led biologist to speculate that they evolved from a common ancestor. Both have a gastro-vascular cavity.

**Digestion:** The food is digested in an intricately branched gastro-vascular cavity that distributes nutrients to all parts of the body.

**Respiration:** Exchange of gases by diffusion between the cells and the environment.

**Excretion:** Simple system of excretion consisting on network of canals ending in bulb shaped cells having cilia called flame cells (Proto-nephridia).

**Transport:** No specialized circulatory system.

**Nervous system:** Ladder type nervous system consists of the two lateral nerve cords, plus the connecting nerves looks like a ladder. Paired ganglia (collection of cells) function as brain.

**Extra reading material**

The flatworms are not really flat and have a rounded body instead. They do have a flat belly through. The flatworms can either be extremely tiny or can grow to become several inches long. They are pointed on both ends are characterized by eye spots on the head. Their colors may vary from being translucent white, green as well as brown. It could also be blotchy and mottled as well.

### 9.5.2 Importance of Platyhelminthes

Flatworms, such as the planarians, are mostly free living while some are parasites.

## 9.6 PHYLUM ASCHELMINTHES (NEMATODS)

### General characters of phylum Aschelminthes

Aschelminths commonly called **round worms** are the most abundant animals on earth, found everywhere in sea, freshwater and soil. Round worms have a varied mode of existence from free living, scavengers to predators and parasitic on animals and plants. Most are microscopic but some parasitic form reach a meter in length, have long bilaterally symmetrical, triploblastic, pseudocoelomate and cylindrical bodies with pointed ends. The muscles of nematodes are all longitudinal and their contraction produces a thrashing motion. Round worm reproduce sexually the sexes are separate in most species females generally larger than males, fertilization is internal. Common Aschelminths: *Ascaris* (Fig: 9.11), *Ancylostoma* and *Wuchereria.*

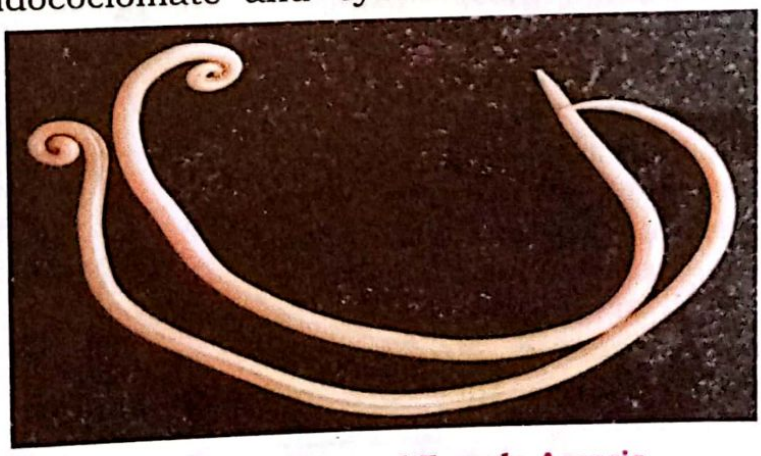


**Fig: 9.11: Male and Female Ascaris**

### 9.6.1 Evolutionary adaptations in Aschelminthes

**Digestion:** Tubular gut running from mouth to anus. Digestive system is complete.

**Respiration:** Diffusion sufficient for gases exchange, has no respiratory system.

**Transport:** Circulatory system not found.

**Excretion:** Excretory system consists of two canals, which run down the length of worm.

**Nervous system:** Sensory organs in the head transmit information to a simple brain composed of a ring of ganglia.

**Extra reading material**

Nematodes are essential in the nitrogen cycle and for regulating the decomposition of organic matter. One species of nematode is known to control mosquitos by eating their larvae.

There are 60 billion nematodes for every human on earth. According to Barnes 80% of the living animals on earth are nematode worms

### 9.6.2. Importance of Aschelminthes

Round worms are important as agriculture pest that attack the roots of plants. Human serve as host of 50 species.

**Extra reading material**

Pest is any organism that spread any disease, causes destruction or is otherwise a nuisance. For example, mosquito, rodents and weeds.

## 9.7. PHYLUM ANNELIDA (SEGMENTED WORMS)

### General characters of Phylum Annelida:

Annelids are commonly called segmented worms, have the most complex body. Structures among of all the worms, they live on land, in moist soil, in freshwater or in sea. Many annelids are active free-swimming predators, some are aquatic filter feeder living in tubes buried in mud whereas leeches are ectoparasites, they are all triploblastic, bilaterally symmetrical, coelomate and protostomes with an organ system level of body organization. Chitinous chaetae also called **setae** with or without **parapodia** are usually present in the most of annelids and help in locomotion. Reproduction is usually sexually, most of annelids are hermaphrodite but in few sexes are separate, development through trochophore larvae. Common Annelids: Earthworm (Fig: 9.12-a), Neries and Leech (Fig: 9.12-b).

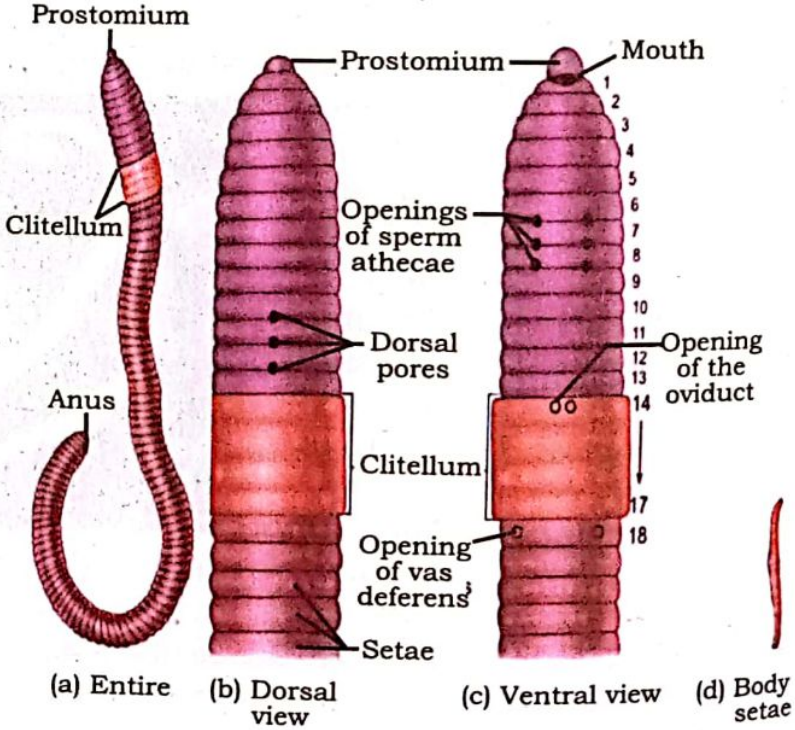



**Fig: 9.12 (a) Earth worm**

### 9.7.1. Evolutionary adaptations in Annelids

Annelids are supposed to have evolved from a primitive flat worm like ancestor in the sea.

**Digestion:** Tubular digestive system with both mouth and anus, complete system.

**Respiration:** Respiratory system is not found, diffusion is sufficient for gases exchange.

**Transport:** Closed type circulatory system with blood confined to the heart and blood vessels.

**Excretion:** Excretory organs are nephridia which are found in most segments.

**Nervous system:** Nervous system consists of simple ganglionic brain in the head.

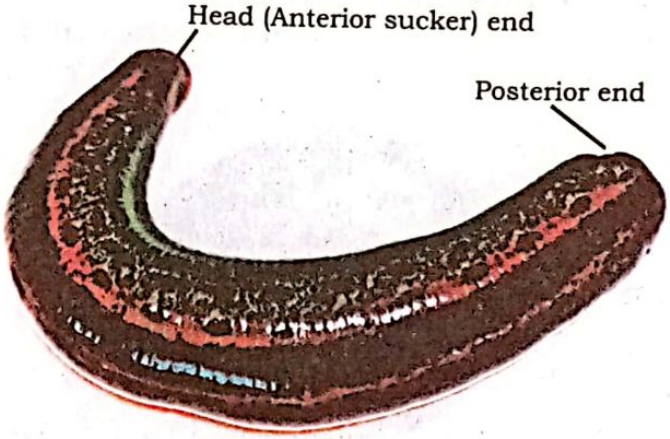



**Fig: 9.12 (b) Leech**

**Extra reading material**

Leeches have been used for medicinal purposes for a very long time. Back then, it was believed that leeching would get rid of the "Bad Blood" that caused diseases.

### 9.7.2 Economic Importance of Annelids

Earth worm help the farmer by continuously ploughing the soil and adding nitrogenous waste into it, thus making soil fertile, they are also used as fish bait. Leeches are ectoparasite and suck the blood.

## 9.8. PHYLUM MOLLUSCA (SOFT BODIED)

### General characters of phylum Mollusca

Molluscs are soft bodied animals, but most are protected by hard shell made of calcium carbonate, slug, squids and octopus have reduced shell, most of which are internal, or they have lost their shell completely during evolution. All the molluscs are triploblastic, bilaterally symmetrical, coelomates and protostomes with organ system grade of body organization. All molluscs have a similar body plan with

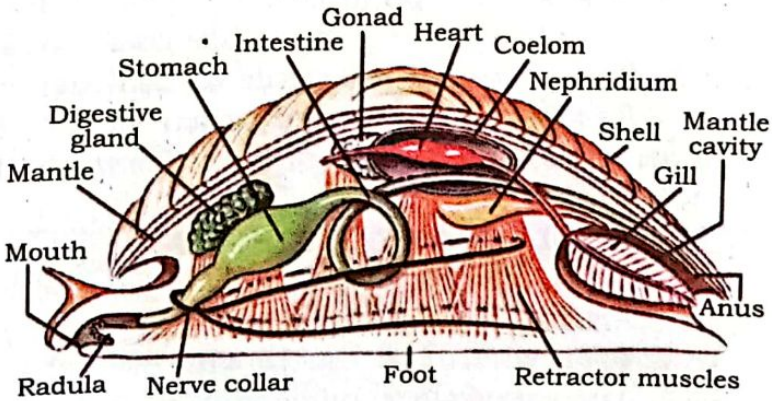



**Fig: 9.13 Anatomy of snail**

three main parts, **Muscular foot** usually used for movement, **visceral mass** containing most of the internal organs and a **mantle** a fold of tissue that drapes over the visceral mass and secretes a **shell**. Many molluscs feed by using a strap like rasping organ called a **radula** to scrape a food. Reproduction is always sexual, some species have separate sexes and others are hermaphrodite, they all pass through a trochophore larvae stage. Common Molluscs: *Unio* (Fig: 9.14-a), *Octopus* (Fig: 9.14-b) and *Pearl oyster*

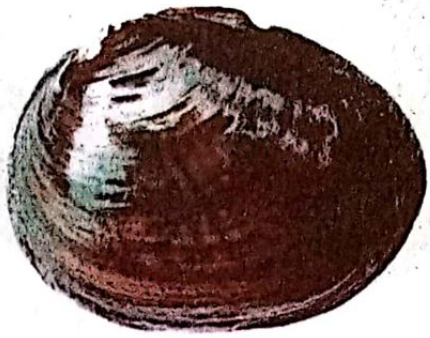


Fig: 9.14 (a) Unio

Fig: 9.14 (b) Octopus

**Extra reading material**

The oyster is usually ambisexual. It begins life as a male and then becomes a female. It may go back and forth many times. The giant squid is the largest creature without backbone. It weighs up to 2.5 tons and grows up to 60 feet long.

### 9.8.1. Evolutionary adaptations in molluscs

**Digestion:** Digestive system is straight with mouth and anus.

**Respiration:** Exchange of gases in aquatic forms with gills and simple lungs in terrestrial form.

**Transport:** Open type circulatory system in which blood directly bathing the organs in a haemocoel.

**Excretion:** well developed excretory system using tubular nephridia.

**Nervous system:** Nervous system consists of ganglia connected by nerves, but many more of the ganglia are concentrated in the brain.

### 9.8.2. Economic importance of mollusca:

A variety of molluscs called shell fish, together with crustaceans are still an important source of food. Their shells are decorative, some members make valuable pearl.

## 9.9. PHYLUM ARTHROPODA

### General characters of phylum Arthropoda

Arthropoda is the largest phylum of the animal kingdom, they are found everywhere on earth wherever the life is possible, even in the oil wells. Arthropods are bilaterally symmetrical, triploblastic, coelomates and protostomes. The diversity and success of arthropods are largely related to their segmentation, hard exoskeleton, and jointed appendages. The body of

arthropods is completely covered with cuticle, an exoskeleton, made of protein and chitin. The exoskeleton protects the animals and provides point of attachment for the muscles that move the appendages. Sexes are usually separate and metamorphosis is common occurrence.
Common Arthropods: *Scorpion* (Fig: 9.15-a), *Prawn* (Fig: 9.15-b), *Mosquito* (Fig: 9.15-c), *Honey bee* and *House fly* etc.

Fig: 9.15 (a) Scorpion

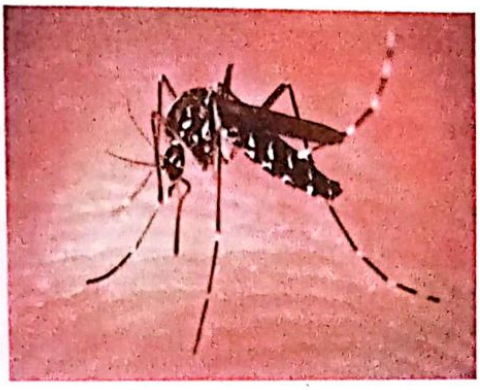


Fig: 9.15 (c) Mosquito

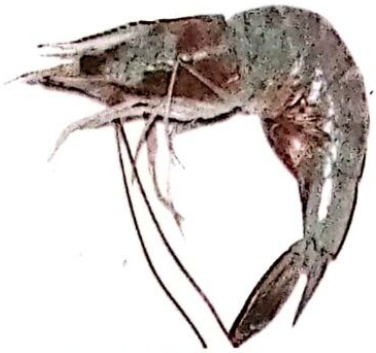


Fig: 9.15 (b) Prawn

**Extra reading material**
Arthropods exist in the harshest conditions in the world, from very cold places to some of the hottest in the world. A scorpion, which is an arthropod, can survive even after being frozen solid.

### 9.9.1 Evolutionary adaptations in arthropods

**Digestion:** Alimentary canal is well developed with mouth and anus. Mouth is assisted by jaws, digestive system is complete.

**Respiration:** Arthropods efficient gas exchange is accomplished by gills in aquatic forms such as crustaceans, and by either tracheae or book lungs in terrestrial forms.

**Transport:** Arthropods have well developed circulatory system, blood not only travels through vessels but also empties into the **haemocoel**, where it baths the internal organs directly this arrangement known as an **open type circulatory system**.

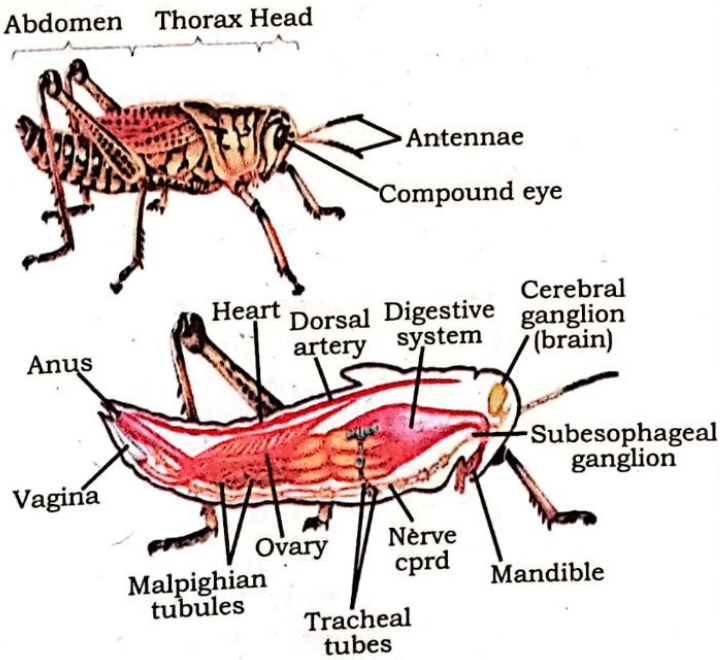



Fig: 9.16 Internal structure of arthropods

**Excretion:** Excretory organs are mostly **malpighian tubules**. They remove nitrogenous waste from the **haemolymph** and also function in osmoregulation.

**Nervous system:** Arthropods nervous system is similar in plan to that of annelids but more complex. It consist of a brain composed of fused ganglia in head, connected to a series of ganglia running down the length of the body and linked by a ventral nerve cord.

### 9.9.2 Economic importance:

Arthropods are of great economic importance, the predominant group of arthropods, the insects not only helps in pollination but also predator on plant pest. Many cause diseases in plant and animals, by transmitting bacteria and viruses. In human beings they are responsible for the transmission of trypanosoma, plasmodium and germs of cholera. Arthropods are an important source of food for many animals and carnivores plants. Sea food that is not fish or molluscs is generally arthropods.

## 9.10. PHYLUM ECHINODERMATA (SPINY SKINNED)

**General characters of phylum Echinodermata** (Gr; Echinos = spiny and dermos = skin)

The representative of phylum Echinodermata are exclusively marine animals, they are radially symmetrical as adult, their larva is a free swimming, filter feeder with bilateral symmetry. Adult echinoderms lack head, brain and segmentation. They are triploblastic, coelomates and deuterostomes with organ-system grade of body organization. The body is covered over by a delicate epidermis stretched over a firm endoskeleton of fixed or moveable calcareous plates with spines. Echinoderms move on numerous tiny tube feet, delicate cylindrical projection that extends from lower surface of the body. Tube feet are part of water vascular system, which functions in locomotion, respiration and food capture.

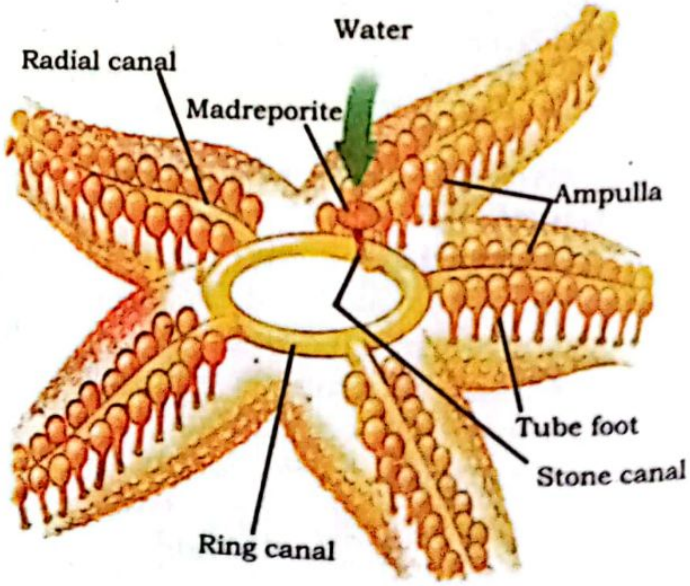



**Fig: 9.17 Water vascular system**

**Extra reading material**

Some echinoderms are vital for the ecology of the world's oceans. Sea cucumbers constantly sift through the bottom sand and absorb dead organic matter from it.

Most echinoderms reproduce by releasing sperms and eggs into the water, where fertilization occurs and a free-swimming larva develop, the sexes are usually separate.

Common echinoderms are Star fish (Fig: 9.18-a), Sea urchin (Fig: 9.18-b), Sea cucumber and Brittle star.

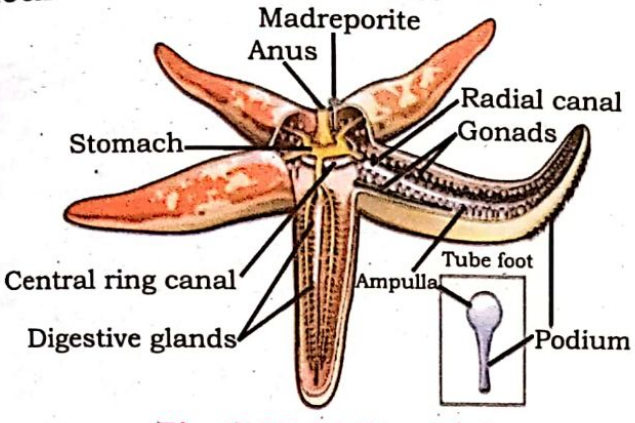



Fig: 9.18 (a) Star Fish

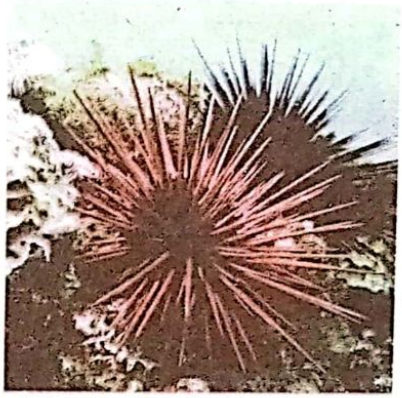


Fig: 9.18 (b) Sea urchin

### 9.10.1. Evolutionary adaptations in echinoderms

**Digestion:** Echinoderms have complete digestive tract but in some species as a brittle star it is incomplete.

**Respiration:** Gas exchange occurs through the tube feet and in some forms numerous tiny skin gills project through the epidermis, respiratory tree in sea cucumber.

**Transport:** The echinoderms lack a circulatory system, although movement of the fluid in their wall developed coelom.

**Excretion:** Echinoderm lack excretory organs, diffusion is responsible for loss of ammonia.

**Nervous system:** Echinoderms have a relatively simple nervous system with no distinct brain.

### 9.10.2. Economic importance of echinoderms

Echinoderms are efficient scavengers on seafloor, sea urchins that burrow into rocks and along a shore can accelerate the erosion of shorelines.

**Extra reading material**

**PHYLUM HEMICHORDATA (Half notochord)**

Hemichordates are exclusively marine, solitary or colonial, mostly tubicolous. Their body is soft, fragile, vermiform, unsegmented, bilaterally symmetrical, triploblastic coelomate and deuterostomes. Reproduction is mainly sexual. Sexes usually separate. Fertilization is external, development direct or indirect with free swimming tornaria larva.

**Digestion:** Digestive system complete with mouth and anus.

**Respiration:** Gas exchange through dorso-lateral pharyngeal gill slits.

**Transport:** Simple open and well developed circulatory system.

**Excretion:** Single glomerulus in the proboscis help in removal of nitrogenous waste.

**Nervous system:** Nervous system consisting mainly of subepidermal nerve plexus and dorsal collar nerve cord. **Common hemichordate:** Balanoglossus & Saccoglossus

## 9.11. PHYLUM CHORDATA

### General characters of phylum Chordata:

Chordates in general, are bilaterally symmetrical, triploblastic coelomates and deuterostomes, animals having a complete digestive tract with a mouth and an anus. Coelom is well developed and internal organs are suspended in the coelomic cavity fixed by a thin membranous tissue called mesentery. They all as a rule, reproduce sexually. The chordates are extremely diverse group of animals united by four features that all possess at some stage of their lives.

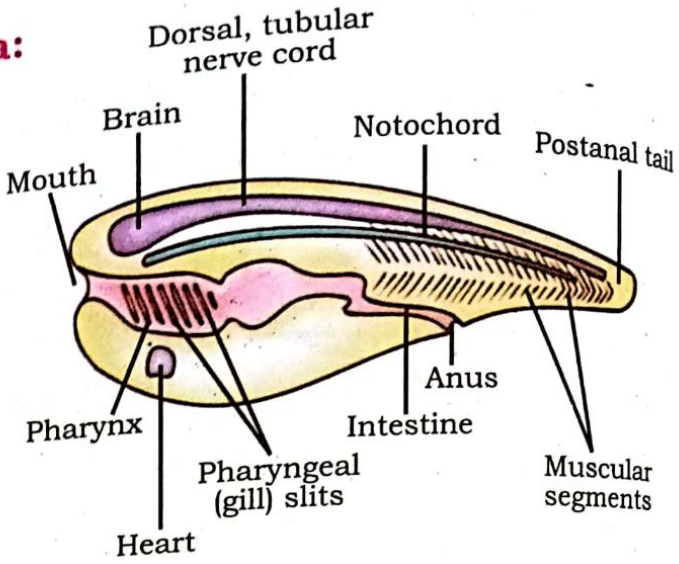



**Fig: 9.19 Chordate body**

**Notochord:** Flexible rod that extends the length of the body and provides an attachment site for muscles.

**Nerve cord:** Lying dorsal to the digestive tract, this hollow neural structure develops a bulging at its anterior end that becomes a brain.

**Gill slits:** located in the pharynx, these may form functional respiratory openings or may appear only as grooves during an early stage of development.

**Post anal tail:** most chordates have a tail extending posterior to the anus.

### 9.11.1 Classification of chordates

According to the recent classification chordates are classified into two groups.

(i) Invertebrate chordates (ii) Vertebrates.

### Group Invertebrate chordates (Protochordates)

The invertebrate chordates lack a head and backbone that is defining feature of vertebrates they are classified into two sub-phyla

(i) Sub-phylum urochordata and (ii) Sub-phylum cephalochordates.

### Sub phylum urochordata

Urochordates are also called tunicate because their body is enclosed in a sac called tunic. They are marine and mostly sessile. The tunic is provided with two openings an incurrent or buccal siphon and an excurrent or atrial siphon. Larva is motile and show chordate characters. Common urochordates: Herdmania (Fig: 9.20) and Ascidia

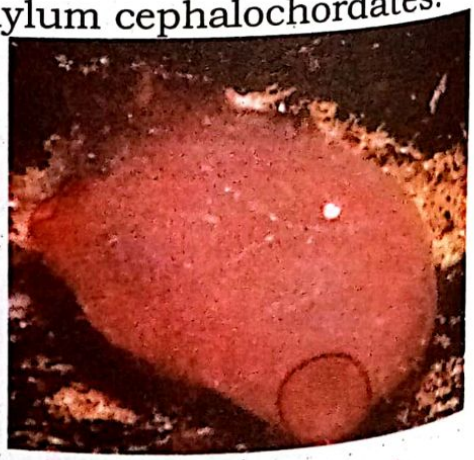


**Fig: 9.20 Herdmania**

## Sub phylum Cephalochordata

The small fish like cephalochordates spend most of its time half buried in the sandy sea bottom filtering tiny food particles from the water. Common cephalochordate: Amphioxus (Fig:9.21)

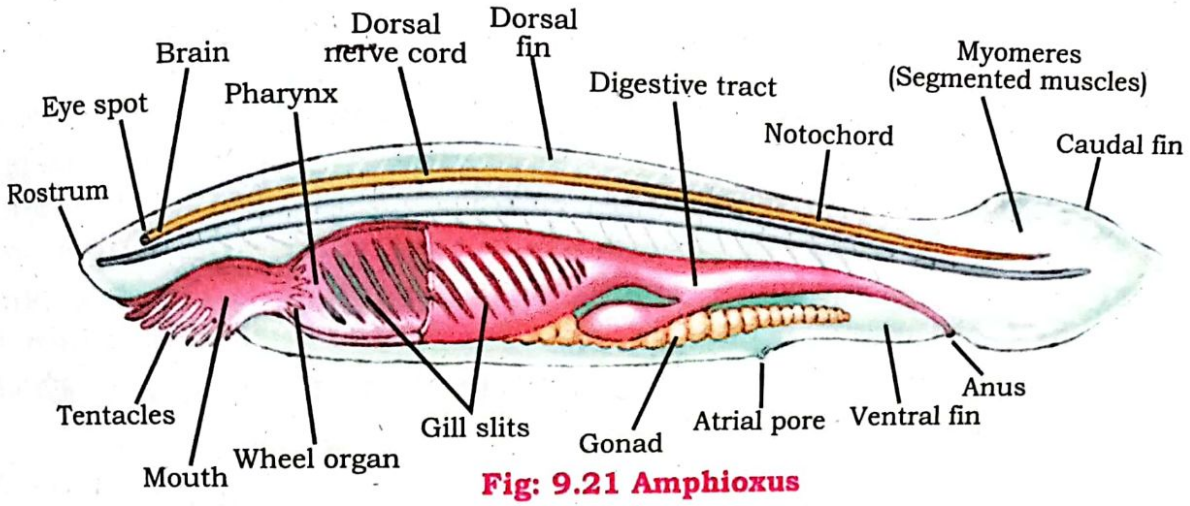



**Fig: 9.21 Amphioxus**

### (ii) Group vertebrata

In the vertebrates notochord is usually replaced during development by a backbone or vertebral column. Vertebrates show other adaptations that have contributed to their successful invasion of most habitats. One is the presence of paired appendages. These first appeared as fins in fish and serve as stabilizers for swimming. Over millions of years, some fins were modified by natural selection into leg that allowed animals to crawl onto dry land, and later into wings that allowed some to take to the air. Another adaptation is an increase in size and complexity of their brain and sensory structures.

**Classification of vertebrates**

Vertebrates are classified into seven major classes

**1. Class Jawless fishes (agnatha)**

Small group of vertebrates which includes two groups of jawless fishes; the hagfishes and the lampreys, both have skeletons of cartilage and are eel like in shape. Both have unpaired fins located along the midline of the body. Both lack scales, and their smooth, slimy skin is perforated by circular gill openings.

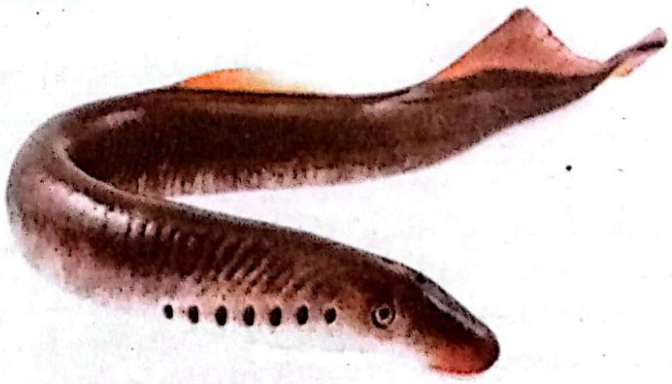


**Fig: 9.22 Lamprey**

### Evolutionary adaptations in agnatha

Hag fishes using pincer like teeth that surround the tongue to burrow into the coelomic cavity and ingest the prey's soft internal organs. Lamprey has sucker like mouth lined with teeth. Gill pouches or opening help in respiration.

### 2. Class Cartilaginous fishes. (Chondrichthyes)

The vertebrates of class Chondrichthyes, sharks, skates and rays are called cartilaginous fishes because they have relatively flexible endoskeleton made of cartilage rather than bone. Exoskeleton is made of enormous number of tiny sharp enamel coated denticles called **placoid scales**. Mouth is ventral in position and their tail fin is heteroceral. There are present many usually 5 exposed gill slits on side which are not covered over by a gill cover the operculum. Scoliodon (dog fish) is small shark which is common in our seas.

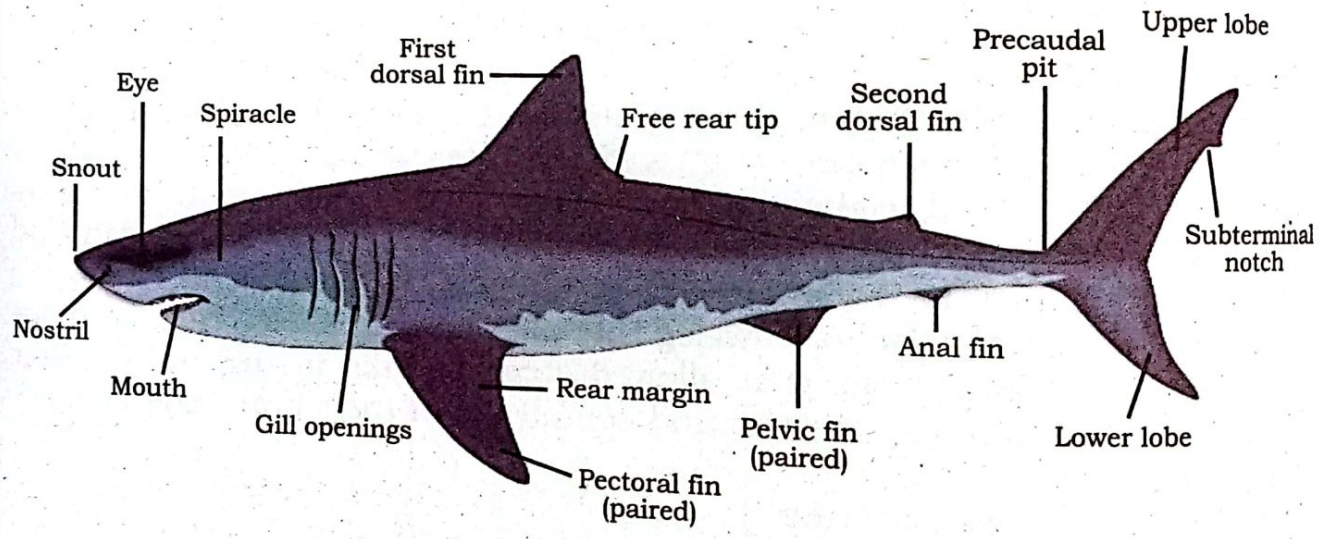



**Fig: 9.23 Shark**

### 3. Class Bony fishes (Osteichthyes)

Class osteichthyes (bony fishes) are the most numerous, both in individuals and in species. Endoskeleton in these fishes is bony and the exoskeleton which is made up of tiny bony plates which are called **cycloid** or **ctenoid**scales according to whether their outer edge is smooth or spiny. Mouth opening is present at the anterior tip. The gills are covered over on each side, by a gill cover called operculum. Most of these fishes have an air bladder which acts as a hydrostatic organ. Tail fin is usually **homocercal**

**Extra reading material**

The fastest fish is the sailfish. It can swim as fast as a car travels on the highway. The slowest fish is a seahorse. It swims so slowly that a person can barely tell it is moving.

or **diphycercal**. This group includes Eel, sea horse (Fig: 9.24-a), flying fish (Fig: 9.24-b), globe fish (Fig: 9.24-c), pomfret (Fig: 9.24-d) and Carps (rahu) (Fig: 9.24-e) etc.

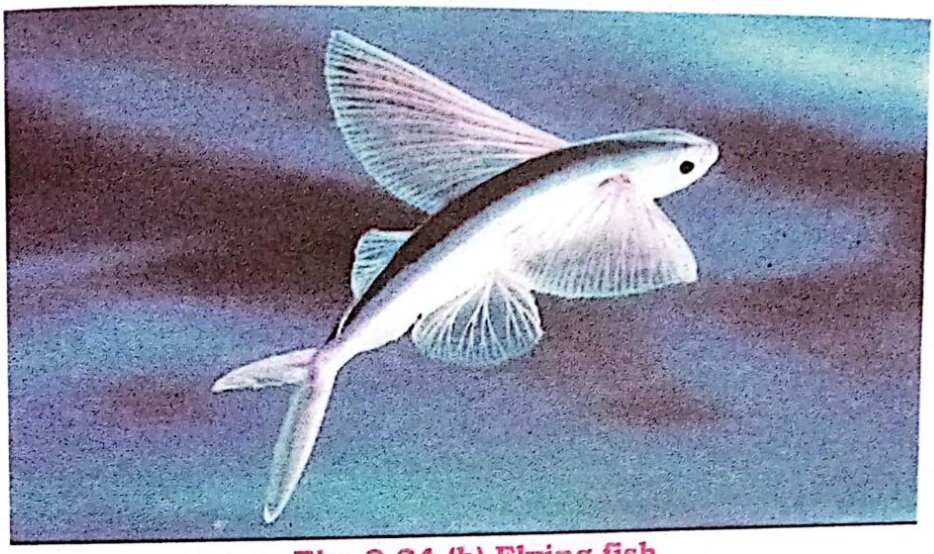


Fig: 9.24 (b) Flying fish

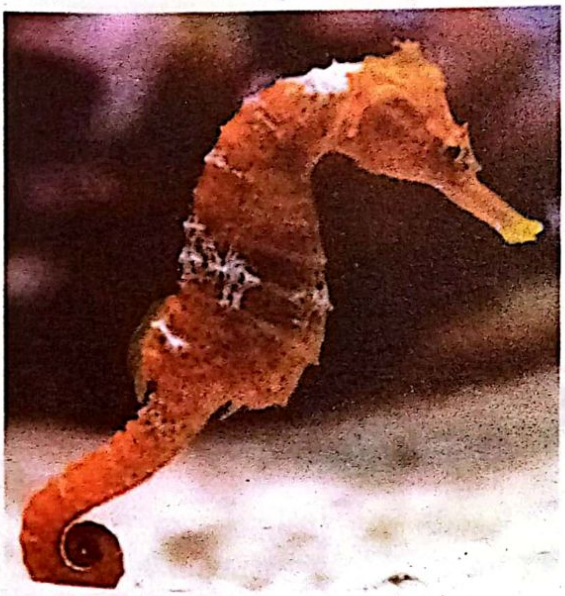


Fig: 9.24 (a) Sea Horse

Fig: 9.24 (c) Globe fish

Fig: 9.24 (d) Pomfret

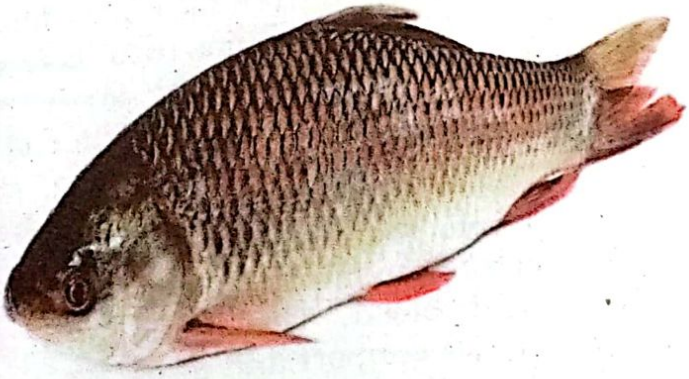


Fig: 9.24 (e) Carps

## 4. Class Amphibia (Living at both places; water and land)

The first vertebrates on land were members of class amphibia. The limbs of amphibians show varying degree of adaptation to movement in land, from the belly-dragging, crawl of salamanders (Fig: 9.25-b) to the efficient dive of frogs (Fig: 9.25-a). Lungs replace gills in most adult forms, and a three chambered heart circulates blood more efficiently. Skin of most of amphibians remains moist, since it serves as an additional respiratory organ that supplements poorly developed lungs. Amphibians are ectothermic depend on environment to regulate their body temperature. To avoid extremes of temperatures they undergo **hibernation** in winter and **aestivation** in summers.

**Extra reading material**

Unlike reptiles and mammals, amphibians don't have the ability to chew their food. They are also poorly equipped dentally, with only a few primitive "vomerine teeth" in the front upper part of the jaws that allow them to hold onto wriggling prey.

Fig: 9.25 (a) Frog

Fig: 9.25 (b) Salamander

## 5. Class Reptilia (To crawl and creep)

Reptiles evolved from an amphibian ancestor about 250 million years ago. Early reptiles the dinosaurs ruled the land for nearly 150 million years. Reptiles contain tough, scaly skin that resists water loss and protects the body. Fertilization is internal and egg is covered with shell. The shell prevents the egg from drying, while an internal membrane, the amnion, encloses the embryo in the watery environment that all developing animal embryo require. Reptiles respire through lungs, three chambered heart became modified, allowing better separation of oxygenated and deoxygenated blood. The limbs and skeleton evolved adaptations that provided better support and more efficient movement on land.

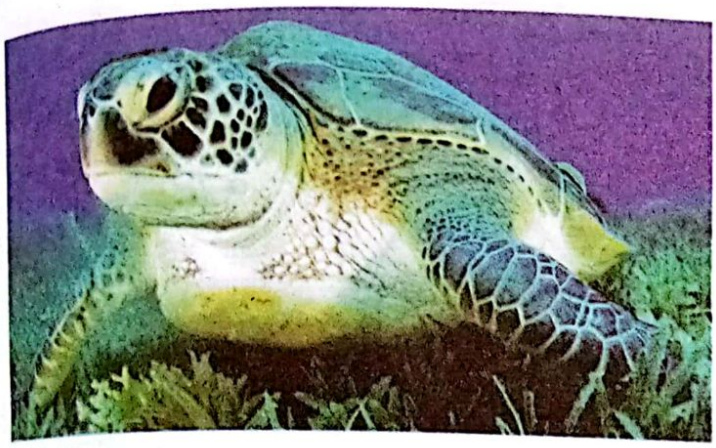


Fig: 9.26 (a) Green Turtle

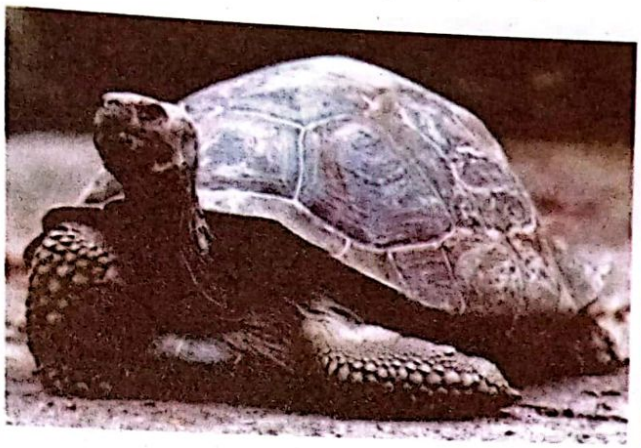


Fig: 9.26 (b) Tortoise

Common reptiles found around the world are tortoise (Fig: 9.26-b) and turtles, lizards (Fig: 9.26-e), snakes (Fig: 9.26-d), crocodiles and alligators (Fig: 9.26-c). Many species of tortoises and turtles including the endangered green turtle (Fig: 9.26-a) the ***chelone mydas*** are found in Pakistan.

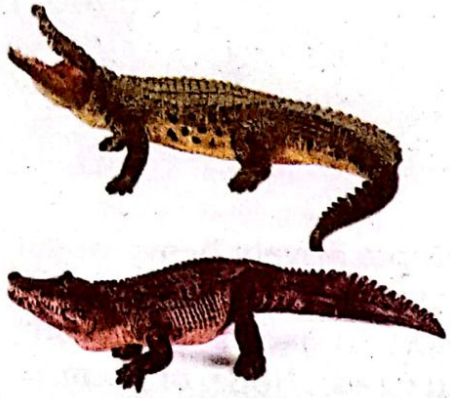


Fig: 9.26 (c)
Crocodile and alligator

Fig: 9.26 (d)
Snake

Fig: 9.26 (e)
Lizard

## 6. Class Aves (Birds)

Birds evolved from reptiles during Mesozoic era. Amniotic eggs and scales on the legs are just two of the reptilian features we see in birds. A bird can be defined as feather covered bipedal flying vertebrate possessing wings. Feathers which cover the body all over constitute a unique and basic identifying character of birds. Birds regulate their body temperature by physiological and behavioral mechanisms, maintaining a temperature that is usually higher than that of their surroundings. These animals have a high metabolic rate that increases their demand for energy and require oxygen for tissues. Four chambered heart keeps oxygenated blood separated from deoxygenated blood. Respiratory system of birds supplemented by air sacs that supply oxygenated air to the lungs. Forelimbs are modified into wings. They have hollow, very light bones laced with air cavities, horny beak has replaced jaws. Fertilization is internal and

eggs are large, amniotic and covered over by hard calcareous shells. The modern birds are divided into two group i.e. Ratitae (running birds) and carinatae (flying birds).

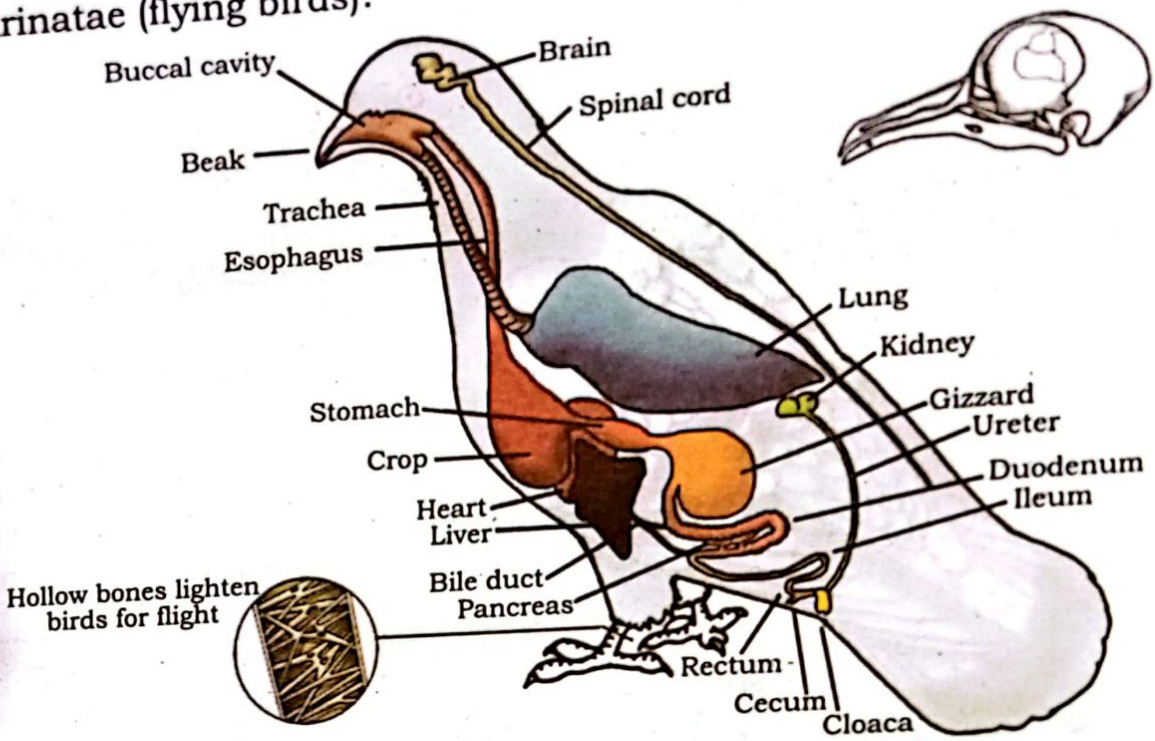



Fig: 9.27 Internal organs of birds

**Sub class ratitae (sternum raft like)**

These birds cannot fly because they have comparatively heavy weight and their wings are either vestigial or rudimentary. They have a flat sternum without keel and accordingly their flight muscles are poorly developed. The distribution of ratitae is also restricted. None of them is found in Pakistan. Common flightless birds are Ostrich (Fig: 9.28-a), emu (Fig: 9.28-b), cassowary, kiwi (Fig: 9.28-c) and penguin.

Fig: 9.28 (a) Ostrich

Fig: 9.28 (b) Emu

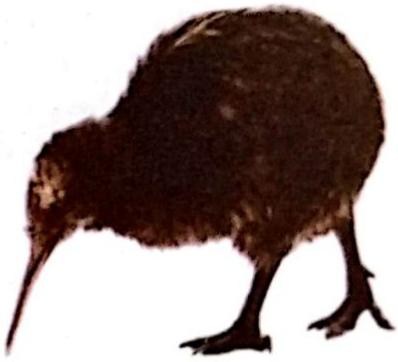


Fig: 9.28 (c) Kiwi

### Sub class Carinatae (sternum with keel)

They are usually small, light weight birds whose wings are highly developed and feathers of their wings have an interlocking mechanism. Their sternum is provided with a crest like keel to accommodate the highly developed pectoral flight muscles. The flying birds are distributed all around the world. Common flying birds are pigeons (Fig: 9.29-a), crow (Fig: 9.29-b), parrot (Fig: 9.29-c), owl, peacock and chakor.

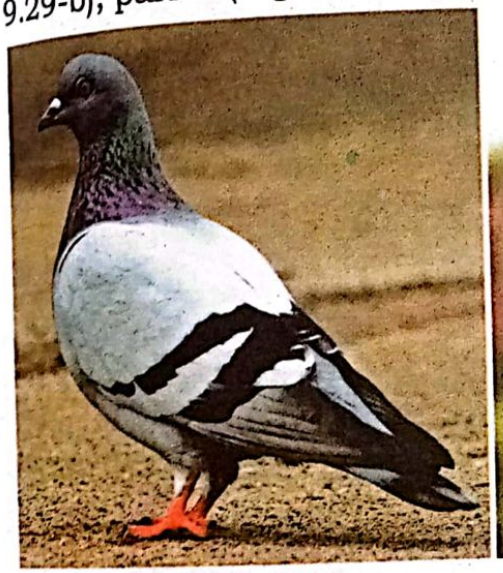


Fig: 9.29 (a) Pigeon

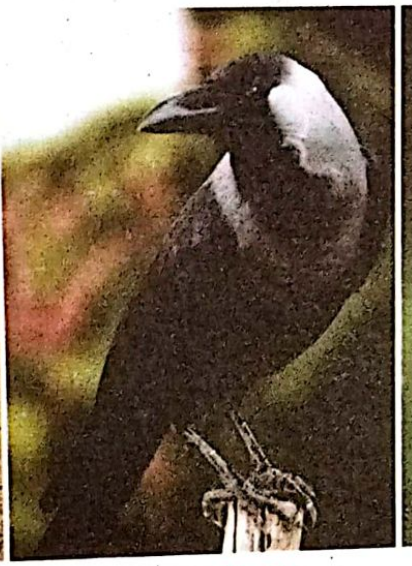


Fig: 9.29 (b) Crow

Fig: 9.29 (c) Parrot

## 7. Class Mammalia

The mammals first appeared approximately 250 million years ago and came into prominence after the extinction of the dinosaurs roughly 70 million years ago. Mammals are named for the mammary glands used by all female members of this class to suckle their young. Mammals have an active metabolism and are endotherms. Efficient respiratory and circulatory systems having four chambered heart support a high metabolic rate. A sheet of muscle called the diaphragm helps ventilate the lungs. Hairs and a layer of fat under the skin help the body retain metabolic heat. With the exception of the egg-laying monotremes, such as the platypus and spiny anteater, mammalian embryo develop in the uterus. Class mammalia is divided into three sub classes Prototheria, Metatheria and Eutheria, on the basis of the mode and developmental conditions of their new born babies.

### Sub class Prototerhia (egg laying mammals)

The platypus (Fig: 9.30-a) and the spiny anteaters (Fig: 9.30-b) are the only living mammals that lay eggs. The egg which is reptilian in structure and development, contain enough yolk to nourish the developing

embryo. Monotremes have hair and produce milk, two of the most important features of Mammalia.

Fig: 9.30 (a) Platypus

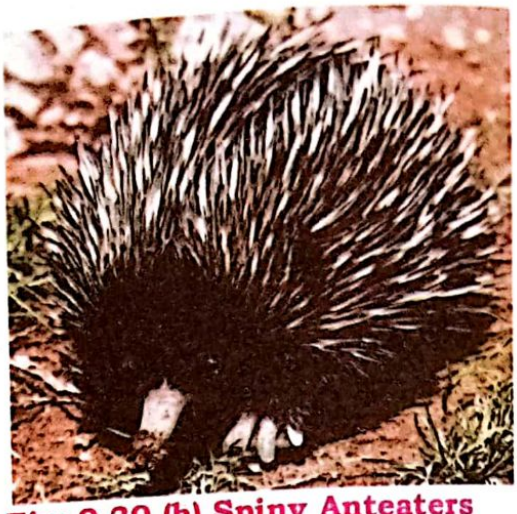


Fig: 9.30 (b) Spiny Anteaters

**Sub class Metatheria (pouched mammals)**

Kangaroos (Fig: 9.31-a), Koalas (Fig: 9.31-b) and Opossums (Fig: 9.31-c) are examples of pouch mammals. A marsupial (pouch mammal) is born very early in its development and completes its embryonic development while nursing. In most species, the nursing young are held within a maternal pouch called a marsupium.

Fig: 9.31 (a) Kangaroo

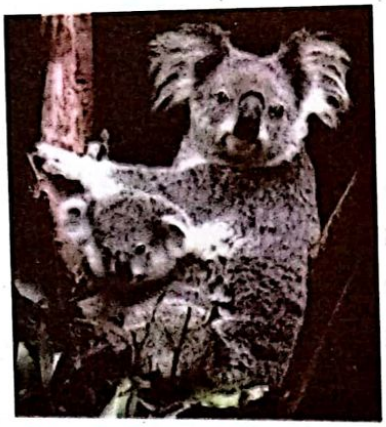


Fig: 9.31 (b) Koala bear

Fig: 9.31 (c) Opossums

**Sub class Eutheria (Placental mammals)**

Eutherian mammals have a longer period of pregnancy. Young eutherians complete their embryonic development within the uterus, joined to the mother by the placenta. Embryo receives oxygen and food from the mother's circulation and discharges the wastes into her blood through the placenta. Common eutherian mammals are Hedge hogs (Fig: 9.32-a), pygmy shrews (Fig: 9.32-b), rats (Fig: 9.32-c), rabbits (Fig: 9.32-d), sheep (Fig: 9.32-e), goats (Fig: 9.32-f), donkey (Fig: 9.32-g), zebra (Fig: 9.32-h) and giraffe (Fig: 9.32-i).

Among the large placental mammals elephants are terrestrial whereas whale the largest of all the animals are aquatic. Bats are the only flying mammals.

Fig: 9.32 (a) Hedgehog

Fig: 9.32 (b) Pygmy shrew

Fig: 9.32 (c) Rat

Fig: 9.32 (d) Rabbit

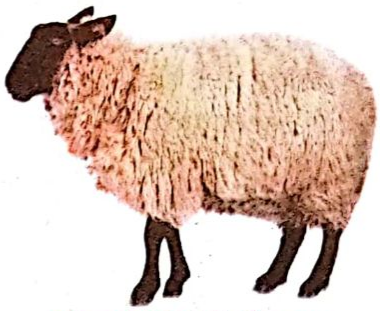


Fig: 9.32 (e) Sheep

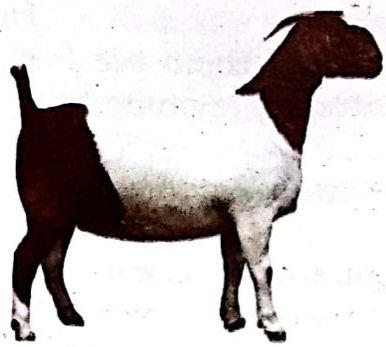


Fig: 9.32 (f) Goat

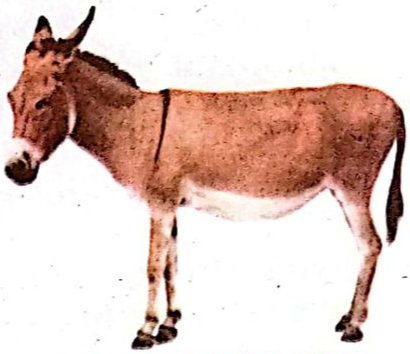


Fig: 9.32 (g) Donkey

Fig: 9.32 (h) zebra

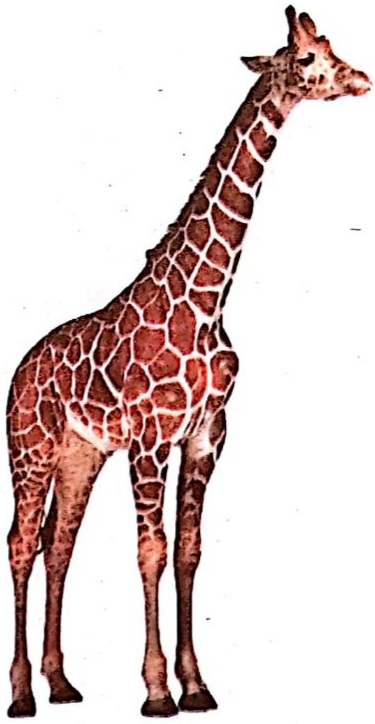


Fig: 9.32 (i) Giraffe

## SUMMARY

- Animals are eukaryotic, multicellular heterotrophs (ingestive) which reproduce sexually and are usually motile.
- Animal kingdom is most diversified group as far as number of species is concerned. They range in size from microscopic to very huge organisms.
- Animals are thought to have evolved from volvox like protoctist.
- Kingdom animalia is divided into 33 groups called phyla, on the basis of comparative morphology and internal architecture.
- Most animals have a recognizable symmetry, either radial or bilateral. Sessile animals usually exhibit radial symmetry whereas motile animals are usually bilaterally symmetrical.
- Most animals have a body cavity (coelom) between their body wall and digestive tube.
- Protostome and deuterostomes differ in early embryological development and fate of blastopore.
- Sponges are asymmetrical sessile aquatic filter feeder lack tissue organization.
- Cnidarians are radially symmetrical diploblastic animals with two body forms polyp and medusa.
- Platyhelminthes are commonly called flat worm. They are bilaterally symmetrical triploblastic acoelomates.
- Round worms are the most abundant animals. Most of them are free living whereas many are parasites. They are bilaterally symmetrical triploblastic pseudocoelomates.
- Annelids are segmented worms. They are bilaterally symmetrical coelomate and protostomes.
- Molluscs are bilaterally symmetrical, non-segmented coelomate animals whose body can be divided roughly into a head-foot, a visceral mass and a mantle.
- Arthropoda constitute the most diverse phylum. They are bilaterally symmetrical coelomate and protostomes. Exoskeleton is made up of chitin.
- Echinoderms are radially symmetrical coelomates and deuterostomes. Body is covered over by spiny calcareous plates and thousands of tiny multipurpose tube feet.
- Chordates are the most advanced animals include a small number of invertebrate chordates and vertebrates.
- All Chordates are bilaterally symmetrical animals that are characterized by a notochord, a hollow dorsal nerve cord and pharyngeal gill slits. Many have post anal tail.

## EXERCISE

**1. Encircle the correct choice.**

(i) Choose the incorrect pair?
- (a) Sponges → Spicules.
- (b) Cnidaria → Nematocycts.
- (c) Segmented worm → Psuedopodia.
- (d) Arthropoda → jointed legs.

(ii) Water movement through sponge?
- (a) Ostia → Spongocoel → Osculum.
- (b) Spongocoel → Osculum → Ostia.
- (c) Ostia→ Osculum → Spongocoel.
- (d) Osculum → Spongocoel → Ostia.

(iii) Choose the term which encompasses all other in the list
- (a) Coelomate
- (b) Protostome
- (c) Bilateria
- (d) Triploblastic

(iv) Dry scaly skin, ectothermic, two pairs of legs, lungs, Internal Fertilization, eggs with amniotic shell, and a three chambered heart are all properties of which class?
- (a) Amphibia
- (b) Reptilia
- (c) Aves
- (d) Mammals

(v) Pick the odd one out?
- (a) Star fish.
- (b) Brittle star.
- (c) Lamprey.
- (d) Sea urchin.

(vi) Which of the following terms or structures is properly associated only with animals?
- (a) Genes.
- (b) Cell wall.
- (c) Autotrophy.
- (d) Sexual reproduction.

(vii) An adult animal that possesses bilateral symmetry is most certainly also
- (a) Triploblastic.
- (b) Deuterostomes.
- (c) Coelomate.
- (d) Protostomes.

(viii) Protostome characteristics generally include which of the following?
- (a) A Mouth that develops secondly and far away from the blastopore
- (b) Radial body
- (c) Radial cleavage.
- (d) Determinate cleavage

(ix) Sponges structural materials (spicules) are manufactured by the
- (a) Pinacocytes.
- (b) Choanocytes.
- (c) Amoebocytes.
- (d) Porocytes.

(x) Which of the following can be used to distinguish a nematode from annelids?

I. Type of body cavity
II. Number of muscle layers in the body wall
III. Presence of segmentation
IV. Number of embryonic tissue layers

(a) I only (b) II only
(c) I and II (d) I, II and III

**2. Write short answers of the following questions:**

1. How animals are classified?
2. Why sponges placed in animal kingdom, when it lacks tissue organization?
3. Why flat worms are named so?
4. Differentiate between invertebrate chordates and vertebrates
5. Differentiate between cartilaginous fishes and bony fishes
6. Why protostomes are named so?
7. Why diploblastic animals are different from the triploblastic?
8. Why echinoderms are placed in bilateria when adults are radially symmetrical?

**3. Write detailed answers of the following questions:**

1. Discuss the basic factors which helps in classification of animals
2. Write down evolutionary adaptations of phylum annelida.
3. Write down the general characters of phylum arthropoda
4. Describe the general characters of phylum mollusca
5. What are mammals? Name its sub-classes. Give the characters and examples of each sub class.

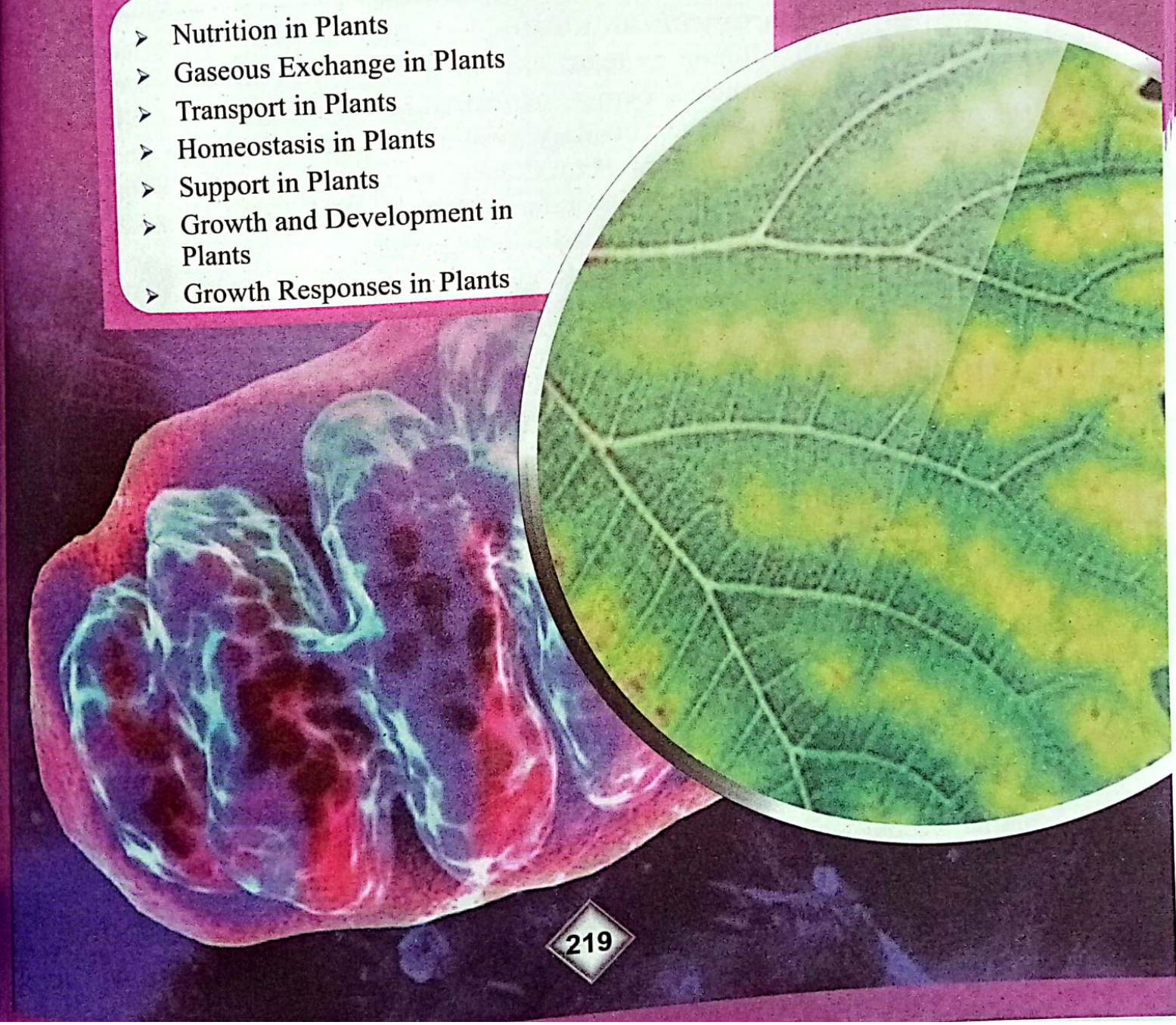
# FORMS AND FUNCTIONS IN PLANT

Chapter 10

## Major Concept

### In this Unit you will learn:

- Nutrition in Plants
- Gaseous Exchange in Plants
- Transport in Plants
- Homeostasis in Plants
- Support in Plants
- Growth and Development in Plants
- Growth Responses in Plants



**Introduction:**

All living organisms must obtain a variety of chemical substances from their surroundings. These substances are essential in order to build up their body. Living organisms also required energy to perform their functions. Nutrition is the process of acquiring energy and materials.

Plants obtain essential nutrients primarily from soil. Nutrient cycle comprises from plants to decomposers and decomposers to soil thus back of plants. Nitrogen in the atmosphere becomes available to plants as nitrates and ammonium by nitrogen fixing bacteria.

Plants are photosynthetic autotrophs .They prepare their food by photosynthesis .In addition to light, carbon dioxide and water ,which are required for photosynthesis, plants use other raw materials to synthesize the organic compounds as a secondary products for growth. These elements are known as mineral nutrients. Plants use minerals like nitrates, sulphates and phosphates to make other secondary products like proteins, lipids that are needed for growth and other metabolic activities.

These nutrients are inorganic elements,14 of which are essential, especially nitrogen (N) phosphorus (P), potassium (K) and magnesium (Mg) etc.

All plants appear to have very similar nutritional requirements, although the amounts required, vary between individual plants and between species. In general ,macronutrients are required in large amounts, Nitrogen (N),Phosphours (P), Potassium (K), Sulphur (S), Sodium (Na), Chlorine (Cl), Magnesium (Mg), and Calcium (Ca) are included in macronutrient, Micronutrient (trace elements) are required in small amounts including. Manganese (Mn), iron (Fe), Cobalt (Co), Copper (Cu), Zinc (Zn), Molybdenum (Mo), Boron (B),Fluorine (F) and Iodine (I).

### 10.1.1 Role of some important minerals nutrients

Analysis of plants shows the presence of a large number of mineral elements. The amount and number of elements presence in plant may differ from plant to plant, place to place and medium to medium in which plant grows. The role of some important macronutrient and micro nutrients in plants discuss below.

## Role of macronutrients and mineral nutrients in plants and their deficiency symptoms:

| Important nutrients | Major Role | Deficiency symptoms |
|---|---|---|
| Nitrogen | Essential constituent of proteins, nucleotides, nucleic acids, chlorophyll etc. | Leaves turn pale yellow due to loss in chlorophyll content and cell enlargement are inhibited. Plants growth remain stunted. |
| Phosphorous | Promotes healthy root growth and fruit ripening, involved in the formation of cell-membrane as phospholipids, nucleic acid, co-enzyme (NAD and NADP) ATP role in energy transfer reaction. | Growth is retarded. Necrosis dead cells patches appear on leaves, petioles and fruits. Cambial activity is checked. |
| Potassium | Role in the stomatal opening and closing, enzyme activator in synthesis of certain peptide bonds and carbohydrate metabolism. | Leaf turns into dull or bluish green, chlorosis, growth is stunted, shortening of internodes. |
| Sulphur | Essential for growth and development of all crops, used in the formation of amino acid, proteins and oils, helps to develop and activate certain enzymes and vitamins. | Plants are small and spindly with short and slender stalks; their growth is retarded and nitrogen – fixation reduced. |
| Magnesium | Activates enzymes, used in the formation of chlorophyll and some carbohydrates, conversion of starches to sugar and it presence in plant tissue helps the plant to withstand in cold temperature. | yellowing of leaves, often interveinal, death of leaf tissue on areas of chlorosis, chlorotic areas may turn brown colored. |

### 10.1.2 Some micronutrients and their role:

**i. Manganese (Mn):**

Manganese are absorbed by plants in very minute quantity and become the part of enzyme phosphotase (transfer $PO_4$ groups). Manganese involved in oxidation reduction reaction.

**ii. Iron (Fe):**

Iron can exist in the forms $Fe^{2+}$ and $Fe^{3+}$ is a constituent of cytochromes, which are involved in the electron transport reactions of photosynthesis and respiration.

**iii. Zinc (Zn):**

The role of zinc in anaerobic respiration in plants (alcohol fermentation)

| Essential Elements | |
|---|---|
| **Non metallic** | **Metallic** |
| Carbon | Potassium |
| Hydrogen | Calcium |
| Oxygen | Magnesium |
| Nitrogen | Iron |
| Phosphorous | |
| Sulphur | |

## 10.2 CARNIVOROUS PLANTS (INSECTIVOROUS PLANTS)

Insectivorous or carnivorous plants are green plants which are specially adapted for trapping and digesting small animals, particularly insects. Such plants typically live in nitrogen deficient habitat, and use the animals principally as a source of nitrogen. They trap the insects with their colours, scent or sweet secretion. Then secrete enzymes and carry out extra cellular digestion of nitrogenous compounds. The products notably amino acids are absorbed and assimilated. Some common examples are nepthens, pitcher plant, *Drosera intermedia* or sundew, *Dionaea muscipula* or Venus fly trap and *Aldrovanda* (water fly trap)

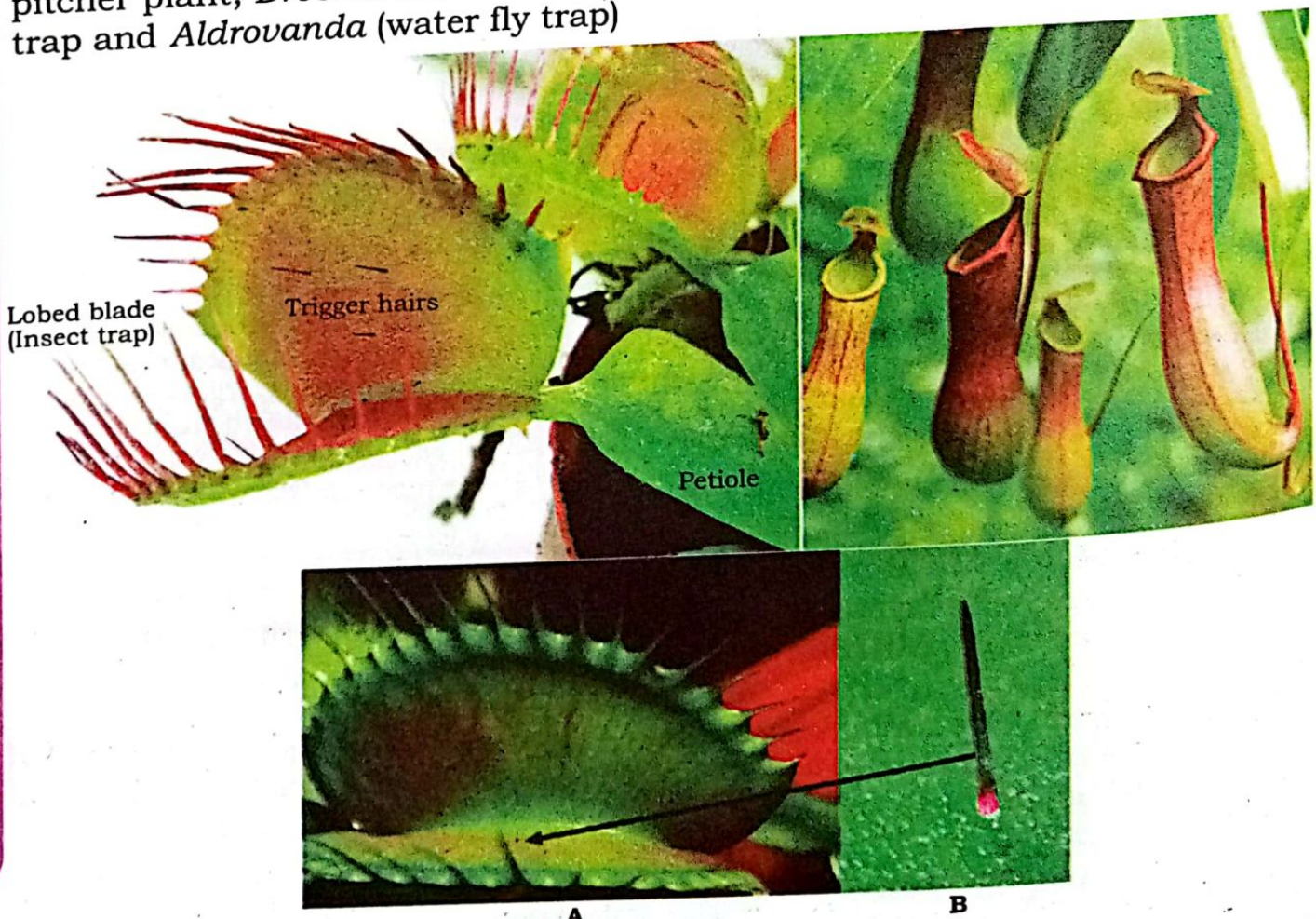



**Fig: 10.1. Carnivores Plants**

## 10.3 Gaseous Exchange in Plants:

All plants exchange gases for respiration as well as for photosynthesis. The process of respiration occurs constantly day and night in all living cells of plants. Oxygen is being continually absorbed whereas carbon dioxide is liberated. During photosynthesis intake of carbon dioxide take place through the stomata and lenticels, while oxygen is liberated during this process photosynthesis occur during day time and in chlorophyll containing cells only.

Gaseous exchange in unicellular organism and lower plants especially in the aquatic ones, takes place by diffusion across a moist cell membrane and wet body surface respectively. Surface area in such organisms is greater than their volume so diffusion alone is sufficient for the transport of gases from surface cells to inner ones. But in higher land plants gas exchange occur by the entire surface of cells present inside the leaves.

Flowering plants exchange gases by diffusion through pores called stomata in their leaves and green stem. Each stoma is formed by two modified epidermal bean-shaped guard cells. Unlike other epidermal cells guard cells bear chloroplast with thicker inner and thinner outer walls. Stomata can be opened or closed depending upon the turgidity of guard cells which is regulated by concentration of sugar and potassium $K^+$ ion.

Stomata regulate the passage of carbon dioxide, oxygen and water as well as concentration of sugar and potassium across the surface of the leaf.

Leaves are the main sites of gaseous exchange. There are two types of leaf **monofacial** and **bifacial**. In bifacial leaves the upper region of leaf consists of an upper epidermis covered with thick cuticle and epidermis contains less number of stomata. While lower region of leaf consist of lower epidermis ,with abundant stomata and spongy mesophyll cells, which functions in gaseous exchange and the regulation of transpiration. Inside the leaf of a dicotyledon(bifacial) there is a spongy mesophyll with large air spaces, which connect with each other and those between the palisade cells. This system of air space allows gases to diffuse freely between the cells. The mesophyll tissue of the leaf possesses a continuous system of intercellular spaces which connects with the external atmosphere through the stomata, which is suited for the diffusion of air into the intercellular spaces.

The intensity of gaseous exchange depends upon the intensity of respiration. Though all living cells of different organs like stem root etc. constantly respire, yet there is no transport system within plants for respiratory gases. Such gases are therefore transported by diffusion only, in order to facilitate the process of diffusion of gases, plant tissues are permeated by air spaces.

Once the air gets inside the plant, movement of oxygen is determined by the diffusion gradients that exist in the intercellular air spaces. In this

way oxygen travels towards the cell and dissolves moisture present on the surface of cell. From here oxygen passes by diffusion into the cells themselves. Carbon dioxide leaves the plant by the same pathway but in the reverse direction. The whole situation becomes more complex in photosynthesizing parts. Here oxygen is also produced by the chloroplast as a waste product of photosynthesis. The oxygen may be used up in immediately in respiration by mitochondria in the same cell, and waste carbon dioxide from respiration may be used by the Chloroplast, for photosynthesis.

Plants perform photosynthesis and respiration both during the day, but in night only respiration does occur, so methodology of gaseous exchange is different in day and night.

During day the rate of photosynthesis is much higher than the respiration, concentration of carbon dioxide release during respiration is very low which does not meet the requirements of photosynthesis. Plants obtain required carbon dioxide for photosynthesis from environment; In the same way the oxygen released during photosynthesis is much more than the requirements of respiration so plants released it from its body.

At night plants absorb oxygen and release carbon dioxide. Thus, in night the carbon dioxide is in excess and oxygen is in deficient.

The plants which growing in well watered conditions a diurnal stomatal rhythm is observed, stomata are open in day closed in night. The factors which influence the opening and closing of stomata are light, concentration of Potassium ($K^+$) ions and concentration of carbon dioxide in the air. Stomata are sensitive to $C0_2$ concentration in the surrounding air.

### 10.3.1 Transport in Plants:

Every living cell, whether it exists alone as a single cell organism or as a component of a multicellular one, must perform its own metabolic activities. It must synthesize its own ATP by cellular respiration. Every cell must obtain the necessary raw materials to support its metabolism for the synthesis of ATP. Obviously, some mechanism is needed for transporting substances between the specialized system of procurement, synthesis or elimination of different compounds.

Plants are in contact with both soil and atmosphere. Various materials from atmosphere and soil are transported in and out of plant body by various process such as diffusion, osmosis, imbibition and active transport.

In plants, cell to cell movement of water and solutes occur via apoplast and or symplast pathways. Long distance transport occurs in xylem and phloem. Transport mechanism include passive processes such as diffusion, mass flow and osmosis and active processes, which require energy from cell metabolism.

Non-gaseous substances that are transported into and within plants are water and solutes such as ions, amino acids and sucrose. There are number of pathways:

- Between solutions in the external environment and plant roots
- Between cells either along the apoplastic pathway or the symplastic pathway via plasmodesmata
- Between compartments within a cell, for example between vacuole and cytoplasm which are separated by a membrane, the tonoplast.
- Long distance transport in xylem and phloem.

Movement of water and solutes takes place through Xylem and mass flow transport of sugar through Phloem. Both Xylem and Phloem are structurally related with their functions.

**Xylem:**

Xylem is a complex tissue consisting of four types of cells in angiosperm out of them two are water conducting cells. These are open ended cells called vessels and porous cells called **trachieds**.

**Vessels:**

Vessels are thick wall tube like structures which extend through several feet of Xylem tissues. They range in diameter from 0.2 mm to as much as 0.7 mm. Their walls are lignified and perforated by pits. At the pit lignin is not deposited and cell wall is thin made up of cellulose. The pits match up with pits of adjacent cells so that cell cavaties are connected to adjacent cells cavaties. Xylem vessels arrive from cylendrical cells, which are placed end to end. At maturity, the end walls of these cells are dissolved and cytoplasmic contents die. Thus a continuous duct is formed which offers a better route for long distance transport of water from roots upto leaves. The rate of flow of water in vessels is 10 times faster than trachieds. Vessels are mostly found in flowering plants.

**Trachieds:**

Trachieds are unusual cells about 0.3 mm in diameter and several mm in length. They can be distinguished from vessels by their angular walls and smaller size. They taper at each end and taper ends of one cell overlap taper ends of other cells, like xylem vessels they are dead with thick lignified walls.

Their walls are perforated by small holes called pits which are of two types; simple and bordered. The pits in the cross walls connect upper trachieds with lower one. Through these pits water and minerals flow freely from one trachied to another. In all tracheophytes except angiosperm trachieds are the only water conducting ducts.

**Phloem:**

Phloem consists of four types of cells

i. Sieve tube elements
ii. Companion cells
iii. Phloem fiber
iv. Phloem parenchyma

**Sieve tube elements:**

Sieve tubes are the long tube like structures that transport photosynthetic products throughout the plants. They are formed by the end to end fusion of cells called sieve tube elements. Sieve tube elements have a very distinctive structure. Their walls are made of cellulose and pectic substances, their nuclei degenerate and are lost as they mature and the cytoplasm becomes confined to a thin layer around the periphery of the cell.

They have thin primary cell wall that connect adjacent cells by their ends. They have perforation in their transvers wall, which look like the holes in a sieve. Sieve cells are elongated and form a continuous conducting pathway throughout a plant.

A conspicuous and characteristics feature of sieve tubes is the sieve plate. This is derived from the two adjoining end walls of neighboring sieve elements.

**Companion cells:**

In flowering plants, each sieve cell is associated with a specialized parenchyma cell a companion. The two cells together form a functional unit. Companion cells retain all their cytoplasmic contents and have a well-developed endoplasmic reticulum with a large dense nucleus. The function of the companion cell is to control the activity of the sieve cell.

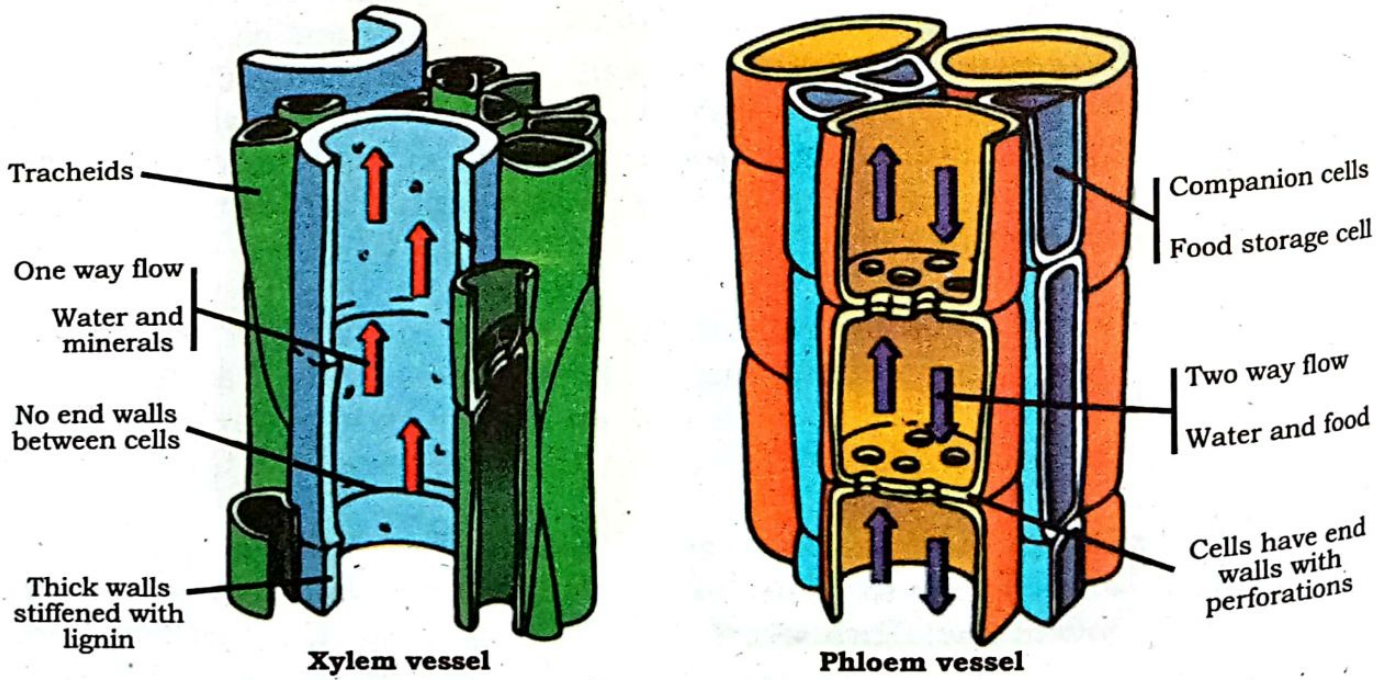



**Fig: 10.2. Xylem and phloem**

### 10.3.2 Water transport:

The movement of water molecules from soil into roots, or from leaf mesophyll cells through stomata to the environment, takes place regularly. Water moves from soil into roots and up to aerial parts of plant by diffusion, osmosis, bulk flow or some combination of their fundamental transport mechanism .The movement of water in or out of the cell exhibit three types of water relations i.e water potential, Osmotic pressure and solute potential.

**i. Water potential:**

The chemical potential of water is a quantitative expression of the free energy associated with the water. Thermodynamically, free energy represents a potential for performing work. All living things including plants, require a continuous input of free energy. In the case of water movements this free energy is involved in water flow. The unit of chemical potential is energy per mole of a substance (joules per mole).

For practical reason, it turns out that the unit of chemical potential is inconvenient for most work in plant physiology. Therefore, plant physiologist have defined another parameter called **water potential** as the difference between the free energy of water molecules in pure water and energy of water in any other system (e.g. water in solution or in cell sap of plant). Now, the free energy of water is expressed in pressure unit such as megapascals and symbolized by Greek letter ᵠ psi (MPa: MPa=9.87) atmosphere).

Pure water has been assigned the value of water potential "0" MP. Addition of solute particles lowers the mole fraction (number of mole of substance divided by total number of all substances in the system / solution of water. Hence, there is a decrease in water potential. Therefore, values of water potential remains less than zero or in negative value.

**ii. Osmotic pressure:**

The pressure exerted upon a solution to keep it in equilibrium with pure water when the two are separated by a semipermeable membrane is known as **osmotic pressure**. Therefore, the osmotic pressure of a solution is a measure of the tendency of water to move by osmosis into it. In other words we can say that the osmotic pressure is the pressure that must be exerted on a solution to prevent the passage of solvent molecule into when the solvent and solution are separated by a differentially permeable membrane. Thus, it prevents the process of osmosis proceeding.

**iii. Osmotic Potential or Solute Potential:**

Osmotic potential is the tendency of a solution to attract water molecules when the solutions of two different concentrations are separated by a differentially permeable membrane. Pure water is assigned the osmotic potential zero as the highest value. Since the osmotic potential decreases as the osmotic concentration (the no: of osmotically active particles per unit volume) increases, all solutions have value of less than zero. Under constant

temperature and pressure, water moves from the solution of lower osmotic potential to the solution of higher osmotic potential when the two solution are separated by a differentially permeable membrane. It is represented by $\varphi$ s or solute potential.

Another term used in relation to water potential is pressure potential, which is defined as the hydrostatic pressure in excess of atmosphere pressure.

**Water relations of Plant Cell:**

For practical purposes a plant cell can be divided into three parts: (i) Cell Wall: This is non-living, permeable, outer most boundary of cell made up of cellulose. (ii) Cytoplasm along with nucleus forms protoplasm-the lining material bounded by cell membrane. (iii) In the centre, there is a vacuole enclosed by tonoplast, central vacuole is filled with cell sap-an aqeous solution of salts, organic acids and sugar.

The presence of solute particles lowers the water potential $\varphi$ of cell sap. Greater the number of solute particles, the more negative will be the water potential of cell sap. The concentration of solute particles in a solution is known as **solute potential** $\varphi_s$ (This has been previously referred as osmotic potential). The value of solute potential is always negative.

When a cell is placed in pure water or in an aqueous solution with higher water potential (less negative) than the cell cap, water flows into the vacuole by osmosis through plasma membrane and tonoplast. As more water flows into the vacuole, the tension developed by cell wall causes an internal hydrostatic pressure to develop. This is called **pressure potential** $\varphi_p$ and it opposes the continued uptake of water into the cell by osmosis. When the cell wall is fully stretched and pressure potential reaches at its maximum, the cell cannot take any more water, and is said to be fully **turgid.** The relationship between water potential $\varphi_w$ solute potential $\varphi$s and pressure potential $\varphi_p$ is represented by following equation.

$$\varphi = \varphi_s + \varphi_p$$

In a turgid cell $\varphi_p$ is equal and opposite to $\varphi_w$ so $\varphi = 0$

### 10.4.1 Water and minerals uptake by root:

Absorption of water and minerals salts takes place through root system. Roots are provided by enormous number of tiny root hairs which are outgrowths of epidermal cells and found at the root tip. The root hairs greatly increase the surface area of root. Because of large root surface area plants absorb enough quantities of water and inorganic ions for their survival and growth.

Root hairs possess sticky walls and adhere tightly to soil particles which are usually coated with water and dissolved minerals salts. Most of the absorption takes place near the root tip where epidermis is permeable to water and root hairs. From root hairs and epidermal cells water flows through cortex into endodermis, pericycle and enters xylem. Since transport of water takes place in radial direction it is also termed as **lateral transport.**

Three path ways are available for water to enter xylem. The first route is from **cell to cell.** Water enters the root hairs or epidermal cell down a gradient of water potential. It flows out of one cell across the cell wall, cell membrane vacoule and enters the adjacent cell which may again pass the substance along the next cell in the path way. This is known as **cellular path way.** The second path way is **symplast.** Through the pores in the cell walls, cytoplasm of cortical cell remains connected with cytoplasm of adjoining cortical cells. These cytoplasmic connections through pores are known as **plasmodesmata** (sing; plasmodesma). These cytoplasmic connections provide another pathway for transport of water and solutes known as **symplastic pathway.** This requires only crossing of plasma membrane at root hair.

The third pathway is **apoplast.** The cell walls of epidermal cells and that of cortical cells form a continuous matrix. These walls are hydrophilic. Soil solution flows freely through hydrophilic walls of epidermal and cortical cells. This movement of soil solution through extracellular pathway provide by continuous matrix of cell walls is known as **apoplastic pathway.** As solutes move along extracellular pathway some of the water and solutes are taken up by the cells of cortex thus changing the route from apoplast to symplast.

The inner limiting layer of cortex is endodermis which serves as a barrier or check point because of **casparian strip** a waxy belt that extends through the walls of endodermal cells. Thus, water and minerals cannot cross the endodermis and enter xylem via apoplast (extracellular pathway). Simplast is the only way to cross the barrier. Endodermal cells actively transport salts to pericycle resulting in high concentration of salts. This causes a low water potential

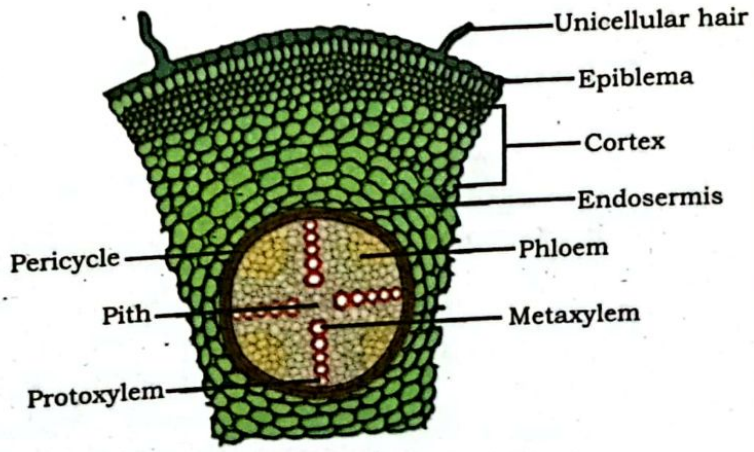



**Fig: 10.3. T.S. of Dicot Root**

and water moves into them by osmosis. From pericycle water flows into Xylem both via symplast and apoplast.

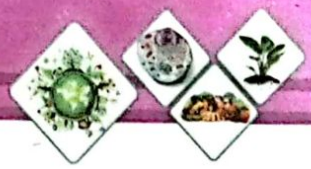
Diffusion moves water from region of high water concentration (low solute concentration) to region of low water concentration (high solute concentration). It occurs because molecules are in constant thermal agitation. Bulk flow occurs in response to a pressure difference. Whenever, there is a suitable pathway for bulk movement of water. Osmosis is the process by which water moves across differentially permeable membrane. It depends upon the chemical potential of water or water potential. Osmotic potential of two separating solution and pressure potential across the membrane and wall of the cells. Therefore, it is necessary to understand these terms to explain the process of water movement across the membrane.

**10.4.2 Movement of water in Xylem:**

Plants absorb large quantity of water from soil. Only 1-2% of the absorbed water used in photosynthesis, in other metabolic activities and in the maintenance of turgidity of the cells. The remainder is lost from the leaves and other aerial parts in the form of vapours. This loss of water in vapour form through aerial parts of plants body is called **transpiration**. Before transpiration water is conducted up to leaves through xylem. This upward movement of water from absorptive surface (roots) up to transpiring surface(leaves) against the downward pull of gravity is known as **ascent of sap**.

The upward movement of water from roots upto leaves takes place through xylem depend upon two factors. These are transpiration pull and physical properties of water i.e., adhesion and cohesion. Water molecules tend to adhere to cellulose molecules of the walls of xylem vessels. Extensive hydrogen bonding in water gives rise to property of cohesion. Its also gives water a high tensile strength defined as the ability to resist the pulling force. The water molecules in xylem vessels forms a continuous column.

Transpiration pull results chain of events that starts when leaves begin to absorb solar radiation in the morning. Sunlight raises temperature of leaves, so the water begins to evaporate from moist walls of mesophyll cells. The evaporated water is immediately replaced from water inside the cell which is replaced with water from neighboring cell deeper in the leaf. Ultimately, water is pulled from xylem to meet the loss of water. Thus, water in xylem is placed under tension which is transmitted to root through vessels. This downward transmission of tension is because of cohesive property of water columns in vessels and trachieds. Water column moves upward by mass flow due to transpiration pull. Adhesion of water molecules to hydrophilic walls of Xylem cells. Small diameter of vessels and trachieds are important factors in overcoming the force of gravity.



To transport water over a long distance, plants do not use their metabolic energy. Force like adhesion, cohesion and evaporating effect of sunlight are mainly responsible for upward conduction of water.

**Mechanism of opening and closing of stomata:**

The opening and closing of stomata and even widening and narrowing of the gap between two guard cells depend upon the turgidity of guard cells, which is due to increase or decrease in the osmotic potential of the guard cells. The change in water potential that result from the osmotic changes cause water to move in or out of the guard cells. If water moves in, the cells expand (become turgid), if water moved out, cells become flaccid. When guard cells are turgid stomata open. When guard cells are flaccid the stomata are closed to affect this movement of water and exchange must take place between the guard cells and surrounding mesophyll and epidermal cells.

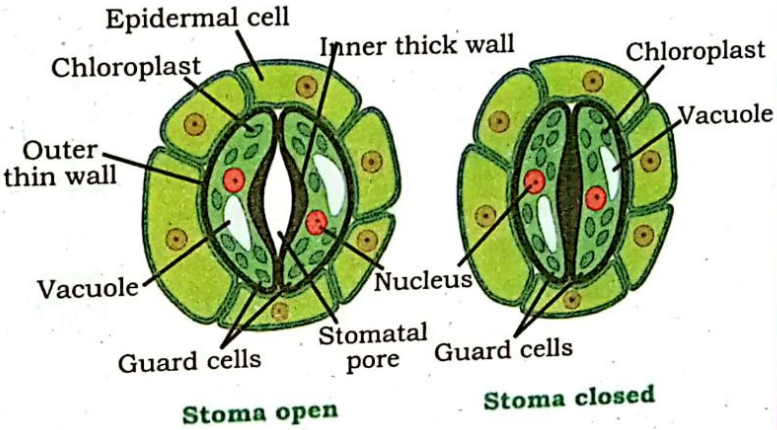



Fig: 10.4. Stomata

**10.5.1 Translocation of organic solutes (phloem translocation):**

The product of photosynthesis move from mature leaves to the growing and storage organs of plants. The direction of transport is determined by the relative locations of the sources and sinks of photosynthates. This movement of photoassimilates and other organic materials take place via the Phloem, and is therefore called **Phloem Translocation.** Transport occurs through specialized tissues called Sieve elements.

**Source-sink movement:**

The translocation of photosynthates always takes place from source to sink tissues, therefore, this Phloem transport is also referred as **source-to-sink movement.** Source are those tissues which produce photo assimilate more than their needs and sink are those tissues which produce photoassimilates less than they need or do not produce photoassimilates, like the mesophyll cells all of middle parts of leaves are source and the fruits, seeds or roots are sink. This pathway follows developmental changes as some sink and source tissues are inter convertible during the development of the plant e.g. developing and germinating seeds, developing and mature leaves.

A number of steps involved in the movement of photosynthates from mesophyll chloroplast to the Sieve elements in the Phloem of mature leaves. Sucrose is synthesized in the cytosol of mesophyll cells. This sucrose is translocated from the mesophyll cells to the vicinity of the sieve elements in the smallest veins of the leave. This generally termed as the short distance transport pathway because the solutes cover only a distance of two or three cell diameters. The sucrose is then actively transport into Sieve elements in the steps commonly called **Phloem loading.**

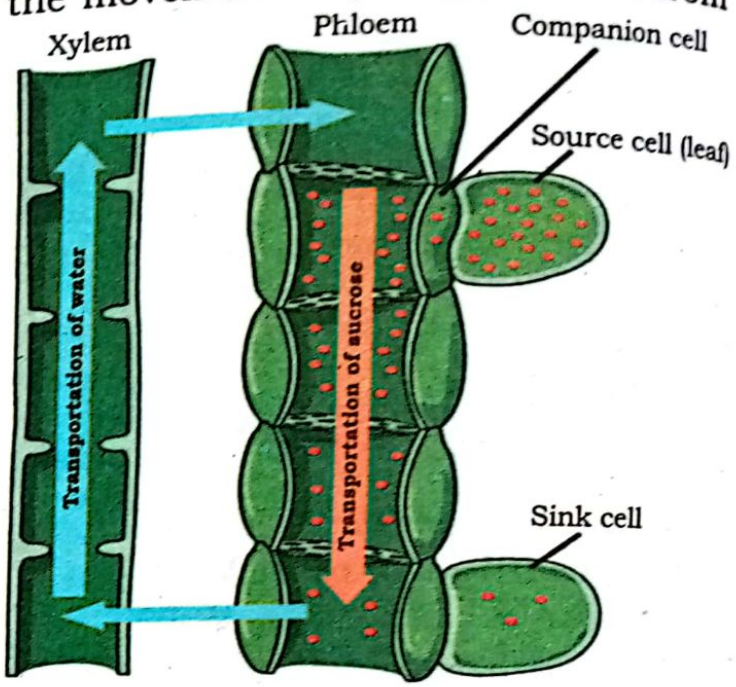



**Fig: 10.5. Phloem translocation**

The pathway of Phloem loading may be either symplastic or apoplastic depending upon the species.

The sucrose in sieve elements is exported away from source tissues. The photoassimilates can be moved a long distance hence this is termed as long distance transport. Finally, the photo assimilates or sucrose is unloaded at the sink in a process referred to as **Phloem unloading.**

### 10.5.2 The mechanism of phloem translocation:

**Pressure flow hypothesis:**

Phloem translocation is mainly explained by a theory called the pressure flow hypothesis proposed by **Ernst Münch** in 1930, which states that the flow of solution in the sieve elements is driven by a pressure gradient produced due to difference in osmotic pressure between sources and sinks. This pressure gradient is produced due to Phloem loading and unloading at the source and sink, respectively. A high osmotic pressure generated due to active Phloem loading in the sieve elements of a source tissue, cause a decline in the water potential. Whereas the xylem has high water potential so water moves out of xylem and enter into phloem and produces a high turgor pressure. In the sink tissue, present at other terminal of the translocation pathway, phloem unloading occurs, which produces a low osmotic pressure in the sieve elements of the tissues. As the low osmotic pressure, the water potential of the phloem rises above that of the xylem and water tends to leave the Phloem in response to the water potential gradient, which causes the decrease in the turgor pressure of the Phloem sieve elements in the sink.

An equilibrium between the two ends (source and sink) would be reached very soon if the entire translocation pathway were a single

membrane bound compartment. The sieve plates which are present in the sieve elements increase the resistance along the pathway and maintain the pressure gradient in the sieve elements between the sources and sinks. The photoassimilates present in sieve elements are physically pushed along the translocation pathway by bulk flow, much like water flowing through a garden hose.

Water movement in the translocation pathway is therefore driven by the pressure gradient rather than the water potential gradient. The passive, pressure driven long distance translocation in the sieve tube ultimately depends on the active short-distance transport mechanism involved in the phloem loading and unloading. These active mechanisms are responsible for setting up the pressure gradient in the first place.

## 10.6 HOMEOSTASIS IN PLANTS:

### 10.6.1 Osmotic adjustment or osmoregulation:

Changing in environmental conditions are the big threat for plants and cause severe stresses on them. Plants cope these stresses by adaptation or adjustment that enablesthem to survive in the stressful condition. They require metabolism to maintain internal condition of plant. This set of metabolic function is called homeostasis. Osmotic adjustment is a beneficial mechanism for water stress and salinity. It is a useful drought tolerance in response to drought condition or saline stress, many plants accumulate organic solutes to lowering the osmotic potential. Osmoregulation is one of the important aspects of **homeostasis.** It involves maintaining a balance between water and solute contents of cells.

In case of plant cells, the water potential of cell sap (solution in vacuole) is termed as **solute potential.** If a plant cell is placed in pure water or solution of higher water potential than the solution in its vacuole, the water moves from outside to inside the cell (endosmosis) and ultimately into the vacuole, As a result, the cells swells or become turgid. Such an extreme solution is called **hypotonic**. Further allowing the cell into such hypotonic medium doesn't cause it to burst because a cells wall develops a tension causing an internal hydrostatic pressure or pressure potential due to which further uptake of water in cytoplasm is resisted and finally stops.

When plant cell is placed in concentrated solution or **hypertonic** solution, there is a net movement of water out of the cell. As a result, the cell become flaccid. Under such condition, the cytoplasm with its plasma membrane shrinks from the cell wall. This condition is called **plasmolysis.**

**Osmotic adjustment:**

Depending upon the availability of water to flowering plants in their natural habitat they are grouped into four categories;

i. Hydrophytes
ii. Halophytes
iii. Mesophytes
iv. Xerophytes

**Hydrophytes:**

The plants which are found in fresh water habitat either partly or completely submerged are termed as **hydrophytes**. They do not have any difficulty in obtaining water. The stems and leaves of hydrophytes generally lack cuticle in partially submerged hydrophytes. Stem is cylindrical and spongy, stomata are restricted on the upper surface of leaves. E.g., Water Lilly.

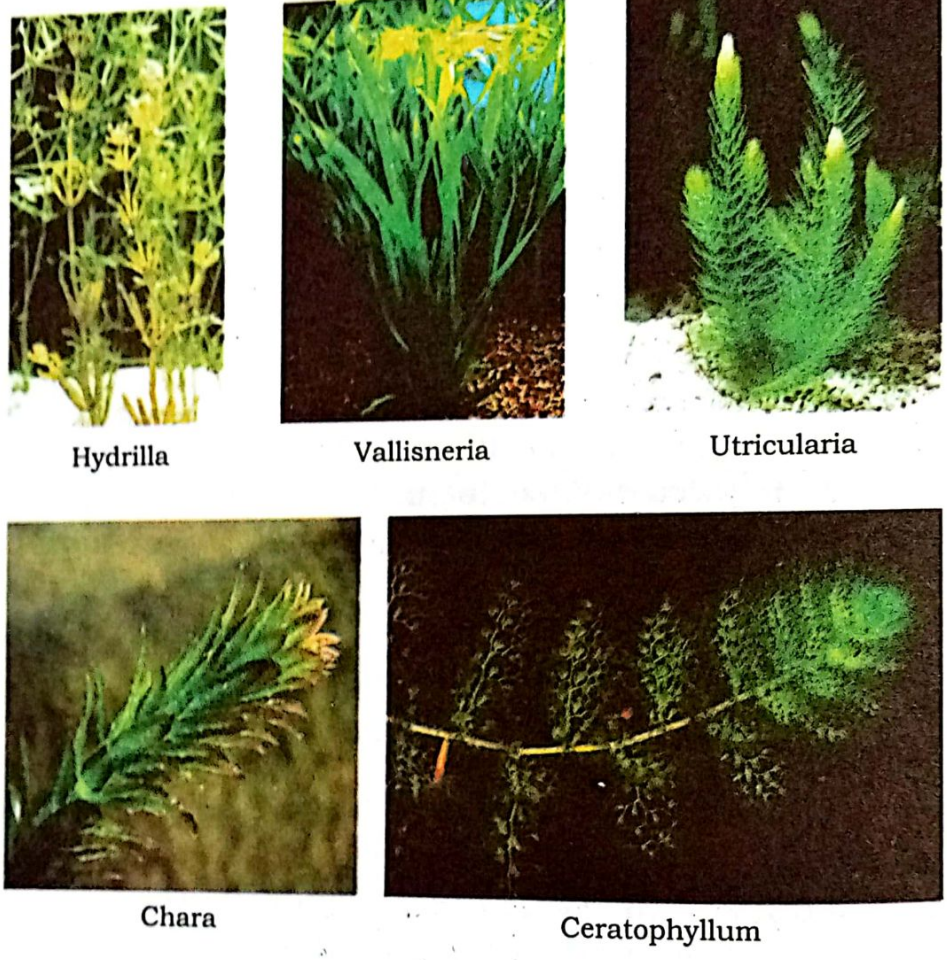



**Fig: 10.6. Submerged Hydrophyte**

In completely submerged hydrophytes (such as hyderilla) roots are poorly developed. Stem is soft, spongy weak and cylindrical. Internally the cortex contains large air cavities, these tissues are called aerenchyma.

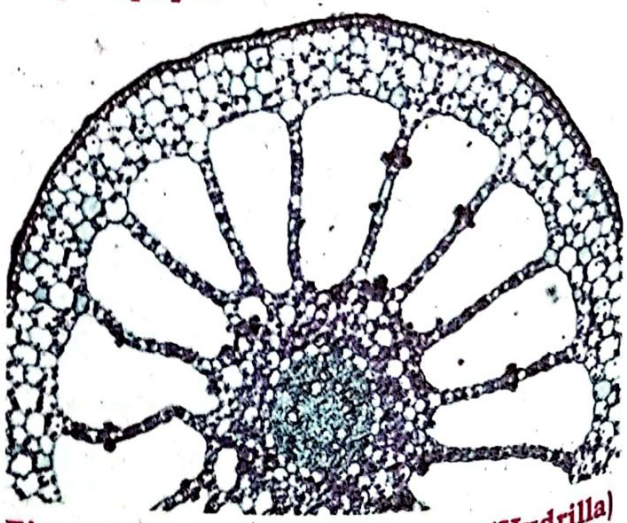


**Fig: 10.7. T.S. of Hydrophyte (Hydrilla)**

**Halophytes:**

The plants growing in salt marshes close to sea are termed as **Halophytes**, some of the examples of halophytes are glasswort, cord-grass. etc., they have to absorb water from such a soil which has higher salt concentration therefore they have lower water potential (higher osmotic pressure). Halophytes cope with this situation by roots develop lower water potential which brings in water by osmosis. The excess salt can be stored in cells or excreted out from salt glands on the leaves. The salt thus secreted by some species help them to trap water vapors from the air which is being absorbed in liquid from by leaf cells therefore this is another way for obtaining additional water from the air.

**Mesophytes:**

These are most of the land plants of temperate zones, which grow in well watered soil they can easily compensate the water lost by transpiration through absorbing water from the soil to prevent excessive transpiration they have developed a water proof external covering called cuticle. In Mesophytes root system is well developed. Stem is erect and branched. Leaves are generally large size. The dorsoventral leaf (dicot) contains stomata in the lower epidermis while upper epidermis has very less number of stomata. Isobilateral leaf (monocot) contains stomata more or less equal in numbers both in upper and lower epidermis.

**Xerophytes:**

Plants living in dry places such as deserts, steep hills and high altitude have to face scarcity of water they are termed as **xerophytes.** Under such condition water potential xerophytes of soil and air are very low. The xerophytes have developed following adaptations to conserve water and to survive during drought condition.

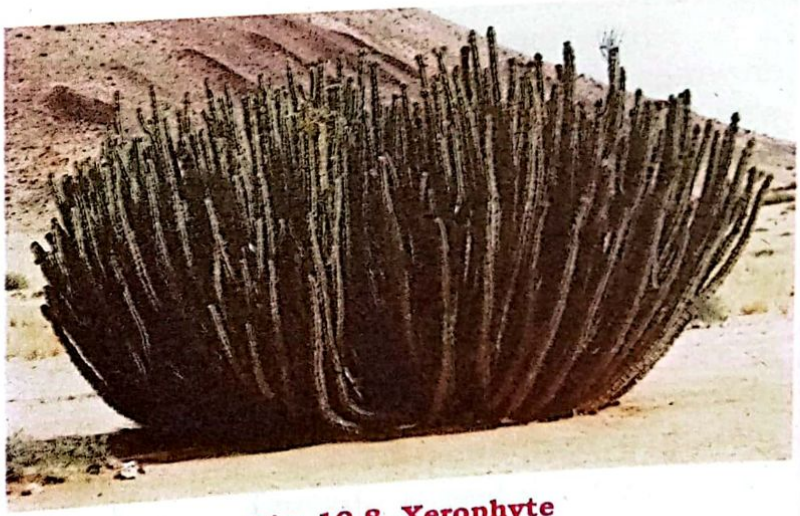


**Fig: 10.8. Xerophyte**

**Seed/spores as adaptations in life cycle during drought condition:**

Land plants produce seeds or spores during their life cycle, the protoplasm's of these structures are quite concentrated and usually protected externally by hard coats and thus these structures remain viable for a considerable period of time.

**Adaptations for balance between transpiration and water uptake:**

Xerophytes develop very deep vertical roots for the better absorption of water from the soil as seen in acacia, banyan etc.

Other plants such as cacti have superficial horizontal roots which can absorb water before it evaporates from the soil. Reduction in number of stomata, sunken type of stomata development of hairy epidermis, folding of leaves, reduction in size of lamina and modification into spines are some of the adaptations for reducing rate of transpiration.

Some plants store water in larger parenchymatous cells present in stem or leaves. Such plants are termed as succulents. As a result, the stem or leavers become juicy.

### 10.6.2 Adaptations of plants to low and high temperature:

**Low temperature:**

Low temperature affects the fluid nature of plasma membrane of plant cell. It is ultimately related to affect the transport of solutes across the membrane. Under such conditions the plants cells increase the proportion of unsaturated fatty acids which prevent crystal formation. The low temperature at the level of freezing point may causes ice crystal formation in cell, this is avoided by the plants inhabiting cold regions by developing freezing tolerance in which the composition of solutes of cell is altered in a way that ice crystal are formed in the cell wall rather than the **cytosol**. The cytosol is super cooled below the freezing point without the formation of ice.

**High temperature:**

High temperature is more harmful than low temperature since enzymes are denatured which is disastrous for metabolism. The principle way to cool down the plant is transpiration. At 40°C or above most of the plants cells synthesize heat shock proteins that protect enzymes. Plants have some other ways of avoiding overheating such as shiny cuticle, a small leaf surface area, wilting, etc.

## 10.7 GROWTH AND DEVELOPMENT IN PLANTS:

When an embryo or small seedling comes into being a second phase of the life starts which is called growth. Growth may be defined as a permanent or irreversible increase in size, weight, shape and structure usually accompanied by a permanent change of form. A new born becomes mature when it passed through growth.

In lower plants the entire plant body to specific may be capable of growth. In the higher plants, however growth is confined regions called the growing points. These regions are called meristems. They consist of group of cells, which are capable of divisions and giving rise to new cells. These dividing cells are called meristematic cells. The most important groups of meristematic cells are found at the stem and root apices and constitute the apical meristem.

**Role of Apical meristem:**

The activity of apical meristem results in primary structure of a plant or the primary growth. They are responsible for the increase in the length of the plant's axis at both the stem and root branches. They are also responsible for the production of lateral appendages such as leaves and floral part. In certain cases, increase in length also takes place by the activity of intercalary meristem. These are part of the apical meristem which have becomes separated from the apex by permanent tissues and left behind as the apical meristem moves on during growth. The lateral meristems occur at the cambium and phellogen of cork. Activity of these tissues result in the increase in diameter of stem and root the secondary tissues of plants are formed, this increase in thickness due to activity of lateral meristems is called secondary growth.

**Turgor pressure:**

The whole body of lower plants (Bryophytes) is made up of soft parenchyma tissues. They usually have thin primary walls but no secondary walls. They have a large central vacuole surrounded by a peripheral layer of cytoplasm. They are loosely packed with intercellular spaces in leaves and green herbaceous stem. They contain chloroplasts largely occurs in these cells. They take in water by endosmosis and become extended, this extended parenchyma are turgid, exert an internal pressure called turgor pressure. Due to this turgor pressure these parts remain firm and rigid. If these cells lose water, they also lose turgidity, which causes wilting in herbaceous stem and leaves. Therefore, this turgid parenchyma important for support and shape of the soft plant.

**10.7.1 Support in plants:**

Young stem have special types of anatomical arrangement, which also helps in supporting plant. The outermost layer of thin walled cells called epidermis. Region beneath epidermis is generally called cortex and the central portion called stele, which is mainly consist of vascular tissues and some soft tissues. This types of stem depends for it's mechanical support in the following tissues:

1. Thin wall parenchyma-having turgidity.
2. Thick walled living tissues like collenchyma and dead tissues like sclerenchyma.
3. Stele the cylindrical core of vascular bundle.

**Parenchyma**, a kind of simple tissue found in epidermis, cortex and pith. These are relatively unspecialized vegetative cells. The whole body of lower plants (bryophytes) is made up of these tissues. They usually have thin primary walls but no secondary walls. They have a large central vacuole surrounded by a peripheral layer of cytoplasm. They are loosely packed with

intercellular spaces in leaves and green herbaceous stems. They contain chloroplasts therefore photosynthesis largely occurs in these cells. They take in water by endosmosis and become extended, these extended parenchyma are turgid, exert an internal pressure called **turgor pressure**. Due to this pressure these parts remain firm and rigid. If these cells loose water, they also looses turgidity, which causes wilting in herbaceous stems and leaves. Therefore, these turgid parenchyma are important for support and shape of soft plant.

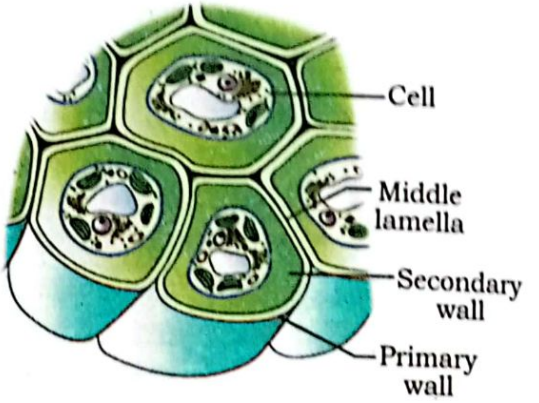



Fig: 10.9. Primary cell wall

**Collenchyma** is another type of simple tissue, which is important to provide support in plants. They are also living tissues, more elongated structurally similar to parenchyma except their walls and irregularly thickened. The thickened area is usually more prominent at edges. They function as an important supporting tissue in young plants, in the stem of non-woody older plants and in leaves.

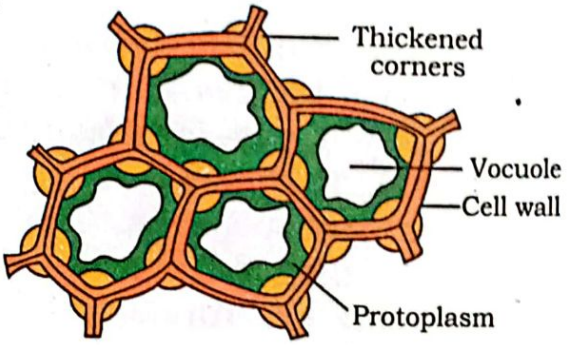



Fig: 10.10. Collenchyma

**Sclerenchyma** another type of supporting tissue. They are simple fundamental dead tissues. They have uniform thickness, heavily lignified secondary walls, which give strength to the plant body. Often these walls are so thick that the lumen of the cells become nearly vanished. Sclerenchyma cells are of two types, fibers and sclereids.

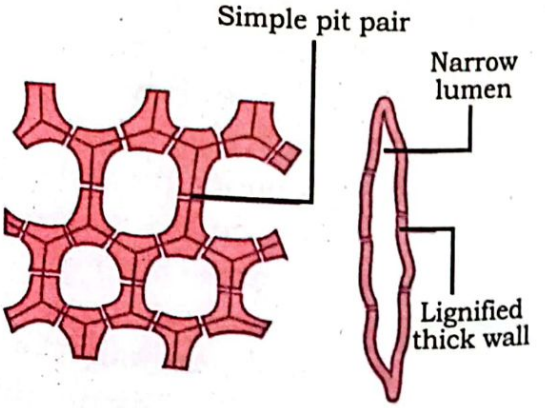



Fig: 10.11. Sclerenchyma

**Fibers** are elongated cells with tapered ends. They are tough and strong, but flexible while **sclereids** are variable, often irregular in shape. The simple unbranched sclereids are generally called stone cells, they are common in nut and hard parts of the seeds.

**Trachieds** are elongated tubular heavily lignified dead cells having large hollow cavities. They have oblique transverse walls making trachieds spindle shaped. They are found in xylem acting as supporting tissue in addition to transport of water and dissolved organic salts.

**Vessels** (trachea) are like trachieds but have no transverse walls and placed end to end forming a structure like open water pipeline. They are also found in xylem acting like trachieds.

**Annual rings:**

The plants of temperate region accumulate secondary xylem in the form of concentric layers every year and called annual rings.

Each annual ring consists of two zones, the inner zone of **spring wood** having larger vessels and an outer zone of **summer-wood** or **autumn-wood** having smaller vessels.

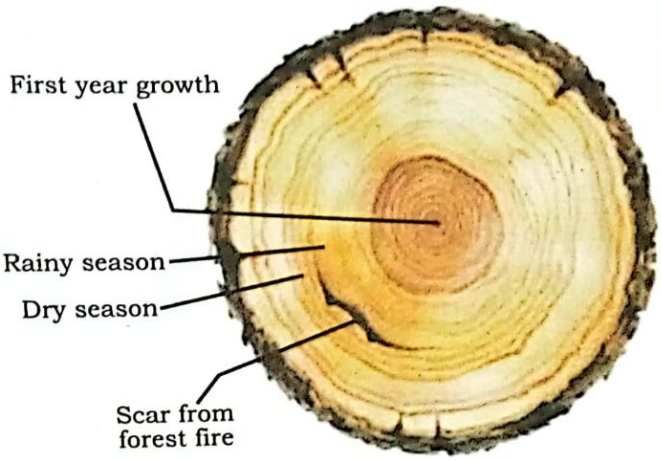



**Fig: 10.12. Annual ring**

A fairly accurate estimate of age of old tree can be made by counting annual rings. Study of the rings of large sample of very old tree can also give clue to the climate of an area. Tree ring dating have been used in archeological studies.

Activity: - Observe annual rings in the log of a tree and calculate age of plants by counting number of annual rings.

## 10.8 GROWTH RESPONSES IN PLANTS:

### 10.8.1 Plant hormones/growth regulators:

Certain chemicals produced by plants have a profound effect on their subsequent growth and development. Such chemicals are called plant hormones or phytohormones. They are synthesized by plants in minute concentration and exert their effect either by altering gene expression, activating or inhibiting enzymes or changing properties of the membrane. They are produced in young embryonic tissues as there is no specific organ for their production in plants.

There are five kind of plant hormones. These are:

i. Auxins
ii. Gibberellins
ii. Cytokinins
iv. Abscisic acid
v. Ethene

**i. Auxins (Gr. Auxano= To increase):**

Auxins is a class of plant growth substances both natural and synthetic first revealed by Fritz-Went (1926).

They were the first of the major plant hormones to be discovered and a major coordinating signals in plant development. Indole-acetic acid (IAA) is the principal type of auxin of higher plants, synthesized at the apices of stem and root (apical meristem)

In addition to (IAA) other naturally occurring auxins are: 4-chloro-Indole acetic acid, phenyl acetic acid (PAA) and indole-3 butyric acid (IBA) where the synthetic auxins include naphthalene acetic acid (NAA), 2,4-dichloro- phenoxy acetic acid (2, 4-D) and others.

Auxins co-ordinate development at all levels in plants, from the cellular level to organs and ultimately the whole plant.

**Role of Auxins:**

**(a) Cell division and cell- enlargement:**

It stimulates cell division, cell enlargement and brings about increase in length of plant. It stimulates wall loosening factor, for example, elastin to loosen the cell-wall. If Gibberellins are also present, the effect is stronger. It also stimulates cell-division if cytokinins are present.

Xylem tissues can be generated when the auxin concentration is equal to the cytokinins.

**(b) Initiation of roots:**

Auxin also initiates development of adventitious roots when applied at the cut base of stem.

**(c) Abscission:**

In mature leaves and fruits when auxin production diminishes, a layer of thin walled cells is formed at the base of petiole and stalk of fruit. This layer is called abscisic layer and causes fall of leaves and fruit with slight jerk.

**(d) Growth of fruit:**

Auxin is responsible for cell division, the tissues of ovary initiate to divide by auxin and the ovary enlarge to develop this process is called fruit setting.

**(e) Parthenocarpy:**

Use of auxin also helps in producing parthenocarpic or seedless fruits.

**(f) Apical dominance:**

Besides growth promoting function, auxin also has inhibitory effect on growth. Growth of apical bud inhibits growth of lateral buds beneath the stem. This phenomenon is termed as apical dominance. Removal of apical bud initiates growth of lateral buds with more leaves and axillary buds.

(g) **Weedicide:**

Auxins are selective weed killer. 2-4-dichlorophenoxy acetic acid (2-4-D) is used to kill weeds in lawns and cereal crops.

(h) **Flowering:**

Auxin plays a minor role in the initiation of flowering. It can delay the senescence of flowers in low concentrations.

ii. **Gibberellins:**

It is a group of chemicals that promote cell division and cell elongation.

First noticed in Gibberella fujikuroi fungus which infected rice seedlings and produced a disease called **bakanae** (foolish seedling). The infected seedlings elongated and ultimately fell over without producing grains. Even extract from the fungus when applied to rice seedlings produced the same disease indicating that a definite chemical compound is responsible for disease. **T .Yabuta** and **T.Hayashi** succeeded in isolating the active substance from the fungus and was named Gibberellin, after the name of genus. Its ability to induce growth attracted the scientists who have isolated 70 different types of Gibberellin, many of them occur naturally in higher plants. Major sites of their production are roots, stem and leaves.

**Role of Gibberellin:**

Gibberellin produces wide variety of effects. One of their effect, like auxin is to stimulate cell division and cell elongation it prevents genetical and physiological dwarfism. They also mobilize food stored in endosperm by producing enzyme (amylase) that converts starch into sugar which is made available to developing embryo.

They also stimulate flowering, fruits development, bud sprouting, growth of pollen tube and parthenocarpy.

iii. **Cytokinins:**

These are a group of substances both natural and synthetic, which react with auxin to induce cell division. Originally obtained from coconut milk, the other sources are Herring sperm DNA and yeast extract. One of the naturally occurring cytokinin is **zeatin**, which was obtained in pure crystalline form from immature corn grains. **Kinetin,** a synthetic cytokinin has the same effect as that of zeatin.

**Role of cytokinin:**

They initiate rapid cell division but only in presence of auxin. They also cause delayed senescence (old age). Detached leaves which would normally lose chlorophyll are prevented from becoming decolourized by their application. They also break seed dormancy and promote fruit development in some species.

**iv. Abscisic acid:**

In contrast to growth promoting hormones like auxin, gibberellins and cytokinins, abscisic acid (ABA) is growth inhibitor produced by plant during adverse environmental conditions such as drought condition and at the onset of winter. It induces dormancy in buds and seeds, causes stomata to close, turns leaf primordia into scale which protects the buds and promotes senescence.

**v. Ethene:**

The most important role of ethane (a gas), is that it triggers ripening of fruit. It affects permeability of cell membrane, which allows enzymes responsible for destroying chloroplast with the result that red and yellow colours are unmasked and fruit assumes ripened colour. It contributes to leaf abscission and also breaks dormancy of buds and seeds in some species. It also initiates flowering in some plants e.g. pineapple.

## 10.9 MOVEMENT IN PLANTS:

All living organisms have the property of movement to fulfill the need of their nutrition, protection, shelter and reproduction. Movement is defined as any action taken by living organism to reduce its irritability produce by stimuli. Plants are usually sessile which respond to environmental factors by adjusting their pattern of growth, development and turgor pressure.

**Types of movement in plants:**

On the basis of stimuli there are two main types of movement found in plants.

1. Autonomic or Spontaneous movement cause by internal stimuli
2. Paratonic or Induced Movement caused by external stimuli

Here we discussed only Paratonic or induced movement in detail.

### 10.9.1 Paratonic or induced movement

Movements which occur due to external stimuli are known as induced or paratonic movements. They may be tropic or nastic. The external stimuli which cause these movements may be light, temperature, water, chemicals, gravity etc.

**Tropic movement: (Directional movement)**

Tropism or tropic movement are growth responses that result in curvatures of whole plant organs towards or away from stimuli.

Movement caused due to external stimuli coming from one side, controlled by the direction of stimulus, respond in the form of growth of curvature in one direction called tropic movement. It is commonly found in radially symmetrical organs of plant such as root and stem. On the basis of stimuli following are the types of tropic movement found in plants.

**Phototropism:**

It is a curvature movement that takes place when plant is exposed to light coming only from one direction. If this curvature movement is towards

the source of light called positive photo tropism and if away from the source of light called negative phototropism. Phototropism curvature is due to light effect on the distribution of auxin (plant growth promoting hormone)

**Geotropism:**

It is the movement caused in response to gravitational stimulus. Positive geotropism is observed in the primary roots of many plants and negative geotropism in their shoot.

**Chemotropism:**

Chemotropism is the movement caused due to chemical for example pollen tube grows through the style towards ovule due to chemical stimulus.

**Hydrotropism:**

The movement of plant organs in response of water stimulus called hydrotropic movement. This also result in curvature of the organs due to unequal growth on its two sides. Roots are positively hydrotropic.

**Thigmotropism:**

Thigmotropism is the curvature movement of plant in response to touch stimulus. It can be observed in twiner and climbers. When they touch the solid object the growth on the opposite side of contact increases and they coiled around the support.

Activity:- Demonstrate folding of Mimosa leaf after touch

## 10.10 PHOTOPERIODISM AND VERNALIZATION:

Photoperiodism and Vernalization serve to synchronize the reproductive behavior of plants with their environment, ensuring reproduction at favorable times of years. They also ensured that members of the same species flower at the same time, encouraging cross pollination for genetic variability.

**Photoperiodism:**

Length of day light period has marked influence on the behavior of plants particularly on their flowering. The phenomenon in which the influence of photoperiod length on plants is studied is called Photoperiodism. It may also be defined as "response of flowering to relative length of the day and night"

On the basis of their differing responses to light and dark, flowering plants can be divided into three groups,

**Long day plants:**

Those require long photoperiod and short nights for their flowering. Long day plants flower only when the light period exceeds a certain critical length in each 24 hour cycle. This varies, but an average is about 23 hours to 14 hours. e.g., Hibiscus, Lettuce, Spinach, Radish, Sugar beet and Potato.

**Short day plants:**

Those that require short days and long nights, for their flowering. Short day plants flower only when the light period is shorter than a critical length in each 24 hours cycle. e.g., Rice, Chrysanthemun, Soya bean, Onion.

**Day neutral plants:**

Plant which are indifferent to day length for their flowering, for example Tomato, Cotton.

**The role of phytochrome in photoperiodism:**

The measurement of photoperiod by short and long day plants is now known to depend on a light sensitive pigment, called Phytochrome, which is distributed throughout the plant in minute quantities, being most concentrated in growing tips. Phytochrome exists in two inter convertible forms. The inactive form of Phytochrome $P_R$ (red) is converted to active form $P_{FR}$, following exposure to red light with peak sensitivity at 660nm. $P_{FR}$ is slowly converted back to the inactive form in darkness or may be rapidly converted to $P_R$ by exposure to far red light with peak sensitivity at 730nm.

Although day light has both red and far-red light but red is pre dominant, so that in day time, $P_R$ is converted to $P_{FR}$ (far-red) which stores in the leaves. The onset of flowering seems to be determined by the balance between the two forms of Phytochrome pigment, which is some way switches on the genes responsible for flowering.

**Vernalization:**

Besides having advantageous effects of temperature on the growth of plants, low temperature plays another role i.e., vernalization which may be defined as: promotion of flowering by a cold treatment given to the imbibed seeds or young plants. The effect of low temperature treatment applied in the earlier stages of development has an after effect on the later stages of the development of a plant, many plants require cold treatment for germination many cereals like wheat and rice exist in two varieties, the annual or spring and biennial or winter variety. The annual or spring variety is sown in spring and flowers in summers of the same year. The biennial or winter variety is sown in fall and the yield is obtained in the summer of the next year. If the seeds of this variety are sown in spring, the plants do not flower and yield no seeds. It appears that low winter temperatures are necessary for the development of seeds in the winter varieties. Similarly, a biennial like turnip, sugar weed, will not produce flowers if not exposed to cold winter temperatures.

# SUMMARY

- Macronutrients are required in large amount, e.g Nitrogen, Phosphorus, Potassium, Sulphur and Sodium etc.
- Micro nutrients, trace elements are required in small amount include manganese, iron, copper, zinc etc
- Carnivorous plant typically live in nitrogen deficient habitats
- Flowering plant exchange gases by diffusion through stomata
- The intensity of gases exchange depend upon the intensity of respiration
- Some mechanism is needed for transporting substances
- Biologists term the maintenance of steady state as homeostasis
- Movement of water takes place through xylem and mass flow transport of sugar occurs in phloem
- In root transport of water takes place in radial direction it is also termed as lateral transport
- The upward movement of water from roots up to leaves takes place through xylem depend upon two factors transpiration pull and physical property of water i.e. adhesion and cohesion
- Mesophytes are most of the land plant of temperate zone which grow in well watered soil
- The best know plant hormones are auxins, gibberellins, cytokinins, abscisic acid and ethane. they are all effective at very low concentrations
- The measurement of the length of the photoperiod appears to depend on the inter action of phytochrome with and internal clock method.
- Growth may be defined as "permanent irreversible increase in size weight, shape and structure usually anaccompanied by a permanent changes of form.
- The plans of temperate region accumulate secondary xylem in the form of concentric layers every year and called annual ring. A fairly accurate estimate of age old tree can be made by country rings.
- Photoperiodism is the response of plants flowering to relative length of the day and night.
- Vernalization may be defined as promotion of flowering by a cold treatment given to imbibed seeds or young plants
- The translocation of photosynthates always taken place from source to sink tissues so referred as source to sink movement.

# EXERCISE

**1. Encircle the correct choice**

(i) From where Plants primarily obtain essential nutrients:
(a) Water (b) Air
(c) Soil (d) Light

(ii) Identify a micro nutrient for plants amongst the following:
(a) Potassium (b) Phosphorus
(c) Iron (d) Sluphur

(iii) In which mineral deficient soil carnivorous plant typically live:
(a) Nitrogen (b) Calcium
(c) Magnesium (d) Potassium

(iv) The plants growing in salt marshes close to sea are termed as:
(a) Hydrophytes (b) Xerophytes
(c) Mesophytes (d) Halophytes

(v) The cause of color of leaf turns in to dull or bluish green is the deficiency of:
(a) Nitrogen (b) Phosphate
(c) Potassium (d) Magnesium

(vi) Which principle type of auxin of higher plants synthesized at the apices of stem and root:
(a) PAA (b) 24-D
(c) IAA (d) NAA

(vii) Active transport of sucrose into sieve elements is a step commonly called:
(a) Phloem loading (b) unloading
(c) Diffusion (d) Osmosis

(viii) The capacity of a living system to lose water is:
(a) Osmotic pressure (b) Water potential
(c) Osmosis (d) Plasma

(ix) The production of lateral appendages depends on the activity of:
(a) Lateral meristem (b) lutercalary meristem
(c) Apical meristem (d) none of these

(x) Which process involved in the promotion of flowering by cold treatment:
(a) Photoperiodism (b) Vernalization
(c) Secondary Growth (d) Transpiration

## 2. Write short answers of the following questions:

1. Why mineral nutrients are necessary for plants?
2. Why $N_2$ is included in mineral nutrient although it is not mineral?
3. Why desert plants reduce their leaf size?
4. Why carnivores plants use insect as food?
5. Why phytochrome pigments are important to photoperiodism?
6. How annual rings are formed?
7. Why cold treatment is necessary for the germination of seed in some plants?
8. How osmotic adjustment is beneficial for plants?

## 3. Write detailed answers of the following questions:

1. Give an account of exchange of gases in plants?
2. How does pressure flow theory explain the movement of sugar through the plants?
3. Describe the cohesion tension theory of water movement through xylem? What supplies the cohesion and what is the source of tension? How do these two interact to move water through a plant?
4. What essential inorganic nutrient does a plant require for growth, which of these nutrients are required in trace amounts? What are some of the general functions of inorganic nutrients?
5. What are growth regulators? Name and discuss five in detail?
6. Discuss categorization of plants based on osmotic adjustment?

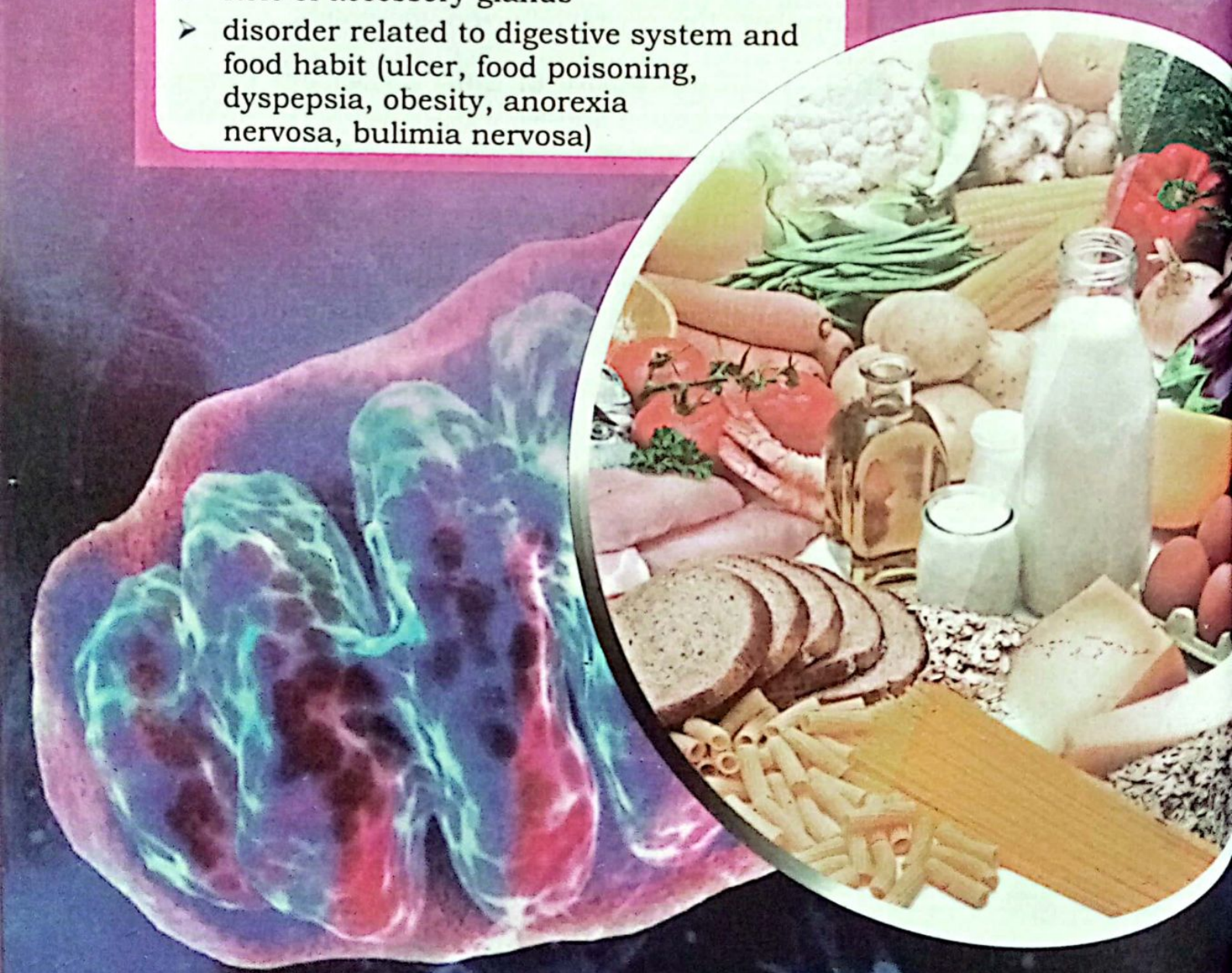
# HOLOZOIC NUTRITION

Chapter 11

## Major Concept

**In this Unit you will learn:**

- Holozoic nutrition
- Digestive system of man
- Alimentary canal; structural and functional details.
- Role of accessory glands
- disorder related to digestive system and food habit (ulcer, food poisoning, dyspepsia, obesity, anorexia nervosa, bulimia nervosa)



### 11.1.1 Holozoic nutrition

Just like a vehicle needs fuel to move, a living cell needs supply of **food** to perform its various biological functions. Through this process, the cells not only obtain energy but also get materials to grow and repair themselves. The food of an organism consists of different substances, the **nutrients** which are essentially required by the protoplasm to perform its different biological functions.

In the process of heterotrophic nutrition, an organism depends upon ready-made food like carbohydrates, proteins, etc., being prepared by other organisms, plants as well as animals. Holozoic (Gr. Holo=Whole; zoikos=of animals) nutrition is one of the type of heterotrophic nutrition which commonly occurs in animals. It is characterized by ingestion or taking in of food in solid or liquid form from the environment. It consists of ingestion, digestion, absorption, assimilation and egestion. Let's discuss them one by one.

**Ingestion:**

Taking in of food into the cell (in case of unicellular organisms) or body (in case of multicellular organisms). It takes place either through cell surface or through specific opening, **mouth.**

**Digestion:**

It is the process of breaking down of complex or non-diffusible food into simple or diffusible molecules so that they may be incorporated in the metabolism. This conversion process takes place chemically with the help of enzymes as well as mechanically.

**Absorption:**

Through the process of absorption, the soluble molecules of food are absorbed by the digestive membranes such as intestinal lining, etc., so that they may be utilized during the metabolic activities.

**Assimilation:**

The process of utilization of the absorbed molecules during the metabolic processes of cell is called assimilation.

**Egestion:**

The process of removal of undigested food from the cell/body is called egestion.

### 11.1.2 Intracellular and extracellular digestion:

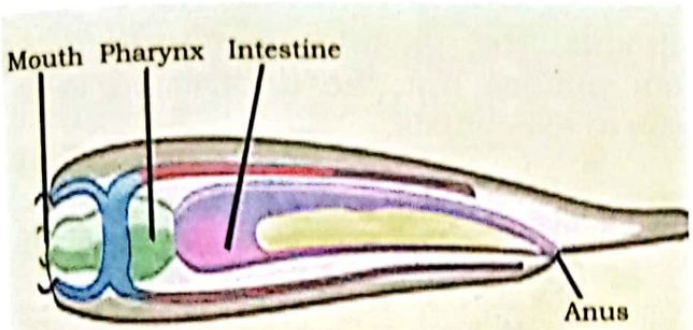
Single cells organisms like protozoa commonly take in food particles present in their environment through their cell surface or plasma

membrane. Thus the process of digestion takes place inside their cell. Such organisms do not release their digestive enzymes outside their cell. This kind of digestion is termed as **intracellular digestion**. Whereas on the other hand, majority of the multicellular animals, like round worms, insects, mammals, etc., take the food inside their body in a specific location called digestive tract/alimentary canal or gut made up of cells. They cannot take it inside their cells directly since the size of food particles is too large to be taken up by the cells. While the food remains outside the cells in their gut, the enzymes are released from the secretory cells into the gut where the food is being digested and converted into simple substances. The latter, is termed as **extracellular digestion**. Both types of digestions involve the process of the breaking down of food not only through **enzymatic conversion or chemical digestion** but in extracellular, also through some kind of mechanical conversion in many animals. The former is termed as **Chemical digestion** while the latter is **Mechanical digestion**. During the process of enzymatic break down of complex food, water is essentially required to facilitate the hydrolytic breaking down of food. On the other hand, mechanical digestion involves some kind of mechanically or physically breaking down (such as mastication, churning, grinding, peristalsis, etc.) of larger particles of food into smaller ones. It facilitates the process of chemical digestion thereby providing more particles of food to be acted upon by digestive juices.

**Sac-like and tube-like digestive system:**

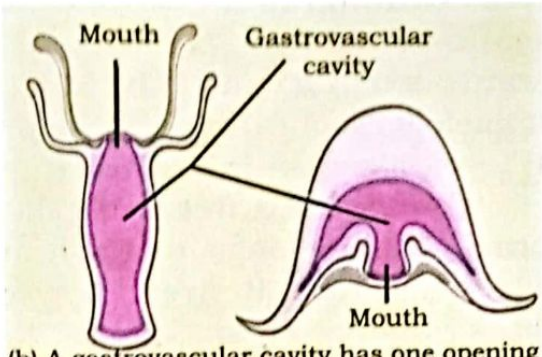
| Tube like digestive system | Sac like digestive system |
|---|---|
| 1. Animals have two openings in their digestive tract | 1. Animals have single opening |
| 2. Present in relatively advanced group of organisms | 2. Present relatively in lower group of organisms |
| 3. Food entrance and waste removal takes place by separate openings | 3. Food entrance and waste removal takes place by single opening |
| 4. Digestive system completes with associated glands and organs | 4. Digestive system is incomplete and without associated glands and organs |
| 5. Mechanical and chemical digestions both takes place actively | 5. Mostly chemical digestion takes place actively |
| 6. Digestive tract with variable pH due to complex nature of food | 6. Digestive tract with not much variable pH due to simple nature of food |
| 7. Enormous enzymes present which act upon food components | 7. Fewer enzymes present which act upon food components |
| 8. Digestive tract well supported by muscles | 8. Digestive tract is not well |

for strong peristalsis and defecation reflexes




(a) An elementary canal has two openings

supported by strong muscles




(b) A gastrovascular cavity has one opening

### 11.1.3 Digestion in *Amoeba*

*Amoeba* is a unicellular, eukaryotic organism which belongs to Protozoa. Being microphagous feeder, it feeds upon minute food particles and other microscopic organisms like bacteria, etc. The food is captured and ingested through its pseudopodia which are temporary finger-like extensions of cytoplasm. Pseudopodia are given out in the direction of food, form a cup-like structure or **food cup**. As soon as the food particles are trapped into the food cup, their tips start moving towards each other till completely enclosing the food. Thus the food is now enclosed in a sphere formed by the membrane which pinches off from the plasma membrane and moves into the cytoplasm. This tiny sphere of plasma membrane containing food particles and water is termed as **food vacuole**. The entire process is ingestion. The food vacuole thus moving inside the cytoplasm is attached with lysosomes containing different hydrolytic enzymes which act upon variable pH ranging from 5.6 to 7.3 depending upon the nature of food components and initiate the process of digestion. Since the food is digested inside the food vacuole, it is termed as **intracellular digestion**. The digestive vacuole moves deeper into the cytoplasm through the streaming movement of cytoplasm(cyclosis). After the digestion process is completed, the food vacuole gives out numerous fine, cytoplasmic canals. The diffusible food particles move into these canals for the absorption process. The absorbed food particles then diffuse out into the different parts of the cytoplasm where they may be assimilated accordingly. The digested food may be incorporated to form new protoplasm or it may be broken down to liberate energy. Meanwhile, in the food vacuole, there

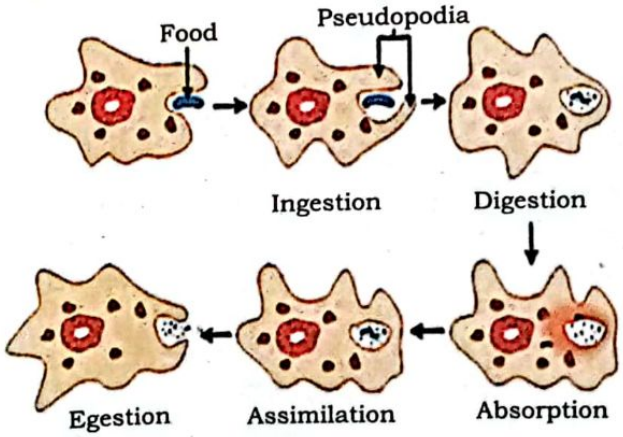



**Fig: 11.1 Digestion in amoeba**

is some undigested food left behind. The vacuole containing undigested food is pushed towards the cell surface where it attaches with interior of plasma membrane. At the point of attachment, the plasma membrane breaks towards exterior side. The cytoplasm pushes out the undigested food to completely egest it through the process of exocytosis.

### 11.1.4. Digestion in *Planaria*

*Planaria* is a free-living flat worm which belongs to Phylum Platyhelminthes. It lives in wet places under rocks, close to streams, canals and in brackish water. It has a soft, elongated, unsegmented and dorsoventrally flat body. The digestive system is very simple and considered to be **incomplete or sac-like**. The mouth lies on a small, muscular tube, **the pharynx** lying almost in the middle of the body. The pharynx is attached to intestine through a very short **esophagus**. The intestine divides into three blind branches, one anterior and two posterior-lateral ones. Each of the three branches, gives out numerous branches or **diverticula**. Each diverticulum further branches into very fine and blind branches or **ramification**. There is no anus.

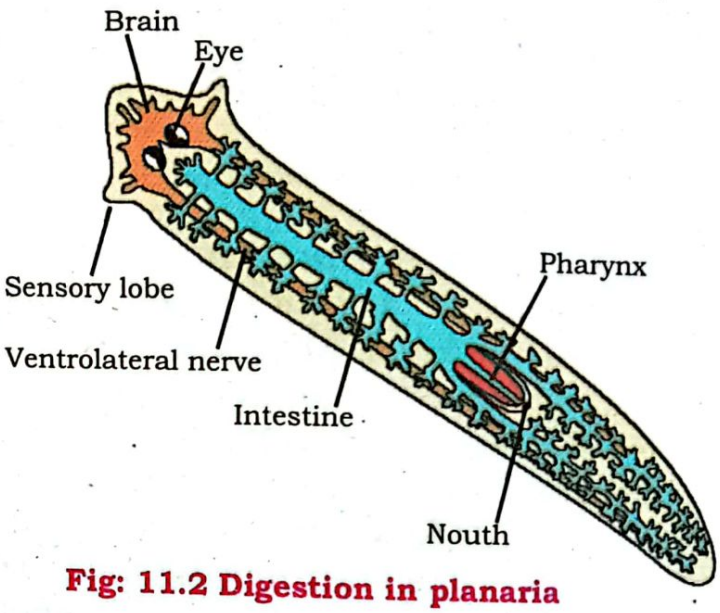



**Fig: 11.2 Digestion in planaria**

The planarians are carnivore. They capture small larvae, small insects, etc., through trapping them into thick mucussecreted from the pharynx. The prey is then sucked up inside the pharynx through the mouth. The glandular cells secrete variety of enzymes to begin the process of extracellular digestion from the pharynx till the end of intestine. The muscular action of the body pushes the food throughout the three branches of intestine. As the food breaks up into smaller and simpler particles, it is taken up through the process of endocytosis by the cells of the gastro-vascular cavity lining the intestine. Inside the cells of the gastro-vascular cavity, the remaining process of digestion takes place. Since it takes place inside the cell of the gastro-vascular cavity, it is now termed as intracellular digestion. So the process of digestion in planaria is both extracellular as well as intracellular. The digested food then diffuses through the cells of the gastrovascular cavity into the mesenchyme cells. The highly branching system of intestine actually helps in quick disposal of the food to all cells of the body, thus it also serves as alternate to the circulatory system. The undigested food in the intestine is egested through the mouth.

## 11.2.1 HUMAN DIGESTIVE SYSTEM

The digestive tract of human is **complete**. It is tube-like gut with two openings, mouth and anus. It is also termed as **gastro-intestinal tract** (G.I.T.). Like other animals with complete gut, it begins with mouth and terminates on anus. Human digestive system consists of digestive tract and accessory glands. Its various regions are specifically designed for different processes of holozoic nutrition. Associated with the G.I.T. are well elaborated accessory glands like salivary glands, liver, pancreas, etc.

The human digestive system consists of mouth, oral cavity (buccal cavity), pharynx, esophagus, stomach, small intestine, large intestine and anus. The glands associated with this are salivary glands, liver and pancreas. Let's discuss them one by one.

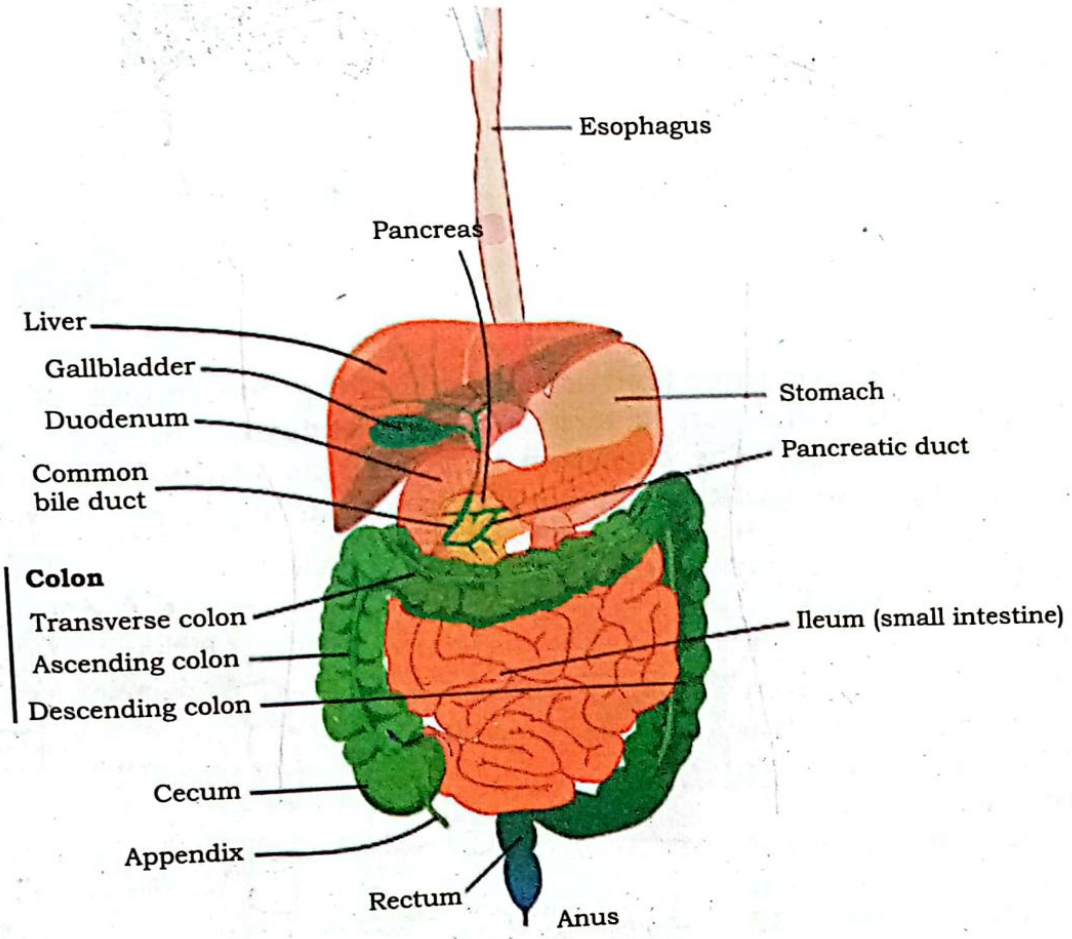



**Fig: 11.3 Human digestive system**

**Mouth:**

It is the anterior opening of alimentary canal bounded by two fleshy lips, termed as upper and lower lips, respectively. It is meant for ingestion of food.

## Oral cavity:

The mouth opens into a wide space called oral cavity formed by upper and lower jaws. It has a muscular tongue on its floor. Its roof is formed by a dome-shaped bony, **hard palate** anteriorly and a **soft palate,** posteriorly. In the middle of the soft palate, hanging down is a muscular **uvula**. Laterally, it has cheeks, while it is connected posteriorly with a pharynx. Both jaws are lined by rows of teeth for cutting and grinding of food. They are meant for **mechanical digestion** in the oral cavity. The upper jaw is fixed while the lower is moveable.

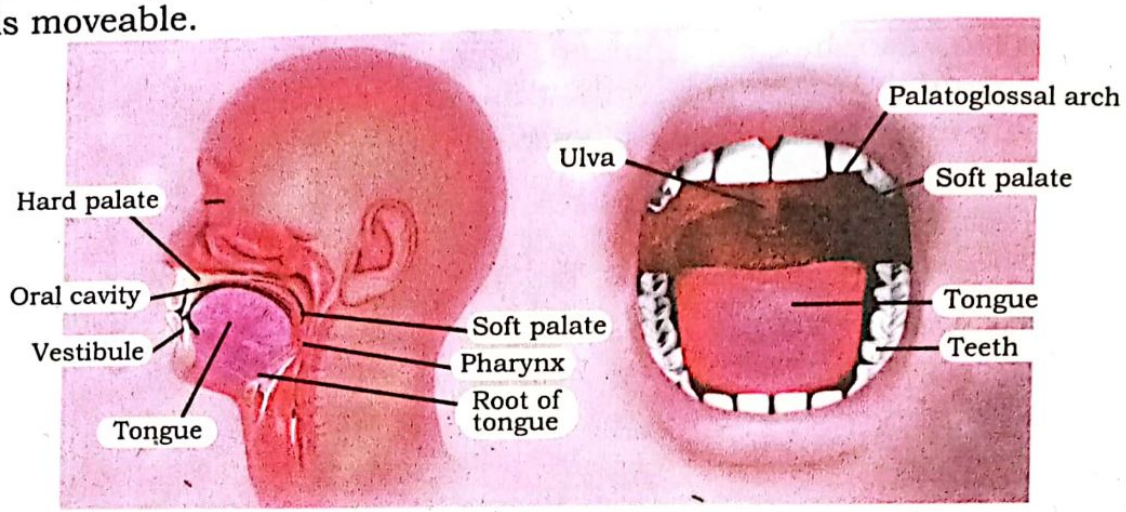



Fig: 11.4 Oral cavity

## Teeth:

The teeth are embedded in sockets along the length of lower and upper jaws. This condition is termed as **thecodont**. We have two sets of teeth during life time. The condition is termed as **diphydont**. Initially, we have **deciduous or milk teeth** which are latter replaced by **permanent teeth**. The number of deciduous teeth is 20 while the number of permanent teeth is 32. Our teeth are different in shape and size, so the condition is termed as **heterodont**. This is correlated with different functions and different diet. Among the 32 permanent teeth, there are 8 Incisors, 4 canines, 8 premolars and 12 molars. The molars have no deciduous predecessors. The incisors are for cutting and

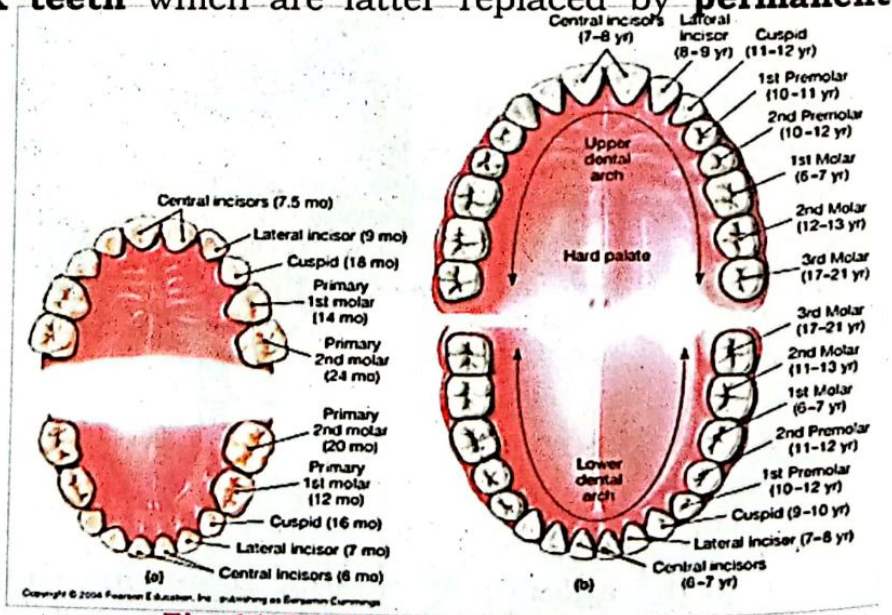



Fig: 11.5 Milk and permanent teeth

biting teeth and have flat sharp edges by which the food is cut into smaller pieces for ingestion. The sharp, pointed canines are for tearing and pulling flesh. The premolars and molars are used for grinding and crushing the food.

**Tongue:**

It's a muscular organ attached through hyoid bone with the floor of the oral cavity from its posterior and middle while free anteriorly at its tip. Its upper surface has numerous projections or **papillae** containing nerve endings for the sense of taste. The under surface of the tongue have a fold of mucous membrane called **frenulum**. The tongue helps in mastication, swallowing, taste and speech.

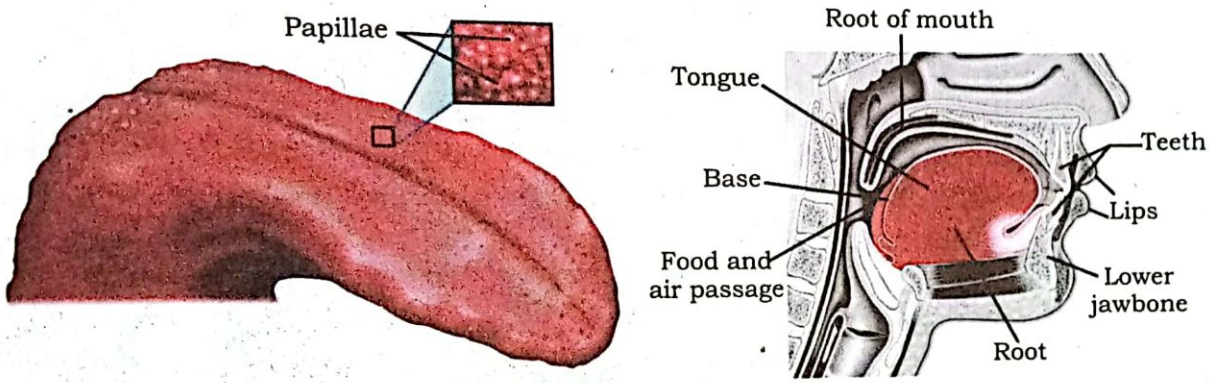



**Fig: 11.6 Human tongue**

**Salivary Glands:**

When you think about taking some spicy food, your mouth instantly get watered. This is actually a watery secretion, the **saliva**, secreted from the salivary glands present in your oral cavity. The saliva helps in lubrication of food through its **mucin (mucous)** which makes its swallowing easy. Its enzyme, **salivary amylase** also partially digests starch into maltose. It also helps in killing bacteria through its enzyme, **lysozyme**. Thus, the process of **chemical digestion** begins in the oral cavity. The human oral cavity has 3 pairs of major salivary glands, viz. **Parotid glands** at the base of the pinnae, **Sub-lingual glands** at the base of the tongue, and **Sub-mandibular glands** at the base of the lower jaw.

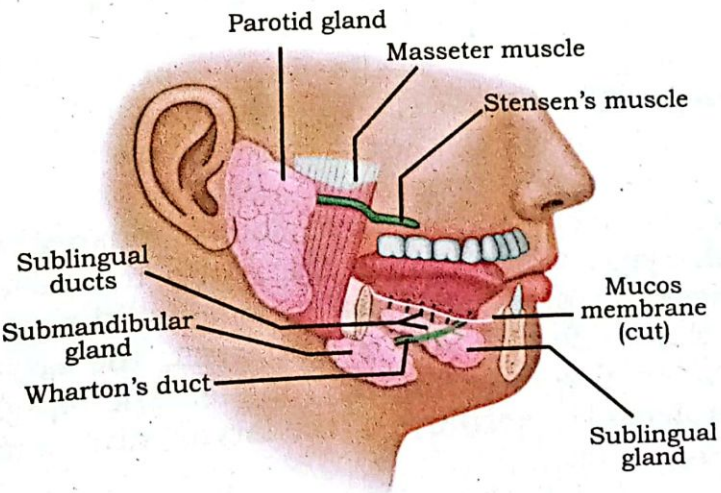



**Fig: 11.7 Salivary glands**

The salivary glands are controlled by autonomic nervous system. Normally, the amount of saliva is constant. It is reported that a normal person secretes 1 to 1.5 liters of saliva in 24 hours.

**Pharynx:**

The pharynx is connected anteriorly to oral cavity and nasal cavity simultaneously, while posteriorly connected to the esophagus and larynx. The pharynx permits the passage of swallowed solids and liquids food into the esophagus, or gullet, and conducts air to and from the trachea, or windpipe, during respiration. The pharynx also connects on either side with the cavity of the middle ear by way of the **Eustachian tube** and provides for equalization of air pressure on the eardrum membrane, which separates the cavity of the middle ear from the external ear canal. The principal muscles of the pharynx, involved in the mechanics of swallowing, are the three **pharyngeal constrictors**, which overlap with each other slightly and form the primary musculature of the side and rear pharyngeal walls.

**Swallowing:**

After sufficient chewing of the food and mixing up of saliva in the oral cavity, the food you ingested becomes a soft, lubricated ball-like structure called **bolus**. It is being pushed behind by the tongue into the pharynx. This process is termed as **swallowing or deglutition**. It is a voluntary process in which the mastication is ceased, air passage way is temporarily blocked, so bolus is pushed behind by the tongue into the pharynx. Entry of the bolus into the nasal pharynx is prevented by the elevation of the soft palate against the posterior pharyngeal wall. As the bolus is forced into the pharynx, the larynx moves upward and forward under the base of the tongue. The **epiglottis**, a lid-like covering that protects the entrance to the larynx, diverts the bolus to the esophagus.

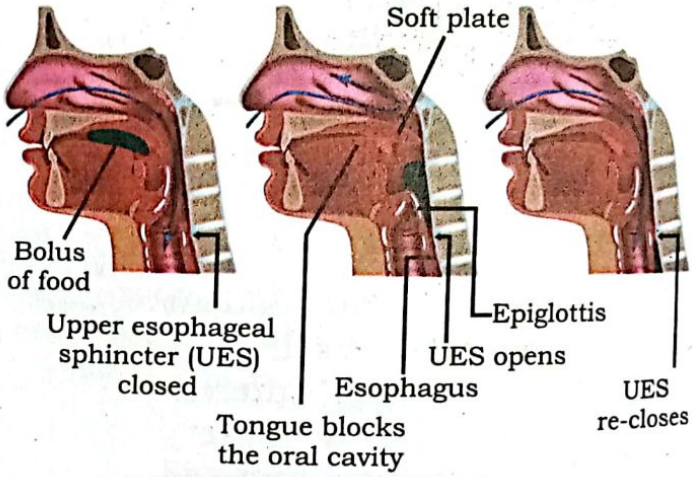



**Fig: 11.8 Swallowing**

**Peristalsis:**

A lot of times especially after taking large meal, you feel some movement in your abdomen. This is actually a wave like involuntary, rhythmic movement of contraction and relaxation of your gut muscles which propels the food forward inside the gut. This kind of movement also occurs in the tube-like or ducts of other systems of the body. It begins from the pharynx and then esophagus and continues propelling the food till the end of the digestive tract. The walls of alimentary canal contains smooth

muscles controlled by autonomic nervous system. The muscular layer of the gut consists of inner layer of **circular muscles** while an outer layer of **longitudinal muscles**. The usual stimulus for peristalsis is distension of the gut wall due to bolus. The distension is due to the relaxation of circular while contraction of the longitudinal muscles. The circular muscles behind the bolus contract while the longitudinal muscles are relaxed simultaneously. This produces a propulsive force on the bolus.

**Antiperistalsis:**

Sometime due to over-eating, we feel some abnormal movement of the gut. This feeling is termed as **nausea**. We feel that the food in gut would come back through mouth and cause **vomiting**. It could be due to over-distension or excessive GIT irritation, a consequence of some poisonous food or toxic chemicals. It is reverse involuntary movement of smooth muscles unlike peristalsis. During the process, the stomach is squeezed. The gastro-pharyngeal sphincter is relaxed which causes the contents of the stomach to move upward through the esophagus in the form of vomiting.

**Esophagus:**

This tubular structure leads the bolus from pharynx to the stomach. It is located between trachea and spinal cord. Internally, it is lubricated by mucous which makes the passage of food through the esophagus easier. Through peristalsis the food is propelled through it into the stomach. The esophagus passes through the diaphragm before entering into the stomach. There is no process of mechanical as well as chemical digestions in esophagus.

**Stomach:**

It is a "J" shaped muscular, pouch-like structure which is associated with esophagus anteriorly and duodenum, posteriorly. It lies in the upper left of the human abdominal cavity. The top of stomach lies against the diaphragm. It receives food (bolus) from the esophagus. It's both ends are guarded by valves, anteriorly it has **cardiac sphincter** while posteriorly it has **pyloric sphincter**. The sphincters prevents the backward flow of gastric contents.

Stomach is the main organ of the digestive system where the processes of mechanical as well as chemical digestions take place. It can store food for several hours.

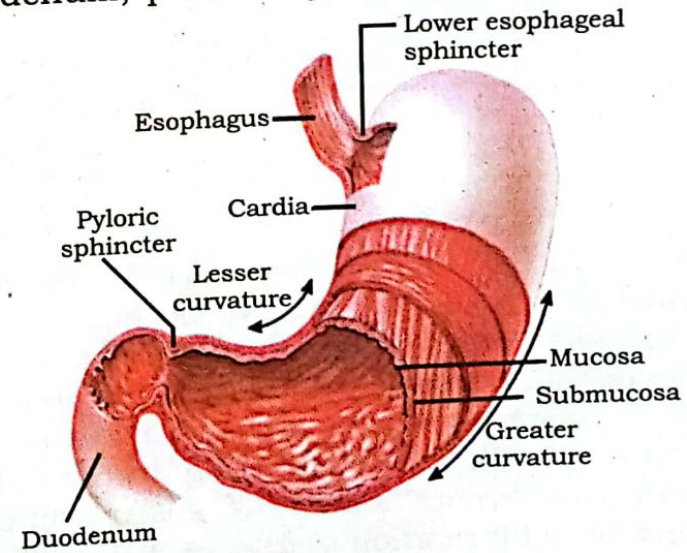



**Fig: 11.9 Stomach**

After several hours of digestion, it turns food into paste-like acidic, **chyme**.

The stomach is divided internally into four regions: the cardia, fundus, corpus (body) and pylorus. The esophagus opens into the cardia through cardiac sphincter. The fundus is the upper curved part which adapts to the varying volume of ingested food by relaxing its muscular wall. It usually contains a gas bubble, especially after a meal. The largest part of the stomach is the central, corpus (body) which primarily serves as the main reservoir of the ingested food. The lower most part of the stomach is pylorus which empties the gastric contents into the duodenum through pyloric sphincter.

The wall of the stomach consists of the usual four layers as present in other parts of the gastrointestinal tract. The inner most layer, **mucosa** is relatively thicker and contains numerous tubular glands. Under the mucosa lies the **sub-mucosa** containing blood vessels, nerves, etc. Below, sub-mucosa lies **muscularis externa.** It is also thick and, in some areas, it consists of 3 layers of smooth muscle, although this layering is not always visible. The three layers of smooth muscles are inner most oblique, the middle circular and the outer longitudinal layers. Glands are absent in the submucosa. The fourth and outermost layer is thin layer, the **serosa**. It secretes a lubricating fluid that reduces friction from muscle movement.

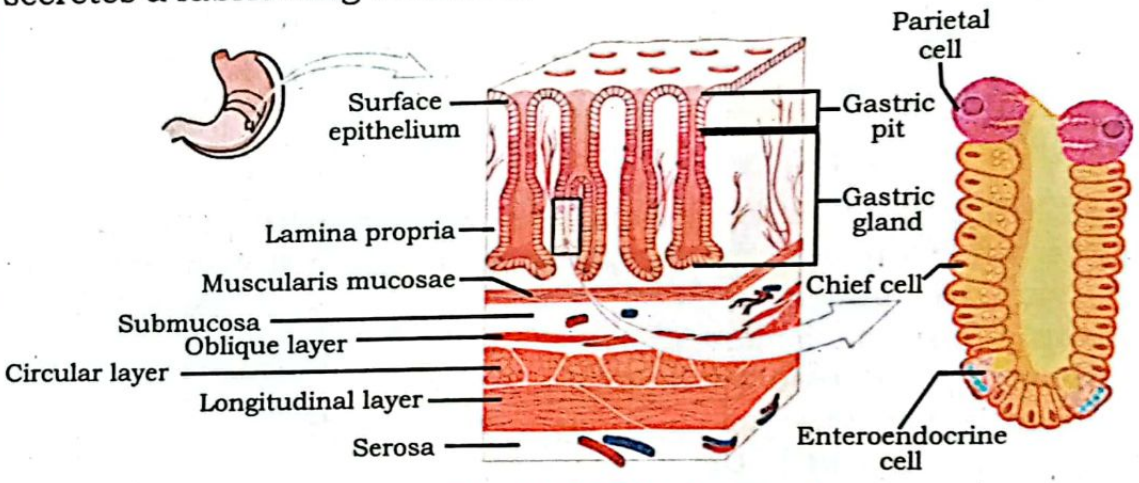
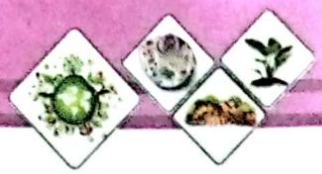



**Fig: 11.10 T.S of stomach**

In the empty contracted stomach, the mucosa is thrown into longitudinal folds or **rugae** because of the contraction of the muscularis mucosae and the loose consistency of the submucosa. The surface is further subdivided by furrows, the **gastric pits**. These funnel-shaped invaginations of the epithelium are continuous at their base with the tubular glands. The mucosa has mucous secreting **mucoid cells** throughout. It secretes mucous and bicarbonate ions. The gastric mucous is a glycoprotein which is a means of lubrication of food as well as protection to the stomach against the action of HCl and its own proteolytic enzyme. On the basis of differences in



the types of glands present in the mucosa, three histological regions can be distinguished in the stomach. The first region around the cardia contains the **cardiac glands**. They secrete mucous only. The second region, which includes the fundus and corpus, contains the **gastric glands proper or fundic glands.** Here the main mucoid cells are lying. Besides the mucoid cells, there are **parietal cells or oxyntic cells** which secrete HCl (pH 1.5 to 2.5) and an **intrinsic factor.** The latter is important in the maturation of red blood cells, vitamin B12 absorption in intestine, and the health of certain cells in the central and peripheral nervous systems. The gastric glands also contain **Chief Cells or zymogen cells** which secrete **pepsinogen**, a precursor to proteolytic enzyme, **Pepsin**. The distal region of the stomach (pylorus) contains pyloric glands which secrete mucous and **gastrin** hormone. The gastrin is released in response to two basic stimuli, i.e., the distention of the stomach and the raising the pH of the stomach by the addition of foods like proteins (decrease in the acidic environment). In addition to the gastrin hormone, there are endocrine cells distributed throughout the body of the stomach. One of their important secretion is **serotonin** which inhibits the gastric acid secretions.

**The physiological processes of mechanical and chemical digestions in stomach:**

As soon as the food enters the stomach, both mechanical and chemical digestions start simultaneously. As a consequence of food anticipation (smell, taste, sight, sound), the stimulation signals are released by vagus nerve to the brain, or the distention of stomach due to actually food input especially proteins in stomach, the **gastrin** hormone is released into the blood. The vagus nerve represents the main component of **the parasympathetic nervous system**, which oversees a vast array of crucial bodily functions, including control of digestion, immune response, heart rate etc. The gastrin via blood stimulates the gastric glands to release their gastric juice into the lumen of the stomach. The gastric juice, as already pointed out, contains HCl and pepsinogen. The **HCl** softens the food, kills the germs, and converts the inactive **pepsinogen** into active proteolytic enzymes, the **pepsin**. The pepsin breaks down proteins into peptones (short chain polypeptides). The stomach itself is protected against the action of HCl through its thick coating of mucous. The pH of the mucosal layer is raised up to 7 due to the release of bicarbonate ions while the pH towards the lumen of the stomach remains around 1.5 to 2.5. Therefore, the factors affecting the gastric juice secretion are neuronal, mechanical and hormonal. In infants, another proteolytic enzyme, **rennin or chymosin** is secreted that turns soluble milk protein, caseinogen into insoluble protein, casein which is then digested by pepsin.

The process of mechanical digestion in stomach is the consequence of smooth muscles of the stomach which, as already pointed out are arranged in 3 layers, the inner most is the unique and obliquely orientated, the middle one is circular and the outer longitudinal smooth muscles. The contracting and peristaltic movements due to these muscles are responsible for the churning of the food in stomach, mixing up of the gastric juice with food and then transport of the food from stomach to duodenum. The food after several hours of mechanical and chemical digestion becomes a paste-like **chyme** which is then transported bit by bit to first segment of the small intestine, the duodenum. The process of mechanical digestion through its breaking down of food particles into smaller parts thus increases the surface area of the food for chemical activity of the digestive juices.

**Absorptive role of the stomach:**

Besides playing a major role in digestion of food, the stomach contributes a minor role in the absorption process also. It absorbs few of the digestive products, water, glucose, some other simple sugars, amino acids, and some fat soluble substances.

**Small Intestine:**

Stomach is followed by a long, coiled tube, the **small intestine**. It is about 6 meters long and 3 to 4 cm wide. It can be divided into three main regions, duodenum, jejunum and ilium. The small intestine is overall involved in completing the process of digestion and also the process of absorption.

**Duodenum:**

The first part is **duodenum** which is short in length. It is about 30 cm long and attached with pyloric stomach. At the junction of these two, there is valve, the **pyloric sphincter.** The duodenum forms a "C" shaped curve. Its initial part forms a bulb like dilation, the duodenal bulb. The duodenum receives a common bile duct and a pancreatic duct opening by a common aperture through which the secretions, bile and pancreatic juice are received from liver and pancreas, respectively. The bile is formed by the liver and stored in the gall bladder. The stimulation of gall bladder to release bile takes place by a peptide hormone of duodenum, the **cholecystokinin** which also plays role in pancreatic stimulation to secrete its pancreatic juice. Upon stimulation of gall bladder, bile is released into the **cystic duct** which is connected with the **common bile duct** before finally reaching the duodenum. The partly digested proteins of acidic chyme that entered the duodenum serve as major stimulus for cholecystokinin secretion. On the other hand, cholecystokinin also stimulates acinar cells of the pancreas to secrete large amount of pancreatic juice. Besides cholecystokinin, the cells of duodenum also secrete another hormone, **secretin** which acts upon pancreas to secrete water and bicarbonate ions. After that, the pancreatic

juice is flushed out into the duodenum. The bicarbonate ions neutralize and turn the acidic chyme into alkaline.

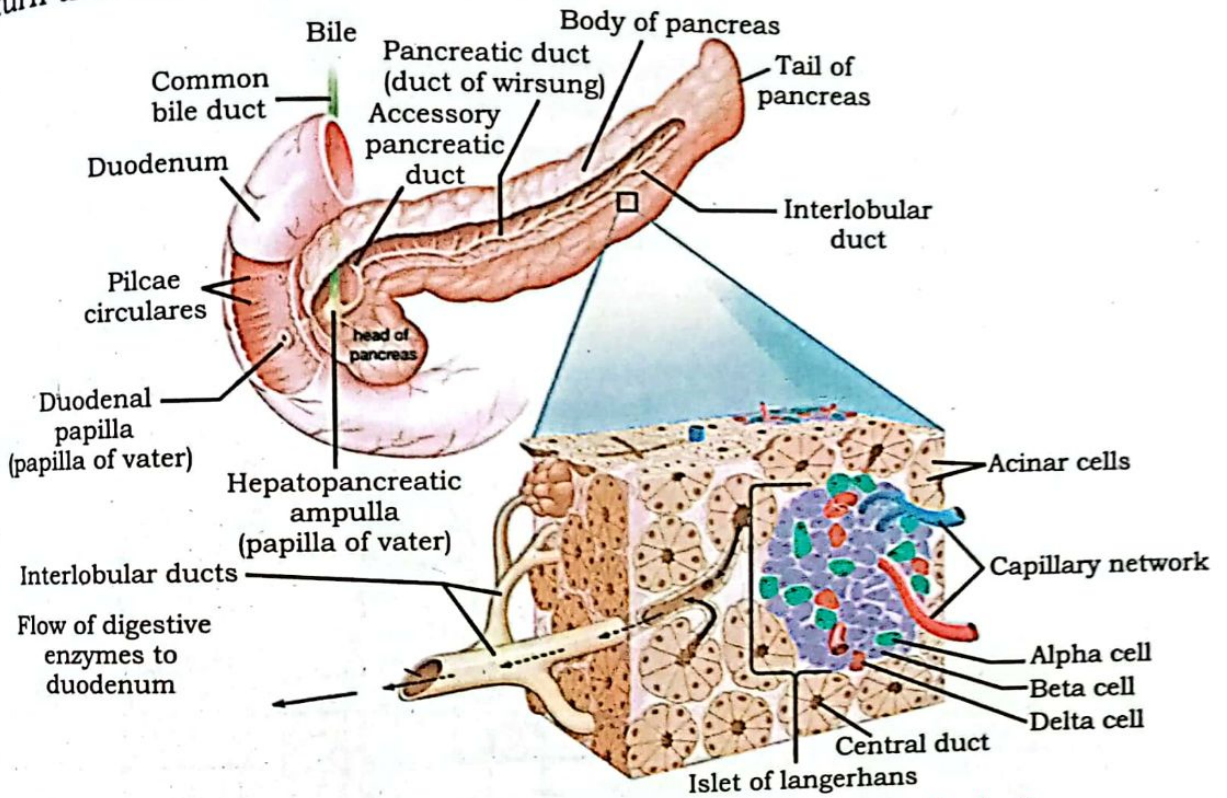



**Fig: 11.11 Common bile and pancreatic duct**

Bile is yellowish green in color and it contains water, salts, and bile pigments (brownish yellow **bilirubin** and greenish **biliverdin**). Its salts sodium glycholate and sodium taurocholate are involved in the emulsification of fats. There is no enzyme in bile. The bile pigments have nothing to do with the process of digestion. They are formed as excretory products of worn out (RBCs)

The pancreatic juice contains inactive enzyme **trypsinogen** which is converted into active **trypsin** by the action of **enterokinase** enzyme secreted by duodenum. The trypsin acts on proteins and peptones to break them into short chain polypeptides. Another proteolytic enzyme, **chymotrypsin** in the pancreatic juice converts casein into short chain amino acids. The other enzyme, the pancreatic acts upon starch and glycogen to break them into maltose (a disaccharide). **Lipase** of the pancreatic juice breaks down emulsified fats into fatty acids and glycerol. This completes the digestion of fats in the small intestine. The duodenum contains specific **Brunner's glands**, which produce a mucus-rich alkaline secretion containing bicarbonate ions. These secretions, in combination with bicarbonate from the pancreas, neutralize the stomach acids contained in gastric chyme.

### Jejunum:

The partly digested food from the duodenum passes into the next region of the small intestine, the jejunum. It is the middle region of the small intestine and about 2.5 meter long. The region is specialized for digestion and absorption of the digested food. The process of digestion is completed by the different enzymes secreted by jejunum. It secretes maltase, sucrase, lactase and peptidase to digest maltose, sucrose, lactose and small peptides, respectively into their simple forms. Nucleotides are broken down into nucleosides by its nucleotidase. The cellulose remains undigested here.

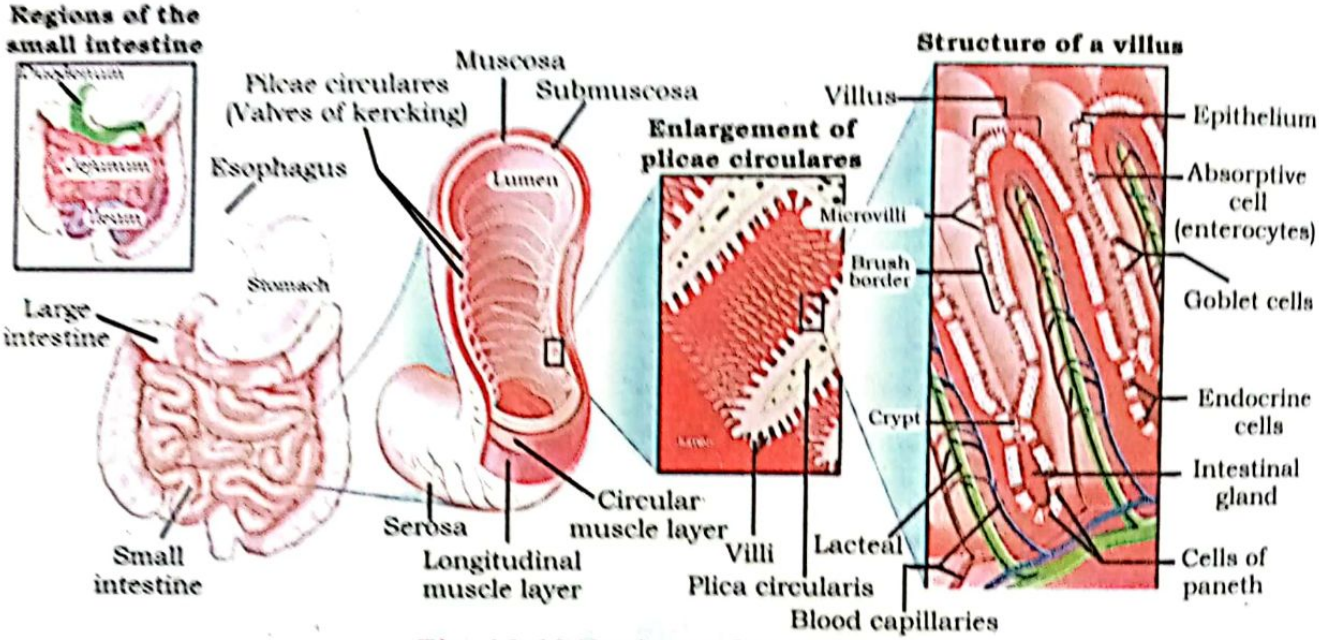



Fig: 11.12 Regions of small intestine

### Ileum:

This is the last region of the small intestine. It is about 3.6 meters in length. The function of the ileum is mainly to absorb vitamin B12, bile salts, and any products of digestion that were not absorbed by the jejunum.

Internally, the walls of small intestine has wrinkle or folds called **plicae circulares**. From each of these folds arise numerous microscopic finger-like projections, **villi**. The individual epithelial cells of each villus membrane have microscopic hair-like projections, **microvilli**. Due to the villi, the ileum has an extremely large surface area for absorption. The plicae

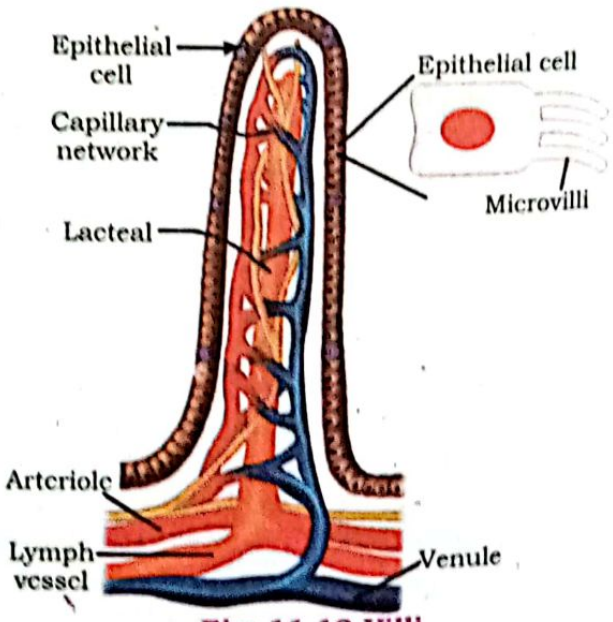



Fig: 11.13 Villi

circulares, villi and microvilli increase the surface are of the small intestine several folds for the absorption of soluble food. Each villus has a dense network of blood capillaries, blind lymph vessels called lacteals, and smooth muscles. The amino acids and monosaccharides are absorbed by the blood capillaries either by diffusion or active transport, while fatty acids and glycerol are taken up by lacteals. Smaller lymph vessels merge to form large vessels that drain fats (chylomicrons) and nutrients to the thoracic duct which is then emptied into subclavian vein. Some of the lipoprotein is taken up by the liver and exported into the blood stream. The blood capillaries containing fats fuse with each other to form **hepatic portal vein** which supplies all the nutrients to the liver for the storage, distribution and metabolism. Due to smooth muscles, the villi can contract and relax, constantly thus bringing themselves into close contact with food.

**Large Intestine:**

It is the last segment of the human digestive tract. The small intestine is connected with it. It is comparatively, shorter in length (about 1.5 meters) but greater in diameter (about 6.5 cm). The main functions performed here are reabsorption of water and nutrients, synthesis of some vitamins, reabsorption of some electrolytes such as sodium and chloride, formation of feces and then its egestion outside the body. It has mucous glands also for mucous secretion which helps in lubrication of the intestinal contents for its easy passage through the intestine. It lacks villi.

Large intestine is divisible into following regions, viz., caecum, colon, rectum and anal canal.

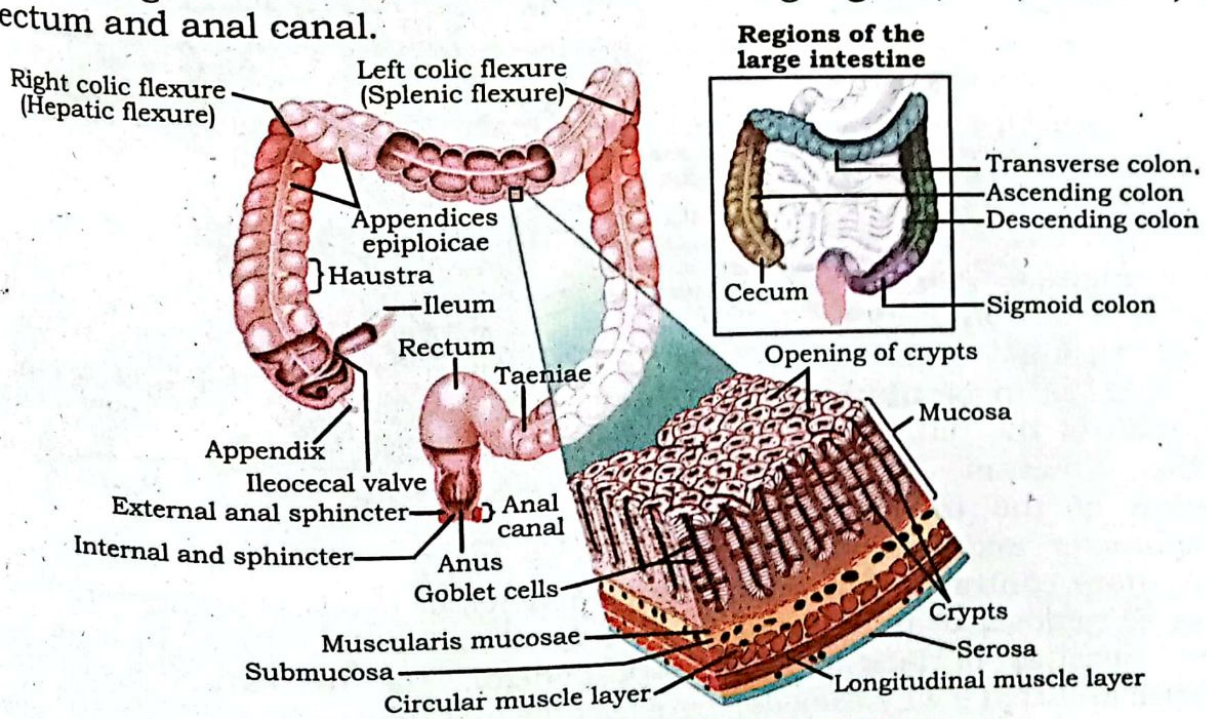



**Fig: 11.14 Regions of large intestine**

**Caecum:**

Small intestine joins the large intestine at a short **caecum**. It is located in the lower right side of the abdominal cavity. At the junction of small and large intestines, there is an **ileocecal valve**. It controls the passage of undigested food from ilium to the caecum. Water and salts absorption takes place here. The caecum, from its lower side, gives out a blind tube of about 18 cm long called **vermiform appendix**. It is a vestigial organ.

**Colon:**

The next region after caecum is colon. It consists of ascending colon, transverse colon, descending colon and sigmoid colon. It is involved in the reabsorption of water, salts and vitamins. The colon also contains large numbers of symbiotic bacteria (e.g., Lactobacillus, etc.) that synthesize niacin (nicotinic acid), thiamin (vitamin B1) and vitamin K, vitamins that are essential to several metabolic activities as well as to the function of the central nervous system.

**Rectum:**

The sigmoid colon opens into rectum. It is about 13 cm long and terminate at anal canal. The rectum ends at dilated portion, **the rectal ampulla.** When the rectum is filled with feces, the impulse to defecate occurs. The anal canal has an internal sphincter valve of smooth muscles and an external sphincter valve of skeletal muscles. In adults, the defecation involves both the involuntary contraction of the muscles of the rectum and relaxation of the internal anal sphincter and finally the voluntary contraction of the skeletal muscles of external sphincter. The process of removal of undigested food is egestion or defecation. In case of infants, because of lack of voluntary control, the defecation reflex is automatic and that's why they defecate inconveniently anytime.

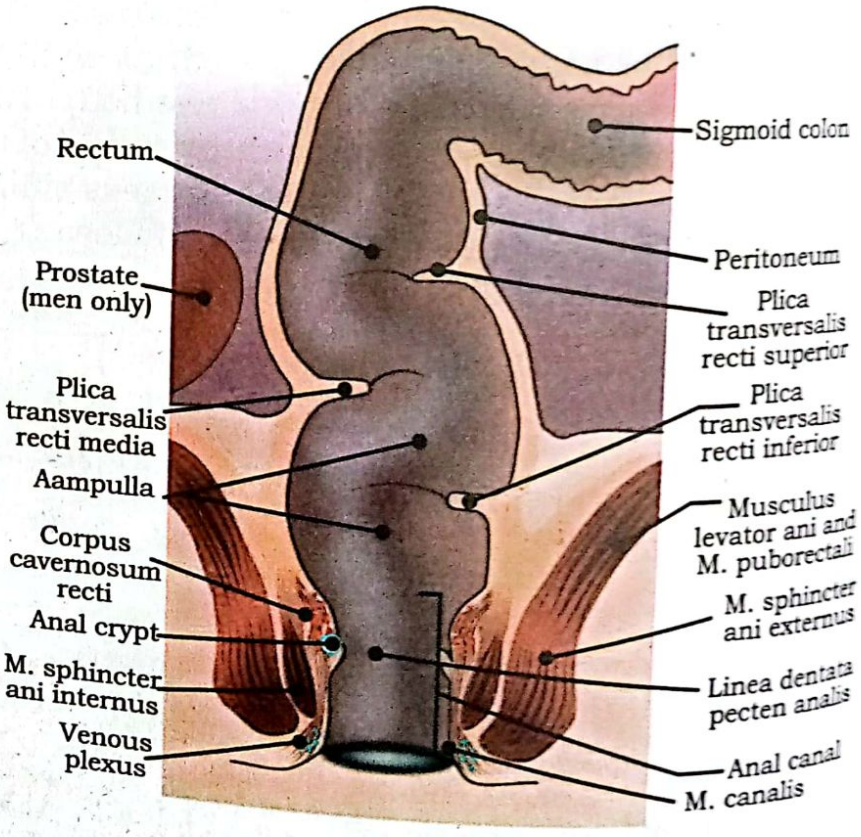



**Fig: 11.15 Rectum**

## 11.3 ROLE OF ACCESSORY GLANDS:

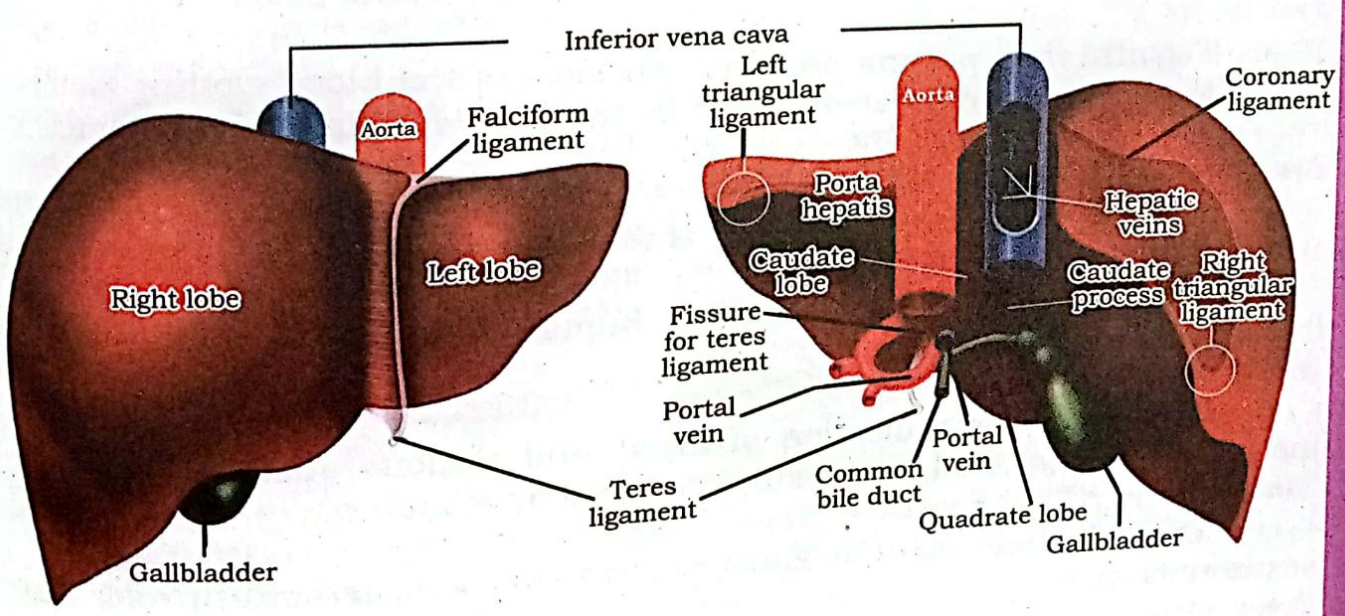
The accessory glands are those exocrine glands which upon appropriate stimulation secrete their secretions (juices) into the alimentary canal through specific ducts. These secretions help in the process of digestion. The accessory glands consist of 3 pairs of salivary glands, liver and pancreas.

**Salivary glands:**

The location, stimulation, secretion and the role of salivary glands have been already discussed earlier.

**Liver:**

The liver is the largest gland in our body. It is situated in the upper part of the abdominal cavity just behind the diaphragm more towards right side. The liver is enclosed in a thin inelastic capsule and incompletely covered by a layer of **peritoneum**. Folds of peritoneum form supporting ligaments attaching the liver to the inferior surface of the diaphragm. The liver has four lobes. The two most obvious are the large right lobe and the smaller, wedge-shaped, left lobe. The other two, the caudate and quadrate lobes, are areas on the posterior surface. The lobes of the liver are made up of tiny lobules just visible to the naked eye. These lobules are hexagonal in outline and are formed by cubical-shaped cells, the hepatocytes, arranged in pairs of columns radiating from a central vein.




**Blood Supply to Liver:**

The liver receives blood supply from two sources, one is hepatic artery which supplies oxygenated blood while the other one is hepatic portal vein which brings nutrient rich blood from various regions of the alimentary canal.

**Functions of Liver:**

Liver is a metabolic factory, synthesis and storage organs as well as homeostatic and secretory organ of our body. It performs hundreds of functions; among them, the important are as follows:

**Secretion of bile:**

The bile is synthesized by the hepatocytes. The bile consists of bile salts, bile pigments, and cholesterol.

**Metabolism& Homeostasis:**

It converts glucose into glycogen in the presence of the hormone insulin secreted by pancreas, and reconverts liver glycogen back to glucose in the presence of another hormone, glucagon, which is also secreted by pancreas. These changes are important regulators of the blood glucose level. It converts stored fat to a form in which it can be used by the tissues to provide energy. It is involved in deamination of amino acids thereby removing the nitrogenous portion from the amino acids not required for the formation of new protein; urea is formed from this nitrogenous portion which is excreted in the urine. It also breaks down the genetic material of worn-out cells of the body to form uric acid which is excreted in the urine. It removes the nitrogenous portion of amino acids and attaches it to other carbohydrate molecules forming new non-essential amino acids.

**Synthesis:**

It synthesizes plasma proteins and most of the blood clotting factors from the available amino acids occur in the liver. It synthesizes vitamin A from carotene.

**Breakdown:**

It is involved in breaking down of worn out erythrocytes.

**Defense:**

This is carried out by phagocytic Kupffer cells (hepatic macrophages) in the sinusoids.

**Detoxification:**

It performs detoxification of drugs and noxious substances. These include ethanol (alcohol) and toxins produced by microbes.

**Inactivation of hormones:**

These include insulin, glucagon, cortisol, aldosterone, thyroid, and sex hormones.

**Production of heat:**

It uses a considerable amount of energy, has a high metabolic rate, and produces a great deal of heat. It is the main heat-producing organ of the body.

**Storage:**

It stores fat-soluble vitamins: A, D, E, K; iron, copper; some water-soluble vitamins, e.g. riboflavin, niacin,pyridoxine, folic acid and vitamin B12.

Some diseases related to Liver:

**Hepatitis:**

It refers to the inflammation of liver. There could be several factors responsible for hepatitis such as autoimmune disorder, viral infection, some toxins, drugs, or drinking alcohol. Hepatitis is commonly characterized by fatigue, flu-like symptoms, pale skin, abdominal pain, dark urine, and pale stool. Infectious hepatitis is accompanied by high fever.

**Jaundice:**

It is a yellowish discoloration of the skin, mucous membranes and of the white of the eyes caused by elevated levels of bilirubin in the blood (hyperbilirubinemia). Bilirubin is a yellow pigment that is created by the breakdown of dead red blood cells in the liver. Normally, the liver gets rid of bilirubin along with old red blood cells. Jaundice may indicate a serious problem with the function of your red blood cells, liver, gallbladder, or pancreas. Jaundice itself is not a disease, but it is a symptom of several possible

**Pancreas:**

It lies behind the stomach in horizontal line along the curve of duodenum. It is 12 cm to 15 cm long. Though it serves as both exocrine as well as endocrine gland, here we will discuss its exocrine role only. It consists of a large number of lobules, the walls of which consist of secretory cells. Each lobule is drained by a tiny duct and these unite eventually to form the pancreatic duct, which extends the whole length of the gland and opens into the duodenum. Just before entering the duodenum, the pancreatic duct joins the common bile duct to form the **hepatopancreatic ampulla**. The duodenal opening of the ampulla is controlled by the hepatopancreatic sphincter (of Oddi).

As an exocrine gland, the pancreas secretes pancreatic juice containing enzymes that digest carbohydrates, proteins, and fats (discussed earlier in detail).

## 11.4 DISORDERS RELATED TO DIGESTIVE SYSTEM AND FOOD HABITS:

**Ulcer:**

An ulcer is a sore (a painful wound) which could be developed anywhere in the body. In the gastro-intestinal tract, the most common ulcers are "peptic ulcers". They may be termed as gastric ulcers or intestinal ulcers depending upon their location in the stomach or intestine, respectively. They are also termed as "peptic ulcers" since the damage is caused by the digestive juices. It happens when the HCl of the gastric juice etches away the protective layer of mucous which may cause painful condition. The common causes of peptic ulcer aresome bacteria, like

*Helicobacter pylori (H. pylori)*, some medication like aspirin, stress, drinking alcohol or taking lots of spicy food. The symptoms of ulcers includes, loss of appetite, sharp abdominal pain, nausea, and vomiting. The treatment depending upon the causes consists of proper antibiotics and proton-pump Inhibitors (PPIs) to reduce the secretion of acid in stomach.

**Food Poisoning:**

Food poisoning or illness is caused by taking contaminated, spoilt or toxic food. The food may be contaminated through some bacteria such as *Staphylococcus*, some viruses, parasites, or other pathogens. The uncooked food is a common factor for food contamination. The common symptoms of food poisoning are stomach cramps, vomiting, fever and diarrhea. The treatment is related to rehydration, electrolyte solutions and some antibiotics.

**Dyspepsia:**

It is popularly known as indigestion. It refers to the discomfort or pain that occurs in the upper abdomen followed by eating or drinking. The common symptoms includes blotting, nausea and abdominal fullness. It may cause heart-burn due to acid reflux.

**Obesity:**

It is related to the accumulation of excessive body fats. Medically, according to WHO, at adult age (around 35 years) person is considered obese when his body-mass Index (BMI) is over 30 $kg/m^2$. BMI is obtained by dividing the weight of a person with the square of his height. Obesity is the result of combination of inheritance, environment, diet and exercise. The obesity increases the risk of diabetes, cardiovascular diseases, hypertension and some cancers. Even though medications and diets can help, the treatment of obesity cannot be a short-term "fix" but has to be a lifelong commitment to proper diet habits, increased physical activity, and regular exercise.

**Anorexia nervosa:**

It is a psychological disorder in which the person has fear of gaining weight so refuse to eat appropriately. It is commonly associated with young girls and women. As a result, the victim develops anorexia (loss of appetite), the weight reduces to normal. It may be accompanied by spontaneous or induced vomiting in some patients.

**Bulimia nervosa:**

Just like anorexia nervosa, it is also psychological disorder of gaining excessive body weight. This may be a very serious, life threatening disorder. It is generally characterized by binge eating (episodes of uncontrollable eating so the person consumes excessive amount of food) followed by purging (induced vomiting). Complications from bulimia may lead to kidney failure, heart problems, teeth decay, electrolyte or chemical imbalances.

# SUMMARY

- The nutrients are required by protoplasm to perform its biological functions.
- Holozoic nutrition is one of the type heterotrophic nutrition occurs in animals.
- Holozoic nutrition is consist of ingestion, digestion, absorption, assimilation and egestion.
- Ingestion is the taking of food into the cell
- Digestion is the process of breaking down of complex or non-diffuseable food into simple or diffudeable molecules.
- Absorption- soluble food molecules are absorbed in the cell or transporting fluid.
- Assimilation- utilization of absorbed food molecules in the cell during metabolic activities.
- Assimilation- utilization of absorbed food molecule in the cell during metabolic activities.
- Egerton- Removal of undigested food.
- There are wo types of digestion, intercellular and extracellular, another way chemical or mechanical digestion.
- Digestion occurs in sac like or tube like digestive tract.
- The digestive tract of human consist of mouth, oral cavity, pharynx, esophagus, stomach, small intestine, large intestine and anus.
- Mechanical digestion takes place in oral cavity and stomach.
- Chemical digestion occur in oral cavity, stomach, duodenum and jejunum.
- The human digestive system also contain salivary glands, liver, gall bladder and pancreas and some glands present in stomach and jejunum.
- Hepatic portal vein bring nutrient rich blood from various regions of alimentary canal to liver.
- Liver is a metabolic factory, synthesis and storage organ as well as homeostatic and secondary organ.
- Pancreas serves as both exocrine and endocrine gland.
- Main disorder of digestive system are ulcer, food poisoning, dyspepsia, obesity, anorexia and bulimia nervosa.

# EXERCISE

**1. Encircle the correct choice.**

(i) The process of nutrition does not include this:
(a) Taking in of food (b) Breaking down of food
(c) Absorption of nutrients (d) Removal of undigested food

(ii) The chemicals playing the most important role in digestion of food are:
(a) Hormones (b) Enzymes
(c) HCl (d) Both a & b
(e) None of these

(iii) The thecodont condition refers to:
(a) Presence of two sets of teeth during life time
(b) all alike teeth
(c) Sharp, pointed teeth
(d) Embedded teeth

(iv) The type of digestion in Planaria is:
(a) Intracellular (b) Extracellular
(c) Intercellular (d) Both a & b

(v) Number of milk teeth is:
(a) 10 (b) 15
(c) 20 (d) 25

(vi) Teeth meant for cutting are:
(a) Incisors (b) Canines
(c) Pre-molars (d) Molars

(vii) The part of gut also associated with respiratory system is:
(a) Stomach (b) Esophagus
(c) Pharynx (d) Both b & c

(viii) The number of salivary glands in our oral cavity are:
(a) 3 (b) 4
(c) 5 (d) 6

(ix) The rugae are related to:
(a) Stomach (b) Duodenum
(c) Jejunum (d) Ilium

(x) BMI over 30 $kg/m^2$ is considered as:
(a) Normal (b) Over-weight
(c) under-weight (d) Obesity

**2. Write short answers of the following questions:**

1. List out the stages in holozoic nutrition.
2. How stomach itself is protected against the strong HCl?
3. Point out the ways through which the internal surface area of the small intestine is increased.
4. How bile help in the digestion of fats?
5. Enlist the role of large intestine.
6. What accounts for the presence of bacteria in large intestine?
7. What are the health risks involved in obesity?
8. List out some factors which may lead to obesity.
9. What is Anorexia nervosa?

**3. Write detailed answers of the following questions:**

1. State and explain the process of digestion in Amoeba?
2. Categorize the animals based upon their size of the food? Give examples of each group.
3. Discuss the process of digestion in stomach?
4. State and explain the role of accessory glands associated with our gut.
5. Explain the process of digestion and absorption of food in small intestine.
6. State and explain the sac-like gut with suitable example.

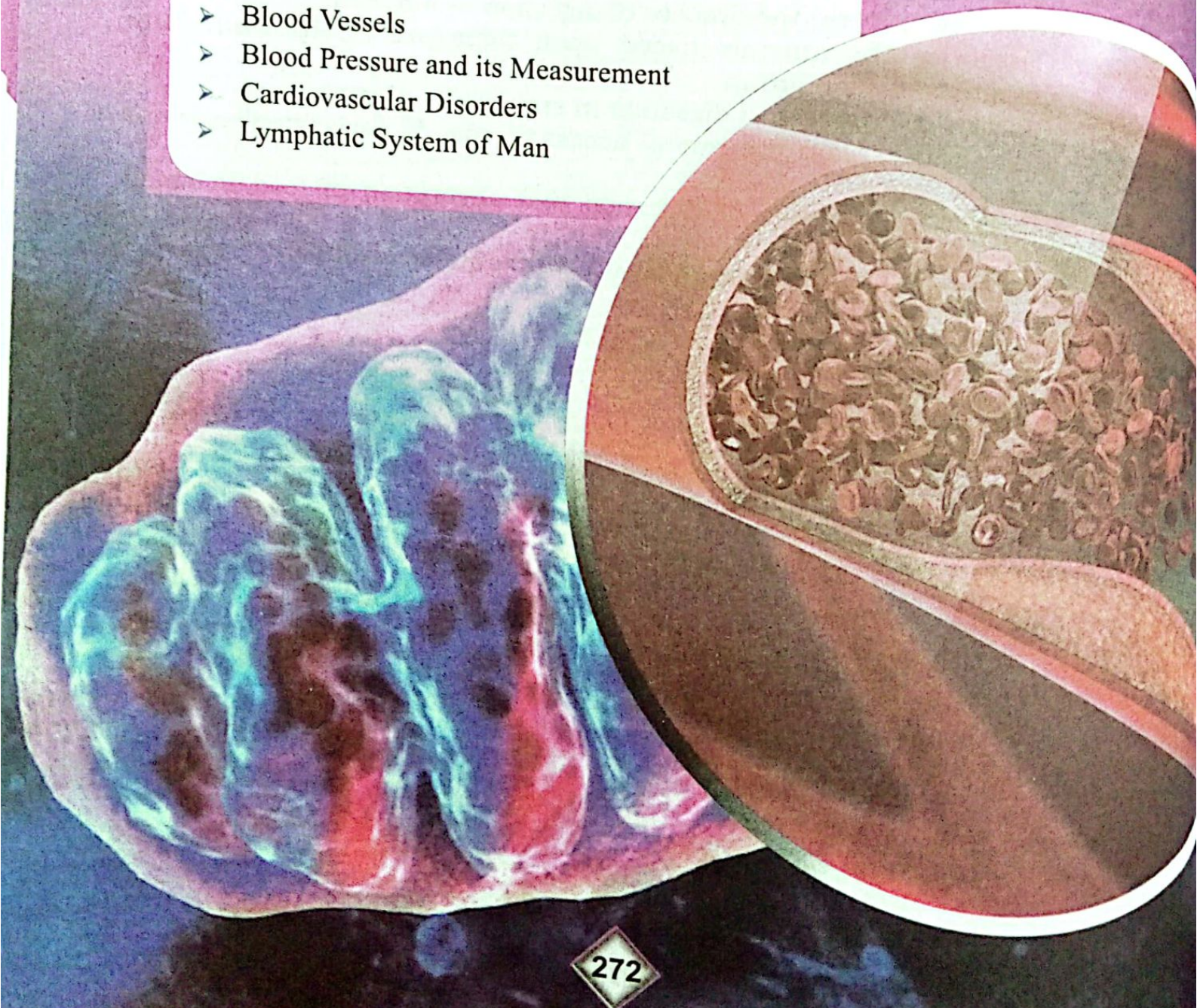
# CIRCULATION

Chapter 12

## Major Concept

**In this Unit you will learn:**

- Circulation
- Blood Circulatory System of Man
- Heart
- Blood Vessels
- Blood Pressure and its Measurement
- Cardiovascular Disorders
- Lymphatic System of Man

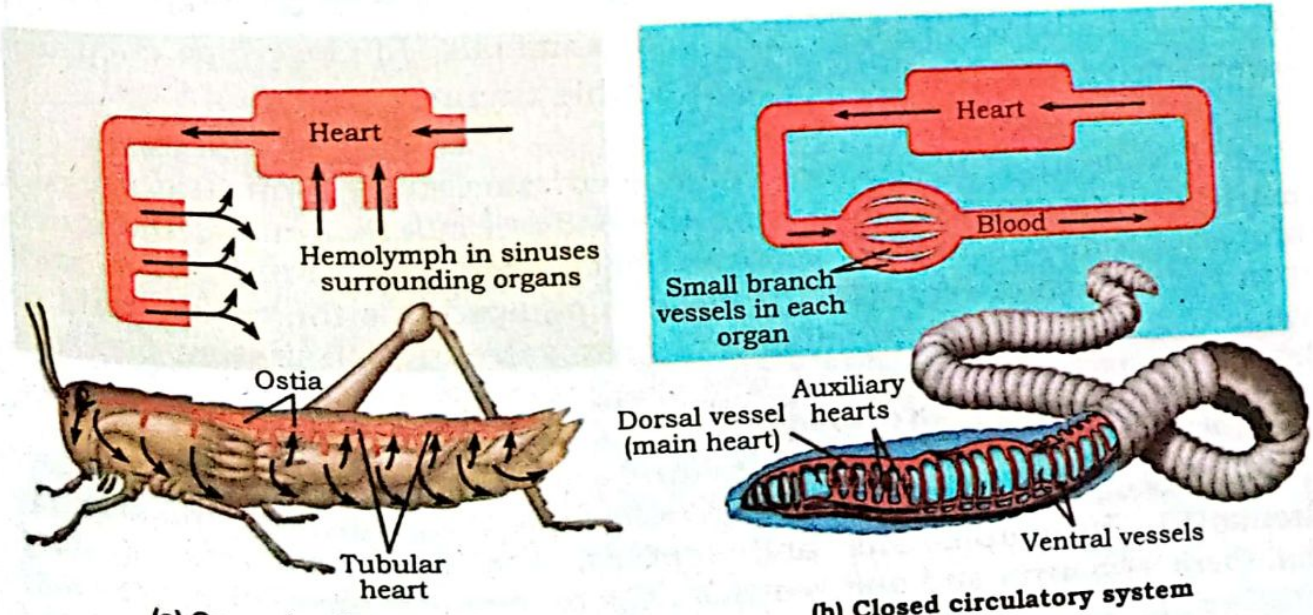


## CIRCULATION

Diffusion alone is not adequate for transporting chemicals over macroscopic distances in animals for examples to transport glucose from the digestive tract and oxygen from the lungs to the brain of animal. The time it takes for a substance to diffuse from one place to another is proportional to the square of the distance the chemical will travel. The **circulatory system** solves this problem by ensuring that no substance must diffuse very far to enter or leave a cell. By transporting fluid throughout the body, it functionally connects the aqueous environment of the body cells to the organs that exchange gases, nutrients and dispose off wastes. In the lungs of a mammal, for example, oxygen from inhaled air diffuses across a thin epithelium and into the blood, while carbon dioxide diffuses in the opposite direction. The circulatory system then carries the oxygen rich blood to all parts of the body. As the blood streams through the tissues within microscopic vessels called capillaries, chemicals are transported between the blood and the interstitial fluid that directly bathes the cells.

## 12.1 TYPES OF CIRCULATORY SYSTEMS

The blood circulatory system is basically of two types in animals open type and closed type.




(a) Open circulatory system

(b) Closed circulatory system

**Fig: 12.1 Open and close type circulation**

### A. Open circulatory system

A gastrovascular cavity is inadequate for internal transport within animals having many layers of cells, especially in terrestrial animals. In arthropods and most molluscs, blood bathes the internal organs directly, this arrangement of called an **open circulatory system**.

There is no distinction between blood and interstitial fluid, so the general body fluid is more correctly termed as **haemolymph**. One or more hearts pump the haemolymph into an interconnected system of sinuses, which are spaces surrounding the organs. Here chemical exchange occurs between the haemolymph and body cells. In grasshopper and other arthropods, heart is an elongated tube located dorsally, when the heart contracts it pumps haemolymph into dorsal aorta which empties into the **haemocoel**. When the heart contracts openings called ostia are closed when the heart relaxes, the haemolymph is sucked back into the heart by way of the **ostia**. The haemolymph of grasshopper and other insects is colourless because it does not contain **haemoglobin** or any other respiratory pigment.

### B. Closed type circulatory system

In a closed circulatory system, blood is confined to vessels and is distinct from the interstitial fluid. One or more heart pumps blood into large vessels that branch into smaller ones coursing through the organs. Here materials, are exchanged between the blood and the interstitial fluid bathing the cell. Annelids, some molluscs (octopus and squid) and vertebrates have closed type circulatory system.

During the course of vertebrate evolution, the heart has become increasingly complex, starting with the two chambered heart of fish and culminating in the four chambered heart of birds and mammals. In close type circulation system, circulation is either single or double circuit.

#### i. Single circuit circulation

The heart of fish is two chambered consisting of an atrium and a ventricle, deoxygenated blood from the body circulation enters the atrium through a thin-walled sinus venosus which open into a muscular ventricle upon contraction of ventricle, the blood is pumped into the ventral aorta via conus arteriosus. All these chambers have valves which prevent backward flow of blood.

#### ii. Double circuit circulation

From amphibians onwards up to the mammals, the circulatory system has double circuit circulation with separate pulmonary and systemic circulation. In amphibians and reptiles, the heart consists of three chambers, two atria and one ventricle, the oxygenated blood from the lungs returned to the left atrium through the pulmonary veins, whereas the deoxygenated blood from the body is passed to the right atrium via sinus venosus by the anterior and posterior vena cavae. These two types of blood streams remain separated due to atrial septum in between the right and left atria, but get mixed to some extent within the ventricle. Since the oxygenated and deoxygenated blood are mixed, the circulation is known as **incomplete double circulation.**

In crocodiles, birds and mammals the heart is four chambered with two atria and two ventricles. The right atrium and right ventricle are completely separated from the left atrium and left ventricle by inter-atrial and inter-ventricular septa. The right side receives deoxygenated blood and the left side oxygenated blood. The blood circulates through the heart twice. Once as deoxygenated blood on the right side, from where it is pumped to the lungs for oxygenation (pulmonary circulation). Next time as oxygenated blood on the left side to be distributed to all the parts of body except lungs (systemic circulation). Thus it is known as **complete double circuit**

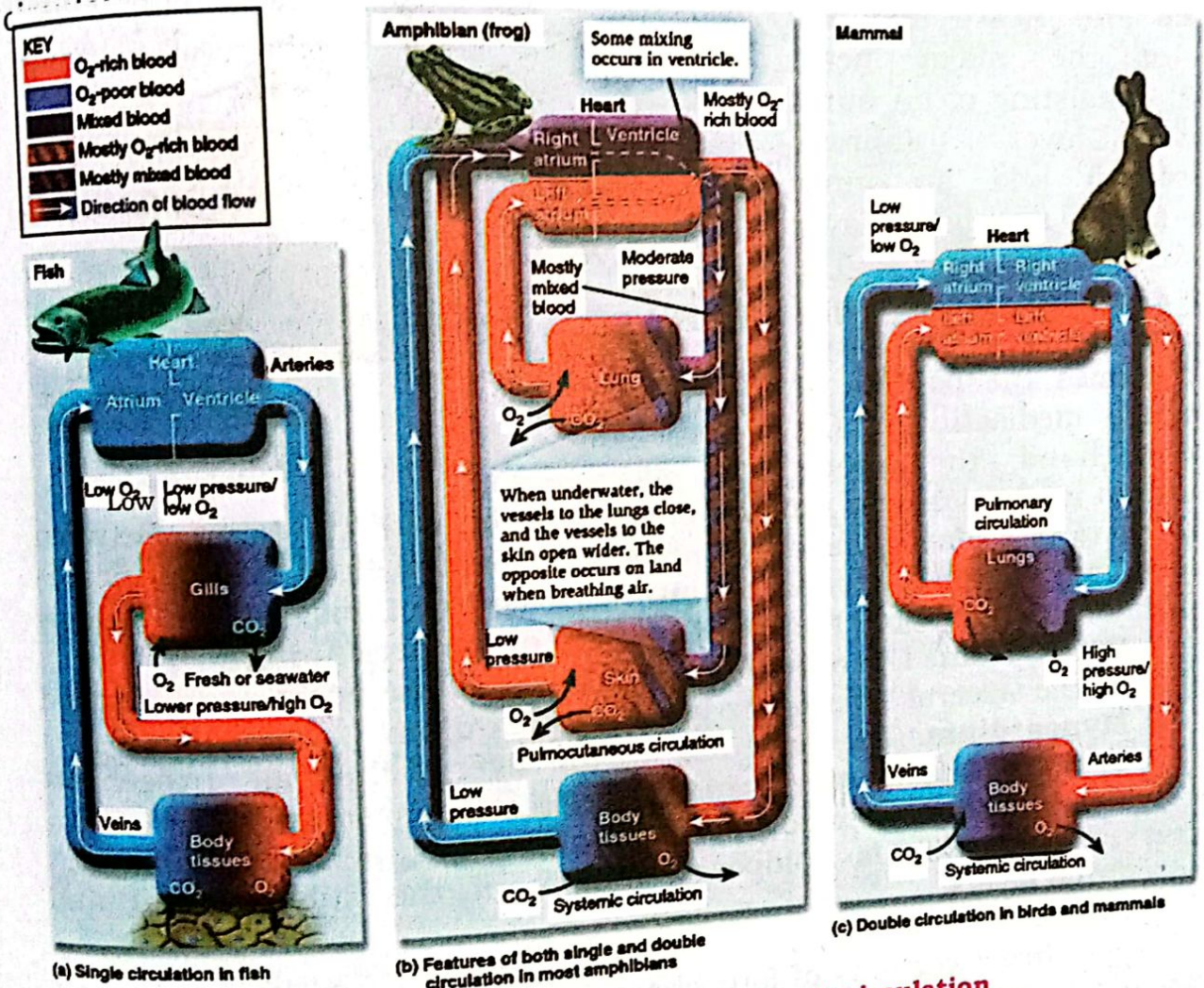



**Fig: 12.2 Single and double circuit circulation**

## 12.2 GENERAL CHARACTERISTICS OF A CIRCULATORY SYSTEM

All circulatory systems have three major components.

I. A fluid, **blood** that serves as a medium of transport.
II. A system of channels or **vessels** that conduct the blood throughout body.
III. A pump, the **heart** or modified blood vessel that keeps the blood circulating.

## 12.3 HUMAN HEART

The human heart has a somewhat conical form and is enclosed by pericardium. It is located between lungs with one third situated on the right and two thirds on the left of the midline, just behind sternum.

### Layers of heart wall

The heart wall consists of three layers enclosed in the pericardium. The pericardium is the thick covering that encloses the heart and the roots of the major heart vessels, consisting of an outer fibrous layer (fibrous pericardium) and an inner double serous membrane layer (serous pericardium). The fibrous pericardium consists of thick fibrous connective tissue and it defines the borders of the middle mediastinum. On the other hand, the serous pericardium is physically in a much closer relation with the heart. Between its two layers is a small amount of serous pericardial fluid that lubricates the layers and prevents friction during heart contractions, which is along with mechanical protection, the basic function of the pericardium.

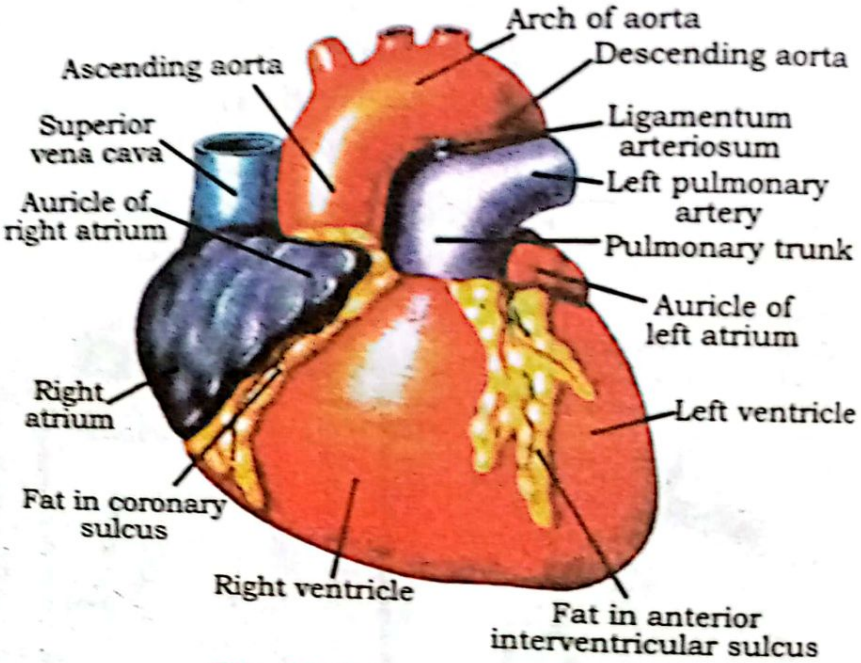



**Fig: 12.3 Human heart**

I. **Epicardium.** The outer layer of the wall of the heart and is formed by the visceral layer of the serous pericardium.

II. **Myocardium.** The muscular middle layer of the wall of the heart and has excitable tissue and the conducting system.

III. **Endocardium**. A middle concentric layer, a subendocardial layer. The rest of the heart is composed mainly of the subepicardial and subendocardial layers.

### 12.3.1 Structure of heart

Human heart consists of four chambers, two upper thin walled atria and two lower, thick walled ventricles. Two large veins, superior and inferior vena cava enter the right atrium and two pairs of pulmonary veins open into the left atrium. Similarly, two large arteries emerge out, one from the right ventricle, the **pulmonary** aorta and other from the left ventricle the **systemic aorta**.

The right and left atria are separated by a vertical membranous inter atrial septum, the right atrium and left ventricles are also separated by thick muscular interventricular septum. Four valves in the heart each consisting

of flaps of connective tissue, prevent backward flow of blood. The right atrium opens into the right ventricle by an artioventricular valve (Tricuspid valve). The left atrium opens into left ventricle by artioventricular valve (Bicuspid valve or mitral valve). The **AV valves** are anchoured by strong fibers that prevent them from turning inside out. Pressure generated by the powerful contraction of the ventricles closes the AV valves keeping blood from flowing back into the atria. Semilunar valves are located at the two exits of the heart, where the systemic aorta leaves the left ventricle and the pulmonary aorta leaves the right ventricle. The blood is pumped out into the arteries through the semilunar valves, which are forced open by pressure created by ventricular contraction when the ventricles relax blood starts to flow back towards the heart, closing the semilunar valves, which prevents blood from flowing back into the ventricles. The cavity of the left ventricle is narrower than the right ventricle because of more muscular walls. It is due to the fact that the right ventricle has to pumps blood into the lungs only (pulmonary circulation) while the left ventricle pumps blood to the entire body (systemic circulation).

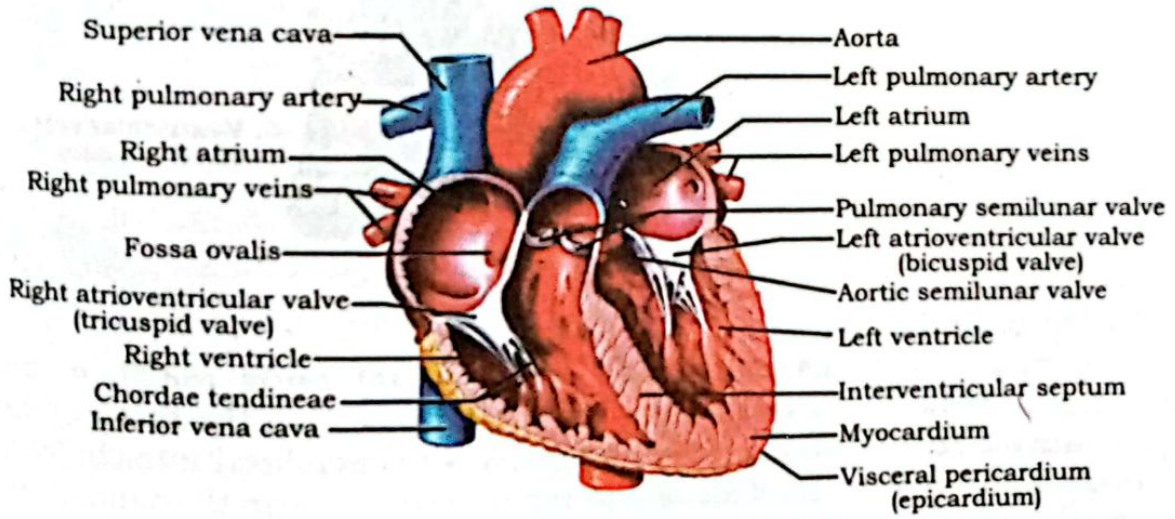



**Fig: 12.4 Anatomy of heart**

### 12.3.2 Phases of heart beat

The contraction of the heart chambers are known as **heart beats**, which are rhythmically and regular. A human normal **heart beats** 72 times per minute at rest. The alternating contraction and relaxation of the heart chambers is called the **cardiac cycle**. The two atria contract synchrony, emptying their contents into the ventricles. A fraction of a second later, the two ventricles contract simultaneously forcing blood into arota leaving the heart.

Both chambers than relax briefly before the cycle-repeated. The period of ventricular contraction is called **ventricular systole**. The rest of

the cycle, including relaxation of all the chambers followed by contraction of the atria, is called **ventricular diastole**. At normal resting heart rate systole lasts about 0.3 second and diastole about 0.5 second. When the heart beats the familiar **LUB-DUB** sound is heard as the valves of the heart close, the **LUB** is caused by vibrations of heart when the artioventricular valves close, and **DUB** is heard when vibration occurs due to the closing of the semilunar valves.

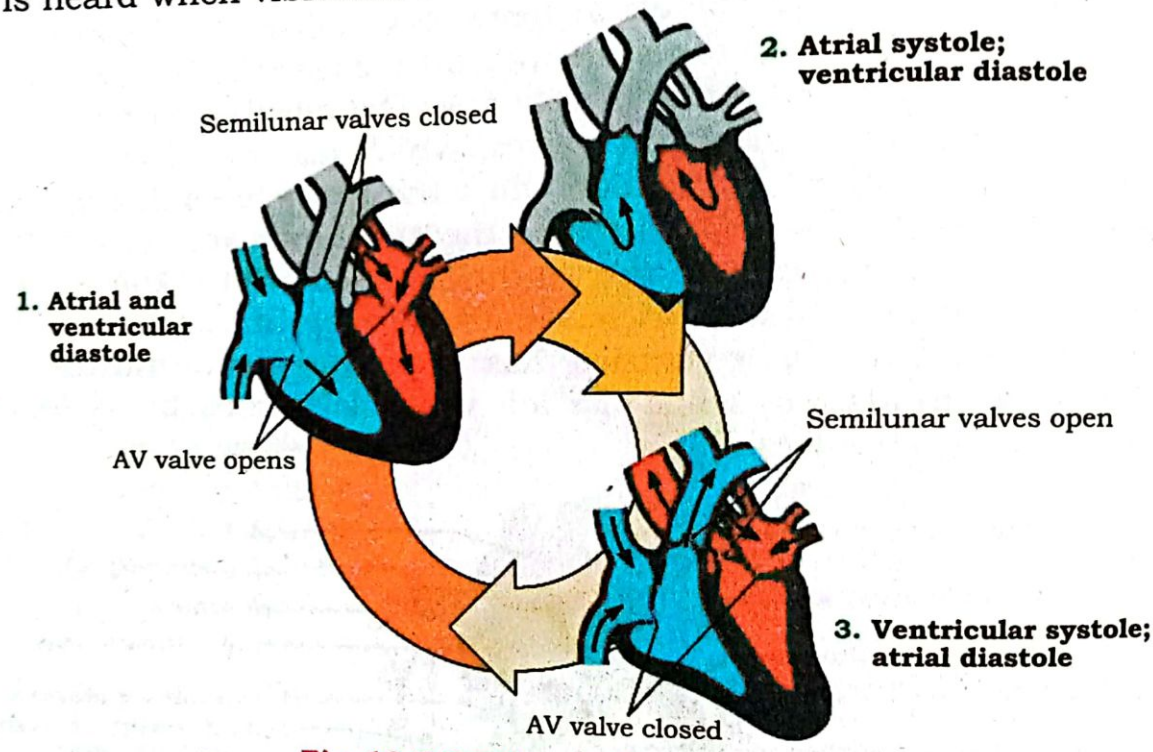



**Fig: 12.5 Cardiac cycle**

### 12.3.3 S.A Node and A.V Node

A region of the heart called the **saino atrial node (SAN),** or **pace maker**, maintains the heart's pumping rhythms by setting the rate at which all cardiac muscle cells contract. It is composed of specialized muscle tissue. The SA node is located in the wall of the right atrium, near the point where the superior vena cava enters the heart. The SA node generates electrical impulses much like those produced by nerve cells. Impulses from the SA node spread rapidly through the walls of the atria, making them contract in unison. The impulses also pass to another region of specialized muscle tissue, a relay point called the atrioventricular (AV) node in the wall between the right atrium and right ventricle. Here the impulses are delayed for about 0.1 second which ensures that the atria will contract first and empty completely before the ventricles contract. Its excitation travels all parts of the ventricles, through two bundles of specialized muscle fibers of atrioventricular bundle or **bundle of His** in the ventricular septum and then into the wall of the ventricle through a network of fibers called **purkinji fibers**.

## 12.4 ELECTROCARDIOGRAM (ECG)

The impulses that travel through cardiac muscle during the heart cycle produce electrical currents that are conducted through body fluids to the body surface where the currents can be detected by electrodes placed on the skin and recorded as an electrocardiogram (ECG)

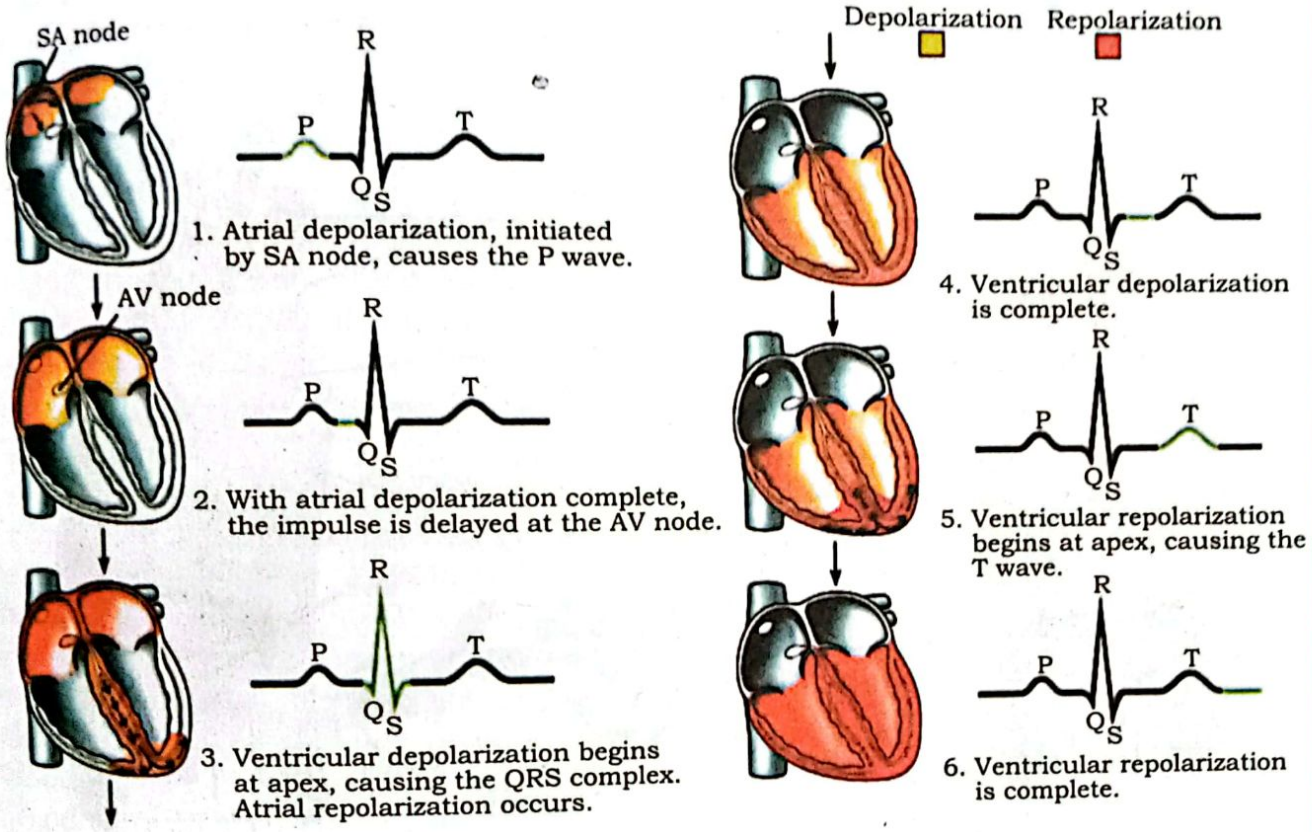



**Fig: 12.6 Electrocardiograms**

### 12.4.1 Uses of ECG

By the help of electrocardiogram, we can see the electrical changes in the form of depolarization and repolarization. Depolarization of the atrial fibers of the SA node produces the **P wave**. The ventricles of the heart are in diastole during the expression of the P wave on the ECG recording. The **P-R interval** is the period of time start of the P wave to the beginning of the QRS complex this interval indicates the amount of time required for the SA depolarization to reach the ventricles. The **QRS complex** begins as a short downward deflection (**Q**). Continue as a sharp upward spike (**R**) and end as downward deflection (**S**). The QRS complex indicates the depolarization of the ventricles during this interval, the ventricles are in systole and blood is being ejected from the heart. The time duration known as the **S-T** segment represents the period between the completion of ventricular depolarization and initiation of repolarization. The **T wave** is produced by ventricular repolarization. A normal ECG indicates that the heart is functioning

properly. The second wave, or the QRS complex occurs just prior to ventricular contraction the third, or T wave occur just before the ventricles relax.

## 12.5 BLOOD VESSELS

As blood leaves the heart, it travels from **Aorta** to arteries to arterioles to capillaries to venules to vein, and then **vena cava** which return it finally back to the heart. In this section, we examine each type of blood vessel in more detail.

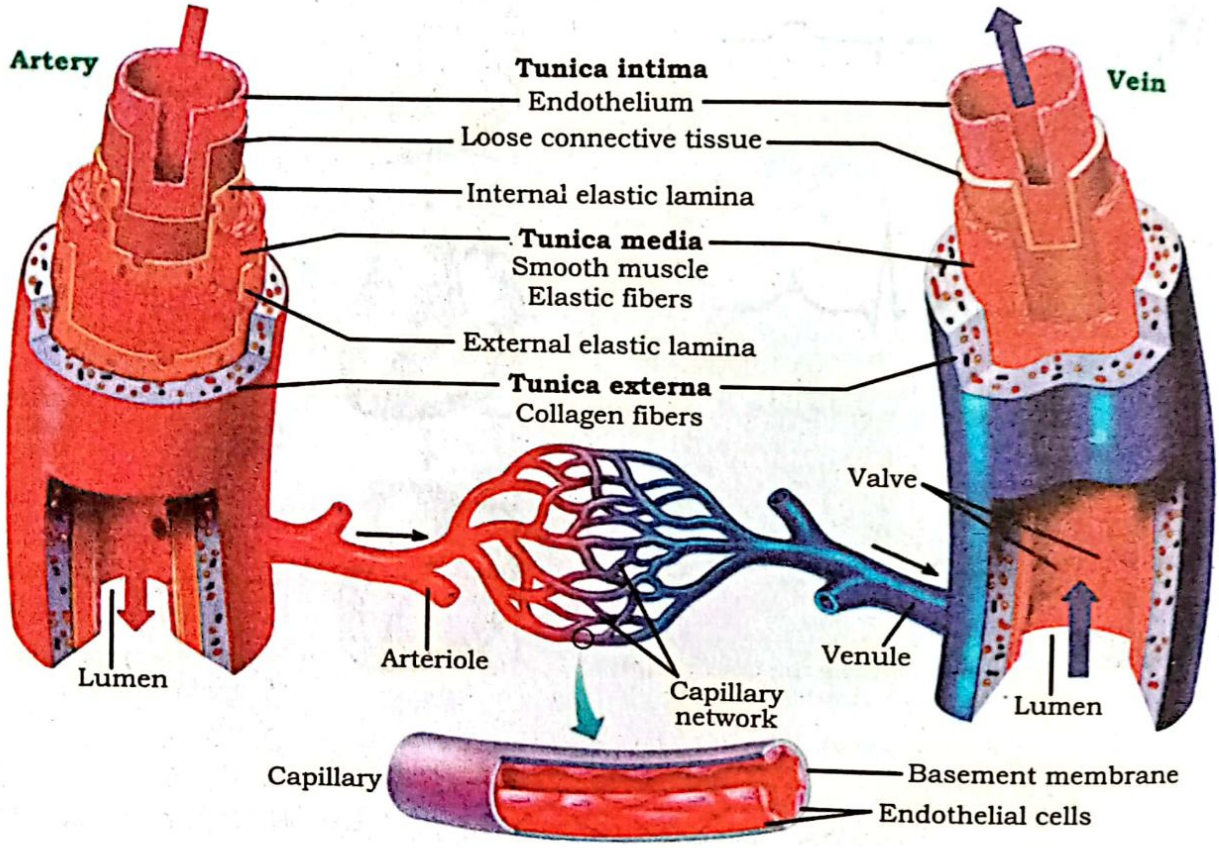



**Fig: 12.7 Blood vessels**

### 12.5.1 Arteries

After leaving the heart blood first enters large vessels called arteries. These are thick-walled vessels consisting of three layers. The outer **tunica externa** composed of fibrous connective tissue having collagen fibers. The middle layer **tunica media** has smooth muscles and elastic fibers. The inner **tunica interna** (intima) consists of squamous endothelium. The arteries expand slightly, like thick-walled balloons. Between heart beats they recoil, helping to pump the blood and maintain a steady flow through the smaller vessels. Arteries branch into vessels of even smaller diameter called arterioles, which play a major role in determining how blood is distributed within the body.

### 12.5.2 Capillaries

The entire circulatory system is an elaborate device for providing each cell of a complex, multicellular organism with the type of exchange-diffusion-practiced by the simplest unicellular organisms. This is accomplished at the level of the capillaries, the tiniest of all vessels. Here wastes, nutrients, gases, and hormones are exchanged between the blood and the body cell. Their walls consist of a single layer of endothelium, which presents very little resistance to the diffusion of dissolved substances in or out. The capillaries are extremely narrow (7-9 μ in diameter). The pressure within capillaries causes a continuous leakage of fluid from the blood plasma into the spaces surrounding the capillaries and tissues. This fluid is known as the **interstitial fluid** and consists primarily of water in which are dissolved nutrients, hormones, gases, wastes and small proteins from the blood. The large plasma proteins, red blood cells, and platelets are unable to leave the capillaries because of their size, although white blood cells can ooze through the openings between capillary cells.

### 12.5.3 Veins

Blood from the capillaries, now carrying carbon dioxide and other cellular waste drains into larger vessels called venules that empty into still larger veins. Veins provide a low resistance pathway by which blood can return to the heart. The walls of veins are much thinner and more expandable than those of arteries although both contain a layer of smooth muscles because blood pressure in the veins is low, the contractions of skeletal muscle during exercise and breathing must assist in the return of blood to the heart. These muscular movement squeeze the veins, forcing blood through them. When veins are compressed, you might predict that blood would be forced away from the heart as well as toward it. To prevent this, veins are equipped with one-way valves that allow blood flow only toward the heart.

## 12.6 ROLE OF ARTERIOLES IN VASODILATION AND VASOCONSTRICTION

The muscular walls of arterioles are under the influence of nerves, hormones and chemicals produced by nearby tissues. They can therefore contract and relax in response to the changing needs of the tissues and organs they supply. On the hot summer day, however you become flushed as the arterioles in your skin expand (vasodilation) and bring more blood to the skin capillaries to dissipate excess heat to the outside and to maintain a proper internal temperature. In contrast in extremely cold weather, finger and toes can become frostbitten because the arterioles supplying the extremities constrict.

## 12.7 ROLE OF PRE-CAPILLARY SPHINCTER IN REGULATING THE FLOW OF BLOOD THROUGH CAPILLARIES

The flow of blood in capillaries is regulated by tiny rings of smooth muscles pre capillary sphincters. That surrounds the junctions between arterioles and capillaries. These sphincters open and close in response to local changes that signal the needs of nearby tissues for examples, accumulation of carbon dioxide, lactic acid or other cellular wastes signals the need for increased blood flow to the tissues. These signals cause pre capillary sphincters as well as the muscles in nearby arterioles to relax, thus increasing blood flow through the capillaries.

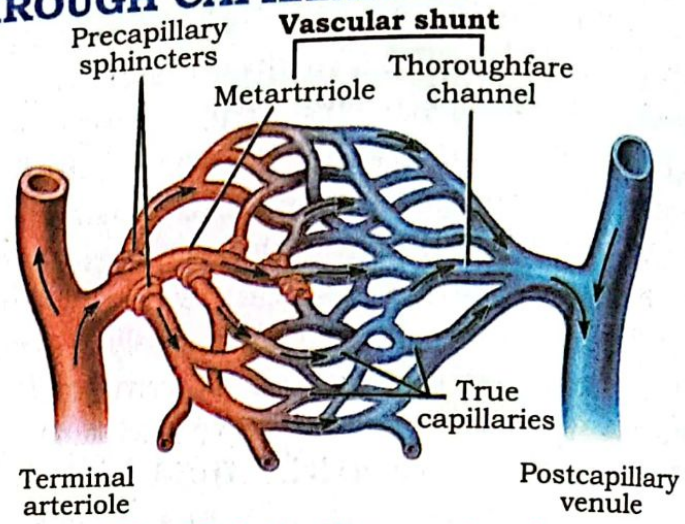



**Fig: 12.8 Capillary network**

## 12.8 VASCULAR PATHWAY

The human cardiovascular system includes two major pathways. Pulmonary circulation and systemic circulation.

### 12.8.1 Pulmonary circulation

In the pulmonary circulation, pathway of blood can be traced as follows. Deoxygenated blood from whole body collects in the right atrium and then passes into the right ventricle which pumps deoxygenated blood into the pulmonary aorta. The pulmonary aorta divides into right and left pulmonary arteries, which carry blood to lungs as blood passes through the pulmonary capillaries, carbon dioxide is given off and oxygen is picked up. Blood returns to the left atrium of the heart through pulmonary veins.

### 12.8.2 Systemic circulation

The systemic circulation includes aorta and vena cava as the major pathways for blood. In the systemic circulation arteries carry oxygenated blood and have a bright red colour, but veins carry deoxygenated blood and appear dull red or, when viewed through skin , blue.

### 12.8.3 Coronary circulation

, The coronary arteries supply blood to wall of the heart (myocardium). The coronary arteries arise from the aorta just above the aortic semilunar valve. They lie at the exterior surface of the heart, where they branch into arterioles and the capillaries. The capillary beds enter venules which join to form cardiac veins, and these empty into right atrium.

### 12.8.4 Hepatic portal system

A portal system is one that begins and ends in capillaries. One place in human body where a portal system is found is between small intestine

and the liver. Blood passes from the intestinal villi into venules that join to form the hepatic portal vein, a blood vessel that connects the intestine with the liver. The hepatic vein leaves the liver and enters the inferior vena cava.

### 12.8.5 Renal circulation

The renal arteries are short and spring directly from abdominal aorta, enters into kidney and gives branches which pass through medulla. In cortex they give rise to glomerular arterioles from here blood enter in the peritubular capillaries and vasa recta, from these capillary networks the blood is drained through veins and leave the kidney as a single renal vein that empties into the inferior vena cava.

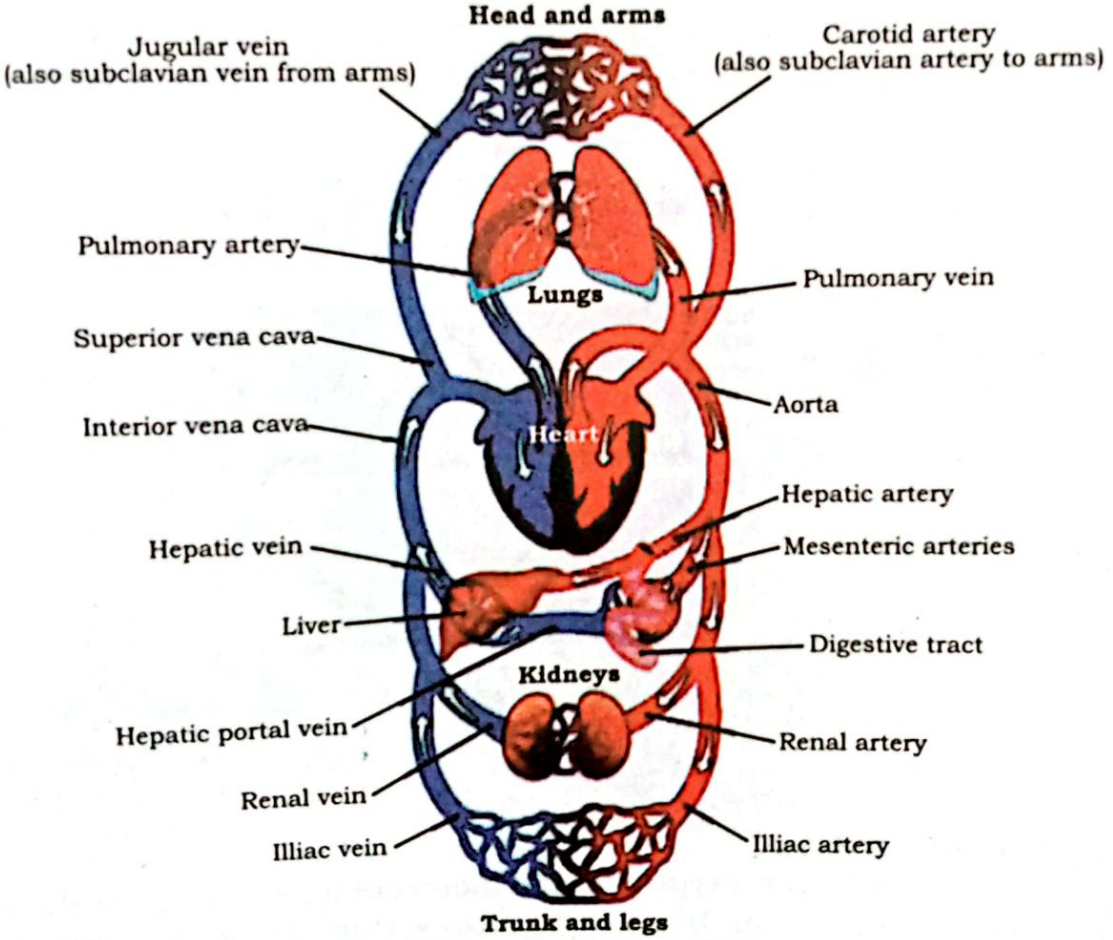



Fig: 12.9 cardiovascular system

## 12.9 RATE OF BLOOD FLOW IN BLOOD VESSELS

Blood flows through the vessels at an uneven speed. It flows faster in large arteries and much slower in capillaries network. Although an individual capillary is much narrower but the capillary beds have an enormous number of such capillaries, so that the total diameter of these vessels is much greater than the arteries. For this reason, the blood flows slowly in the capillaries, permitting the exchange of materials between the

blood and interstitial fluid. As blood leaves the capillary bed and passes to the venule and veins it speeds up again due to the reduction of in total cross-sectional area.

## 12.10 BLOOD PRESSURE

The hydrostatic force of blood exerted on the wall of vessels is called blood pressure. Blood pressure is the main force that propels blood from the heart through the arteries, arterioles to the capillary beds. Fluid always flows from area of higher pressure to area of low pressure. Blood pressure measured with sphygmomanometer. It is normally measured on the brachial artery, which is in the upper arm, and is stated in millimeters of mercury (mmHg). Blood pressure readings consist of two numbers 120/80 mmHg. First the systolic pressure (120 mmHg) and second diastolic blood pressure (80 mmHg).

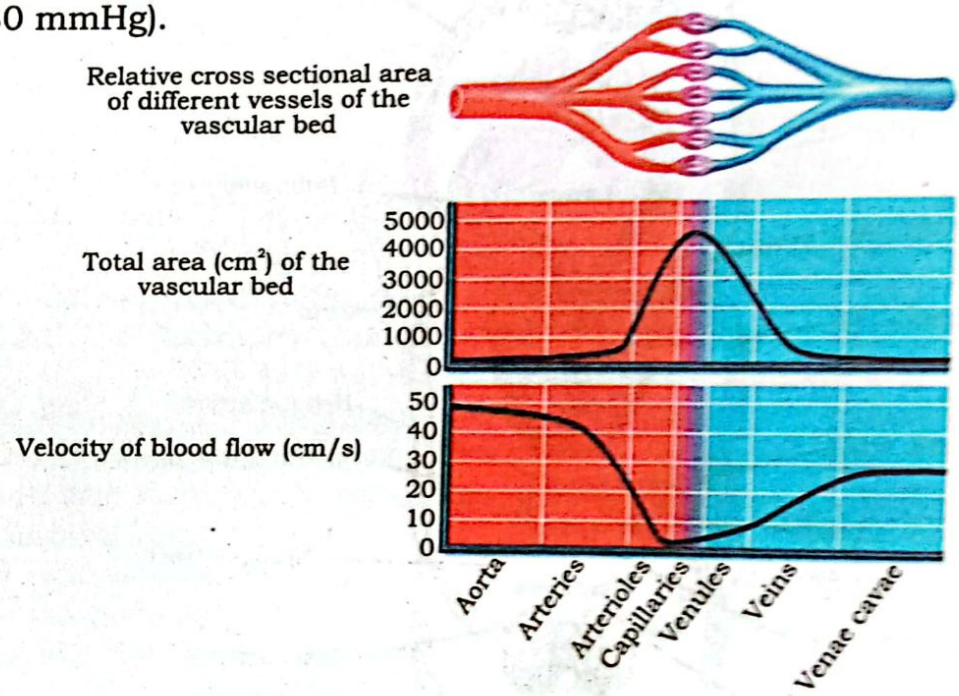



**Fig: 12.10 Velocity of blood flow through blood vessels**

### 12.10.1 Baroreceptors

Baroreceptors are a type of mechanoreceptors allowing for the relay of information derived from blood pressure within the autonomic nervous system. There are two types of baroreceptors:

**High-pressure arterial baroreceptors**

They sense the blood pressure and relay the information to the nervous system, so that a proper blood pressure can be maintained.

**Low pressure volume baroreceptors**

These are found in the large veins and in the walls of the atria of the heart. The low pressure baroreceptors are involved with the regulation of blood volume.

## 12.11 CARDIOVASCULAR DISORDERS

Diseases of heart, blood vessels and blood circulation are generally termed as cardiovascular disorders.

### 12.11.1 Thrombus

The formation of blood clot (thrombus) within an intact blood vessel is initiated by atherosclerotic plaques. The plaques when destroy the endothelium of the blood vessels, platelets gather at the damaged site to initiate the process of clot. **Thrombus** and **embolus** are potentially life threating blood vessel problems that increase the risk of having a heart attack or stroke. Thrombus happens when a blood clot or thrombus grows in blood vessels. This can reduce blood flow. An embolus is any foreign material that travels within the body. If it becomes stuck and severely blocks the flow of blood. The issue is called embolism.

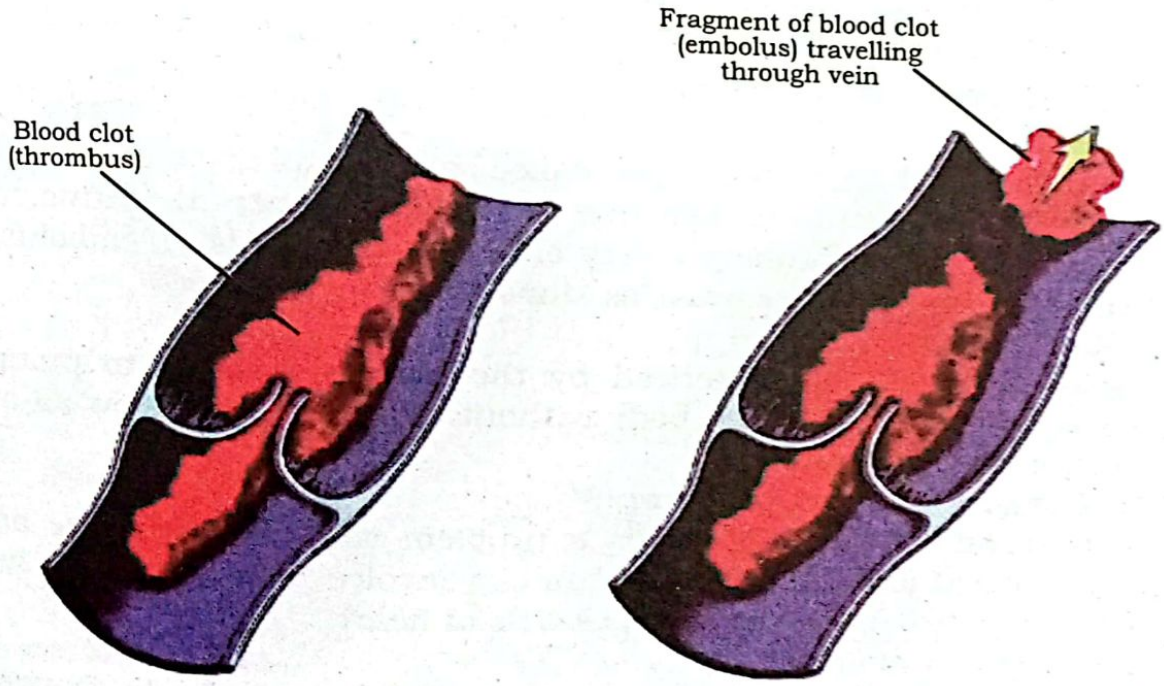



**Fig: 12.11 Thrombus and embolus**

### 12.11.2 Atherosclerosis

It is a disease of the arterial wall (intima) which loses its elasticity gradually its inner layer thickens causing narrowing of the artery and consequently impairing the blood flow. The narrowing is due to the formation of fatty lesions called atheromatous plaques in the inner lining of the arteries. These plaques consist of low density lipoproteins (LDL or cholesterol and protein) decaying muscle cells, fibrous tissue, clumps of blood platelets and sometimes calcium. The arteries become extremely hard and the disease is called arteriosclerosis or simply hardening of the arteries.

**Factor causing atherosclerosis**

The possible causes of atherosclerosis are smoking, hypertension, male gender, obesity physical inactivity, a high serum cholesterol level, severe diabetes, family history of arterial disease and possibly an anxious or aggressive personality. The risk of atherosclerosis increases with age.

### 12.11.3 Heart problems

Cardiovascular disorders related to heart called heart problems. It includes angina pectoris, heart attack and heart failure.

**Angina pectoris**

Strain on the heart by increasing resistance to blood flow. Although the heart may enlarge in response to this added demand, its own blood supply may not increased proportionately. The heart muscle is then inadequately supplied with blood, especially during exercise. Lack of sufficient oxygen to the heart can cause chest pain and a radiating pain in the left arm called angina pectoris.

**Heart attack**

A myocardial infraction also called heart attack, occurs when a portion of the heart muscle dies due to lack of oxygen it is due to the blockage of any of the coronary artery either by thrombus or embolus, the blood supply to some cardiac muscles stops.

**Heart failure**

Heart failure is characterized by the heart's inability to pump an adequate supply of blood to the body without sufficient blood flow all major body functions are disrupted.

### 12.11.4. Congenital heart problem

A congenital heart problem is a problem with the structure of the heart. It is present at birth. The problem can involve the walls of the heart, the valves of the heart, and the blood vessels of heart.

### 12.11.5 Principles of angiography

Angiography is the x-ray imaging of blood flow in the body. During an angiogram, substances that are opaque to x-rays are inserted into the bloodstream. The images of the path they take through blood vessels can be diagnostically useful. It is useful to locate blockages in the blood vessels.

### 12.11.6 Treatment of cardiovascular disorders

**Coronary bypass**

It is a medical procedure to improve blood flow to the heart. It may be needed when the arteries supplying blood to heart tissue, called coronary arteries are narrowed or blocked. Coronary bypass uses blood vessels from another part of the body and connects them to blood vessels above and below the narrowed artery, bypassing the narrowed or blocked coronary arteries.

## Angioplasty

It is a medical procedure used to improve the flow of blood through narrowed artery. It involves placing a long thin tube (catheter) into a blood vessel to place a small balloon at the site if the narrowing. When the balloon is inflated, the blood vessel should open and allow a healthy flow of blood.

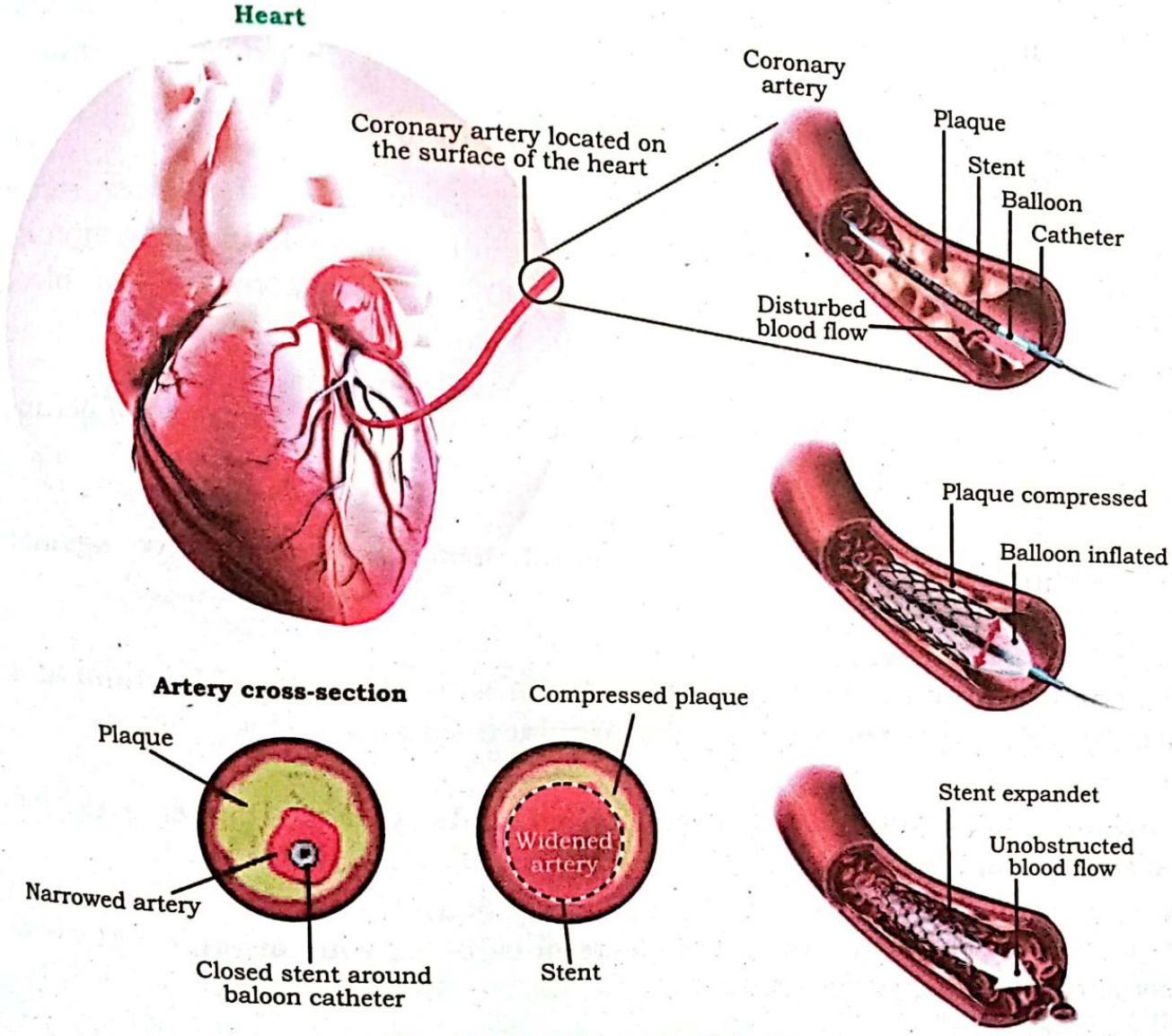



**Fig: 12.12 Balloon angioplasty**

## Open heart surgery

It is a surgical procedure in which breast-bone being cracked open, providing direct access to the heart, allowing surgeons to fix heart problems while the patient is placed on a heart-lung machine. Open heart surgery is probably the most widely known and feared of all operations, but in the right hands open heart surgery can be remarkably safe and effective, associated with excellent outcomes for patients.

### 12.11.7 Hypertension

When the mean arterial pressure is greater than the upper range, women of any age are considered to have hypertension if their blood pressure reading is 160/95 or above. For a man under age 45, a reading above 140/95 is considered hypertensive. Hypertension is called as "Silent Killer", because the affected individuals may show no outward symptoms until a stroke or heart attack occurs. Several factors such as heredity, higher intake of salts in diet, smoking, obesity and disorders of kidney or adrenal gland are responsible for hypertension.

**Hypotension (low blood pressure)**

When the mean arterial pressure is lower than the lower range, people with low blood pressure (Hypotension) may experience symptoms when their blood pressure drops below 90/60. Symptoms of low blood pressure fatigue, dizziness, nausea and lightheadedness.

### 12.11.8 Life style modification prevents cardiovascular disorders

There are several things you can do to reduce your chances of getting cardiovascular disorders.

**Eat healthy diet:**

Low salt and low saturated fats and cholesterol as protective against cardiovascular disorders.

**Stay at a healthy weight:**

Hypertension occurs more often in persons who are obese. Maintaining a healthy weight reduces risk of cardiovascular disorders

**Don't smoke:**

Smoking raises your blood pressure so puts you at higher risk for cardiovascular disorders

**Keep your cholesterol and triglyceride levels under control:**

High level of saturated fats and cholesterol can clog your arteries and raise risk of cardiovascular disorders.

**Exercise:**

Those who exercise are less apt to have cardiovascular disorders.

## 12.12 LYMPHATIC SYSTEM

The lymphatic system consists of a network of blind vessels (lymphatics) that drains lymph from all over the body back to the circulatory system. Numerous small lymph nodes, and two additional organs thymus and spleen although not strictly part of the circulatory system, the lymphatic system is closely associated with it.

### 12.12.1 Composition and formation of intercellular fluid

All the body tissues are bathed in a watery fluid derived from the blood stream. This intercellular or tissue fluid is formed when blood passes through the capillaries. The capillary walls are permeable to all components of blood except the R.B.Cs and blood proteins.

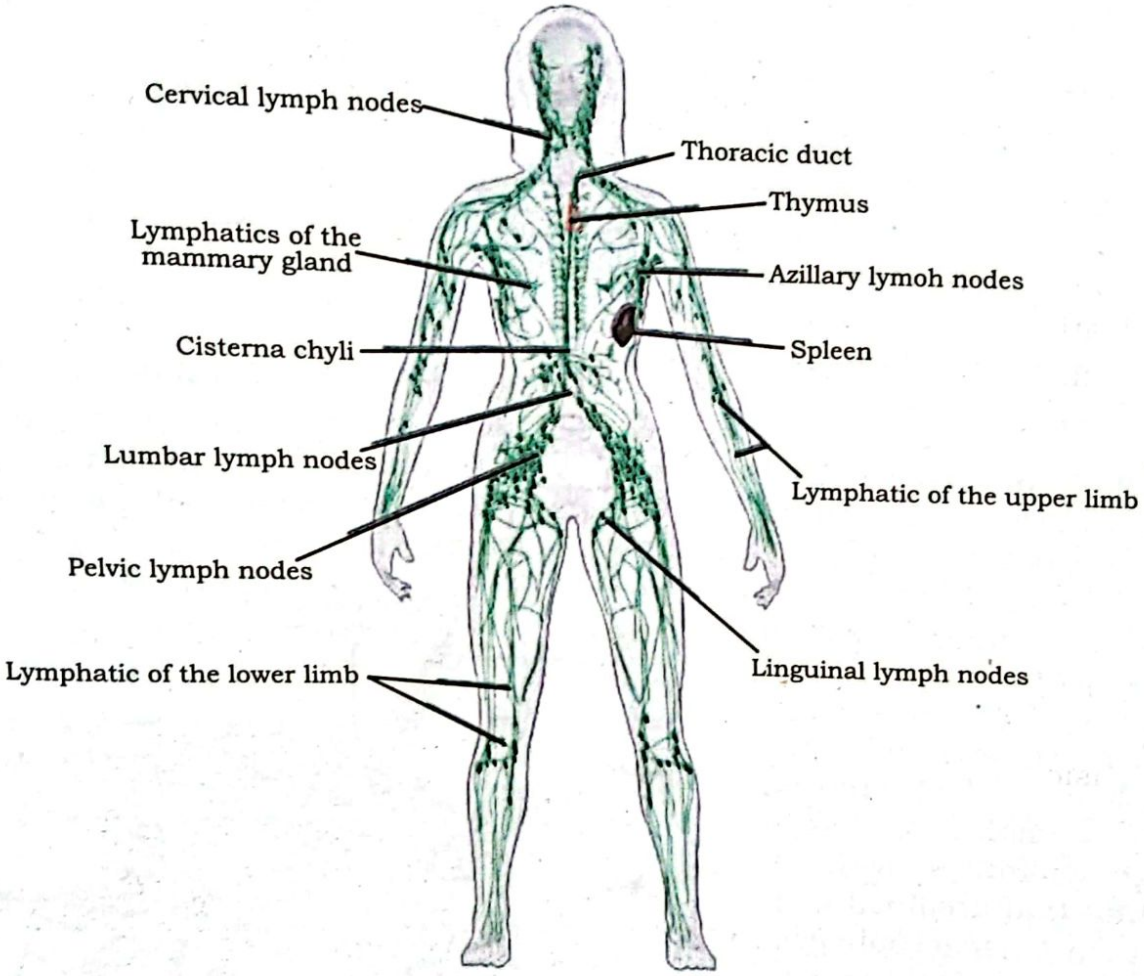



**Fig: 12.13 Lymphatic system**

### 12.12.2 Comparison of the composition of intercellular fluid and lymph

The fluid passes from the capillary into the intercellular spaces as the intercellular or tissue fluid. About 85% fluid returns into the blood at the venous end of the capillary. The rest 15% of the tissue fluid drains into blindly ending lymphatic capillaries as lymph along with W.B.Cs, cell debris and microorganisms like bacteria, are transported back to the heart through lymphatic system. Thus lymph can be defined as colourless body fluid that contains lymphocytes, small proteins and fats. Lymph takes fluid substances from cells of tissues and intercellular spaces, which cannot penetrate the blood capillaries.

### 12.12.3 Lymphatic vessels

Like blood capillaries, **lymph capillaries** form a complex network of microscopically narrow, thin walled vessels into which substances can move readily. Lymph capillary walls are composed of cells with openings between them that act as one way valves. These openings allow relatively large particles along with fluid, to be carried into lymph capillary. Materials collected by the lymph capillaries flow into larger **lymph vessels**, through which lymph is forced as blood is through veins. Large vessels have somewhat muscular walls, but most of the impetus for lymph flow comes from the contraction of nearby muscles, such as those used in breathing and walking. As in blood veins, the direction of flow is regulated by one-way valves. Efferent lymph vessels merge before entering one of two ducts: the thoracic trunk or the right lymphatic trunk

### 12.12.4 Role of lymph vessels in villi

The small intestine is richly supplied with lymph capillaries. After absorbing digested fats, intestinal cells release fat globules into the interstitial fluid. These globules are too large to diffuse into blood capillaries but can move easily through the openings between lymph capillary cells. These fat globules may make up 1% of the lymphatic fluid.

### 12.12.5 Lymphoid tissue

The large lymph vessels are interrupted periodically by kidney bean shaped structures about one inch long called **lymph nodes**. Lymph is forced through channels with in the nodes that are lined with masses of macrophages.

Lymphocytes are also produced in the nodes. Both of these white blood cells recognize and destroy foreign particles, such as bacteria and viruses, and are killed in the process.

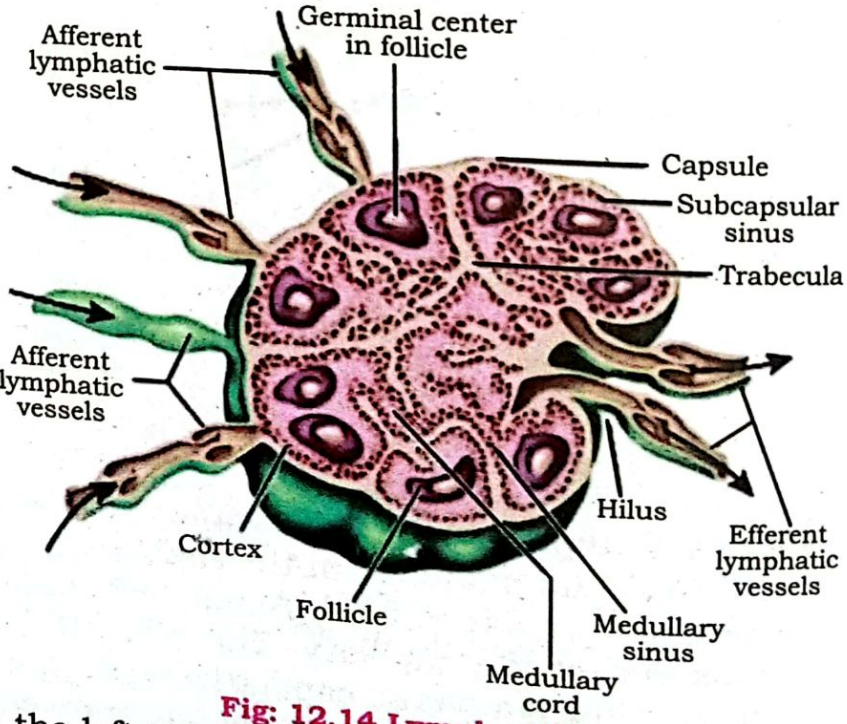



Fig: 12.14 Lymph node

**Spleen**

The spleen is located in the left side of the abdominal cavity, between the stomach and diaphragm. The spleen filters blood, exposing it to macrophages and lymphocytes that destroy foreign particles and aged blood cells.

# SUMMARY

- Living organisms obtain necessary raw materials, to synthesize molecules for metabolism. These materials are transported with the living organisms or from environment to living organism.
- The circulatory system is of two types: open type and closed type.
- In arthropods and molluscs blood baths the internal organs directly.
- There is no distinction between blood and interstitial fluid, and the general body fluid is more correctly termed as haemolymph.
- In a close type circulatory system, blood is confined to vessels and is distinct from the interstitial fluid.
- The heart of fish is two chambered consisting of an atrium and a ventricle.
- From amphibians onwards up to the mammals, the circulatory system has double circuit plane with separate pulmonary and systemic circulation.
- In amphibians and reptiles, the heart consists of three chambers, two atria and one ventricle.
- In crocodiles, birds and mammals the heart is four chambered with two atria and two ventricles.
- The right atrium and right ventricle are completely separated from the left atrium and left ventricle by inter atrial and inter ventricular septum.
- The human heart has somewhat conical form and is enclosed by pericardium.
- The heart wall consists of three layers enclosed in the pericardium.
- Human heart consists of four chambers. Two upper thin walled atria and two lower thick walled ventricles.
- The contractions of heart chamber are known as heartbeat.
- A region of the heart called the saino atrial (SA) node or pace maker, maintains the heart's pumping rhythms.
- As blood leaves the hearts, it travels from arteries to arterioles to capillaries to venules to vein, which return it finally to the heart.
- The hydrostatic force of blood exerted on the wall of vessels is called blood pressure.

# EXERCISE

**1. Encircle the correct choice.**

(i) Lymph most closely resembles which of the following?
(a) Blood (b) Urine
(c) Plasma (d) Interstitial fluid

(ii) What event initiates blood clotting?
(a) Contact with an irregular surface by platelets and other factors in plasma.
(b) Production of the enzyme thrombin
(c) Conversion of fibrinogen into fibrin
(d) Excess flow of blood through a capillary

(iii) Damage to the S.A Node in humans
(a) Is a major contributor to heart attacks.
(b) Would block conductance between the bundle branches and the purkinje fibers.
(c) Would have a negative effect on peripheral resistance
(d) Would disrupt the rate and timing of cardiac muscle contractions.

(iv) Which of the following is measured by an electrocardiogram?
(a) Impulses from the AV node
(b) Impulses of the parasympathetic nervous system that control heartbeat
(c) The speed on impulses from the SA node
(d) Contraction of the two atria

(v) Where are semilunar valves to be found in the mammalian heart?
(a) Where blood goes from atria to ventricles
(b) On the right side of the heart only
(c) Where the pulmonary veins attach to the heart
(d) At the places where blood leaves via the aorta and pulmonary arteries

(vi) Organisms in which a circulating body fluid is distinct from the fluid that directly surrounds the body's cells are likely to have which of the following?
(a) An open circulatory system
(b) A closed circulatory system
(c) A gastrovascular cavity
(d) Branched tracheae

(vii) Average blood pressure is lowest in which structure (s)
(a) Aorta (b) Arterioles
(c) Capillaries (d) Vena cava

(viii) Which of the following is/ are a cause (s) of vasoconstriction?
(a) Lying down after standing
(b) Standing after lying down
(c) Stress or hormone concentration
(d) Histamine secretion

(ix) Blood returning to the human heart in a pulmonary vein drains first into the?
(a) Left atrium (b) Right atrium
(c) Left ventricle (d) Right ventricle

(x) Which of the following is NOT an important function of the human circulation?
(a) Transport of nutrients and respiratory gases
(b) Regulation of body temperature
(c) Protection of the body by circulating antibodies
(d) Removal of waste products for excretion from the body

## 2. Write short answers of the following questions:

1. Why higher animals need circulatory system?
2. Why SA node is called pace maker of heart?
3. Why the capillaries have a single layer of endothelium?
4. What are LUB and DUB?
5. Why circulatory system of arthropods is called open type?
6. Why blood flow faster in arteries?
7. Distinguish between single circuit circulation and double circuit circulation.

## 3. Write detailed answers of the following questions:

1. Describe the structure of blood vessels in man.
2. Describe the structure of human heart.
3. What is circulation? Explain needs of circulation
4. State the phases of heartbeat in man.
5. Describe the flow of blood through human heart as regulated by the valves.
6. Describe the lymphatic system of man
7. Explain the electrocardiogram with the help of diagram.
8. Describe pulmonary circulation and systemic circulation

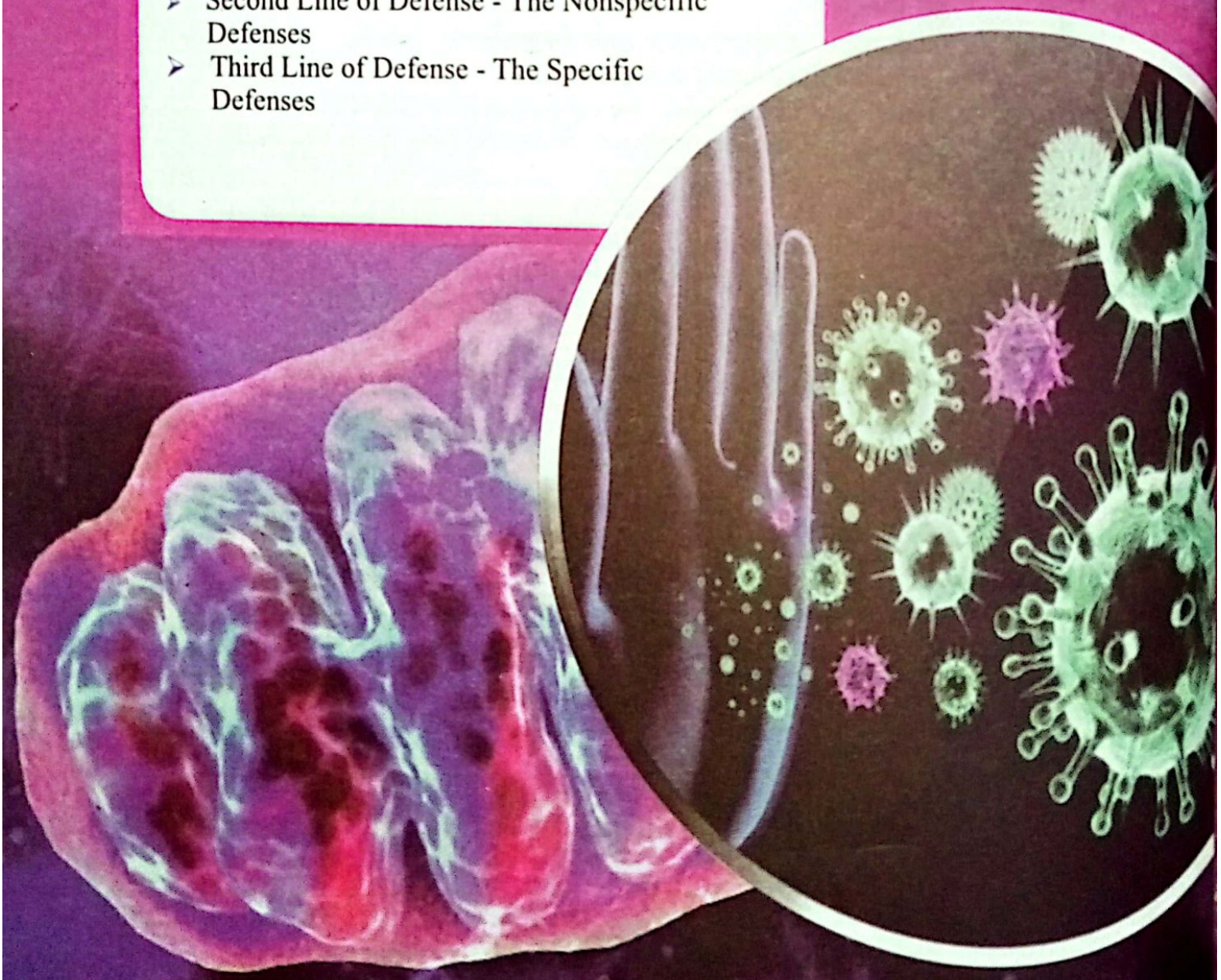
# IMMUNITY

Chapter 13

## Major Concept

**In this Unit you will learn:**

- First Line of Defense (Skin, Digestive Tract, Air Passageway)
- Second Line of Defense - The Nonspecific Defenses
- Third Line of Defense - The Specific Defenses



## Immunity:

No matter how much hygiene one keeps, our body is always exposed to pathogenic organisms such as viruses, bacteria, etc. They are present everywhere and have their own unique ways to infect our body. It's a matter of common observation that sometimes we feel abnormalities or disturbances in our normal systems, initially we use to bear and plan to visit some physician in the evening. Later, the complaint is resolved automatically and we forget what wrong early morning was. This miracle happens due to the immunity of our body which may be defined as "the resistance of our body against pathogenic living things and organisms". Due to the immunity, we not only check the entry of pathogens in our body but also the toxins they released after gaining access into our body. However, it's not the end of the defense tale, we do check and destroy our own abnormal cells as well as the foreign cells in our body.

Immunity is conferred to the animals through the activities of the **immune system**. It is a collection of cells and proteins that work in integrated fashion to protect the body from potentially harmful, infectious microorganisms. It is very important in the control of cancer, allergy, hypersensitivity and rejection problems when tissues and organs are transplanted. The study of the functioning and disorders of immune system is termed as **immunology**.

The immune system can be divided into following two functional divisions;

(i) Innate Immune System, and (ii) Adaptive Immune System

### (i) Innate immune system:

It's the part of our immune system which is provide us natural immunity. It is non-specific type as is against any pathogenic organism which tries to enter our body. It consists of two lines of defenses, viz., First and Second Lines of Defenses, respectively.

Table:13.1 Table summarizing our three lines of defenses

| **INNATE IMMUNE SYSTEM** | | | **ADAPTIVE IMMUNE SYSTEM** |
|---|---|---|---|
| **First Line of Defense** | | **Second Line of Defense** | **Third Line of Defense** |
| **(NON-SPECIFIC)** | | **(NON-SPECIFIC)** | **(SPECIFIC)** |
| **Physical Barriers:** Intact Skin, Mucous Membrane, Ciliated Epithelium | **Biochemical Barriers:** Saliva, Mucus, HCl, Gastric Juice, Tears, Spermine(in semen) | Phagocytes, Natural Killer Cells, Inflammation, Antimicrobial Proteins, Fever. | Cell Mediated Immunity; Antibody Mediated Immunity; B & T Cells |

## 13.1 FIRST LINE OF DEFENSE:

Our first line of defense is considered to be non-specific in nature since it prevents the entry of all kinds of pathogens into our body. It is manifested by physical as well as biochemical barriers. The **physical barriers** as summarized in the (table 13.1) are skin, mucous membrane and ciliated epithelium. **The biochemical barriers** consist of saliva, tears, mucous, gastric juice, etc. Let's discuss their structure and role in protection one by one.

### Skin- its structure and role in immune system

The skin is the one of the largest organ of our body. Being consists of 1.8 $m^2$, it is a multitasking organ, playing its role not only in protection but also the regulation and sensation. It is always exposed to environmental hazards and stresses. The primary function of the skin is to act as a barrier. It provides protection from mechanical impacts and pressure, variations in temperature, micro-organisms, radiation and chemicals. It also regulates several aspects of physiology, including body temperature via sweat and hair; changes in peripheral circulation, and fluid balance via sweat. It does act as a reservoir for the synthesis of Vitamin D. As a sensory organ, it contains an extensive network of nerve cells that detect and relay changes in the environment. There are separate receptors for heat, cold, touch, and pain.The skin is composed of three main layers of closely packed cells. Among its layers are epidermis, dermis and hypodermis.

### (i) Epidermis:

It is the outermost layer of skin. Since, it lacks blood supply, it is entirely dependent upon dermis for the supply of nutrients and disposal of wastes. It is made up of closely packed dead cells with keratin which makes the skin's surface mechanically tough and resistant to degradation by bacterial enzymes. Fatty acids on the skin's surface create a dry, salty, and acidic environment that inhibits the growth of some microbes and is highly resistant to breakdown by bacterial enzymes. In addition, the dead cells of the epidermis are frequently shed,

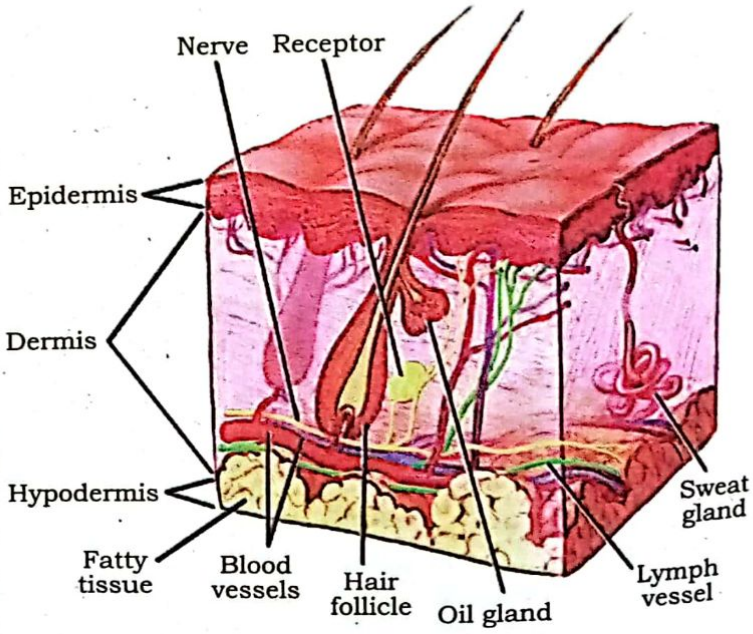



**Fig: 13.1**
**3D image of human skin**

along with any microbes that may be clinging to them. Shed skin cells are continually replaced with new cells from below, providing a new barrier that will soon be shed in the same way. Wandering among the three layers of skin, there is a variety immune cells such as **Langerhans Cells** (skin resident macrophages) and T cells for the elimination of intruding microbes.

**(ii) Dermis:**

Underneath the epidermis, the layer of skin is called dermis. It consists of living cells, blood vessels and nerves. It has sweat secreting **sweat glands** and sebum (oil like substance) secreting **sebaceous glands**. The later opens into hair follicles to lubricate the hair. The sebum contains some acids which make a thin film on the skin surface. It acts as chemical barrier for microorganisms to penetrate through it. On the other hand, sweat glands do contribute to this chemical barrier thereby secreting variety of polypeptides for the inhibition of the growth of microorganisms on the skin surface.

**(iii) Hypodermis:**

Below the dermis lies the hypodermis. It contains mainly fat storing adipose tissue and connective tissue. It connects the skin with the underlying muscles and bones. It serves as insulating layer.

**Digestive Tract: Role in immune system**

Our gut is lined internally with mucosa. In addition, our stomach has gastric glands which secrete HCl and variety of enzymes to destroy intruding noxious microorganisms. The internal lining of mouth, nose, digestive tract, respiratory passage and lungs, urinary tract, etc., contains mucous secreting cells hence is also known as **mucous membranes** or **mucosa**. These internal linings are made up of epithelial cells. The mucosa not only serves as non-specific physical barrier due to its compact nature but also provides a biochemical barrier through its mucous which contains many antimicrobial peptides. Moreover, the mechanical action of the peristalsis of the gut also moves out the sloughed mucous along with the undigested food (feces).

In addition to the above mentioned defenses, our digestive tract is also equipped with substantial amount of lymphoid tissue being located into three sectors, viz. **Tonsils** in pharyngeal region; **Peyer's patches** in small intestines and the **Appendix.** The lymphoid tissue is rich in macrophages and lymphocytes for the protection against pathogenic microorganisms which they encounter. Another sector of the lymphoid tissue are the W.B.Cs (e.g., Plasma Cells and Lymphocytes) wandering in the basement membrane of the small intestine. A number of lymphocytes also present in the epithelial

cells of mucosa offer another protection against the pathogenic microorganisms.

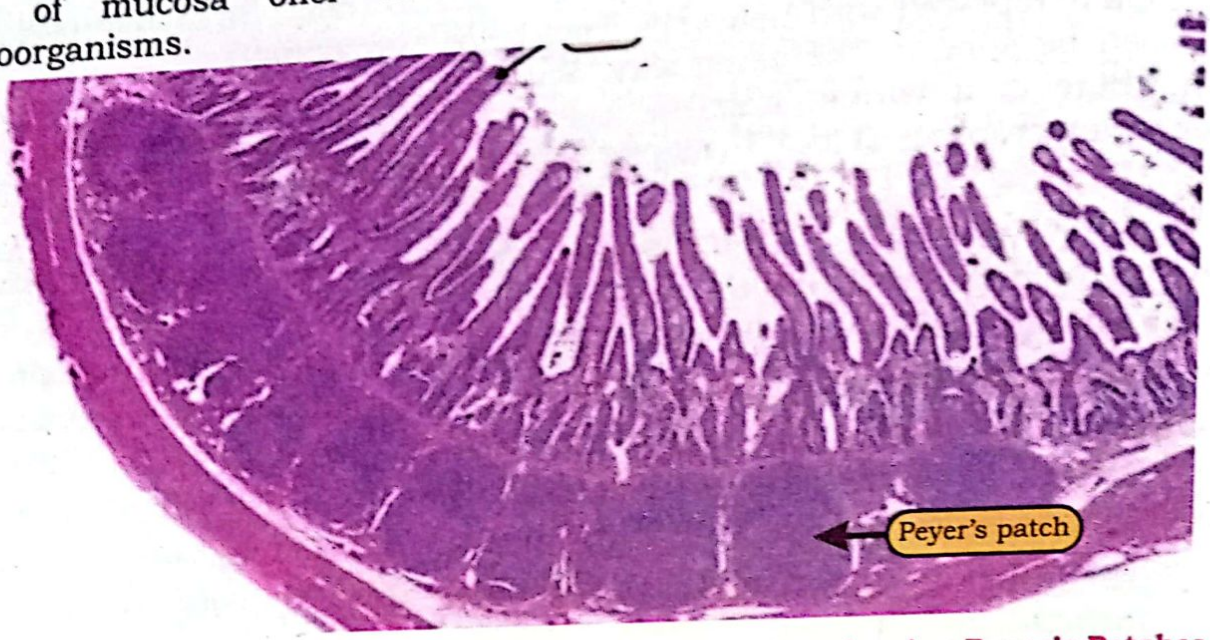



**Fig: 13.2 Microscopic cross section of Human Small Intestine showing Peyer's Patches**

**Air Passage Way: Role in first line of defense:**

In some systems like respiratory system, where there is a great risk of entry of pathogenic microorganisms through air, the mucosa traps the microorganisms and its ciliated surface flushes off the contaminated mucous outside so as to avoid retention of dust, dirt, pathogenic microorganisms inside thereby playing important role in first line of defense.

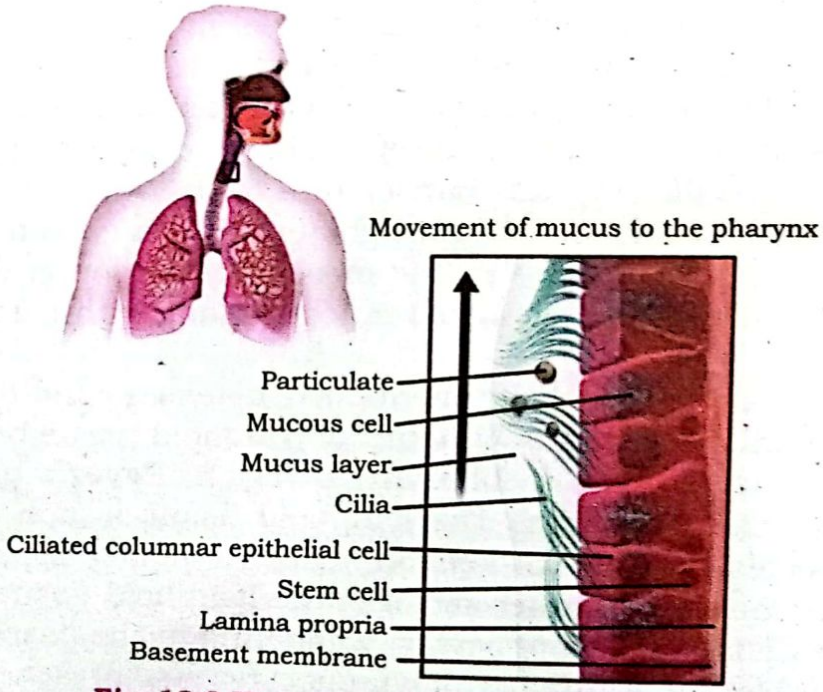



**Fig: 13.3 Human respiratory epithelium**

The hairs present in our nose do trap the dust, dirt, etc., from the inhaled air thus make it sure that the air passing into the rest of the air passage ways should be free of such contaminations.

The mucous membrane of the respiratory system is composed of ciliated columnar epithelial cells layer. It contains numerous mucous secreting mucous glands. Due to mucous, the dust and germs stick to it which is removed by the synchronized upward movement of cilia towards the pharynx. It is either pushed into the esophagus or removed through the mouth.

## 13.2 SECOND LINE OF DEFENSE (The Non-specific Defense)

The pathogenic microorganisms may enter our body when it is broken either accidently like cut, burnt, etc. or through insect bite. Thus, if somehow the first line of our defense is breached, we do have the second line of defense to encounter. Like first line of defense, it is also non-specific in nature and comprised of a wide variety of our WBCs and defensive proteins. It is accomplished by the following major responses: Phagocytosis, cytotoxicity, inflammation and fever.

### 13.2.1 Killing Cells of Blood:

Whenever some pathogen gets access into the body through wound, broken skin, inhaled air, etc., it encounters WBCs, some of which recognize and kill it either by phagocytosis or direct killing. Let's learn them one by one.

#### (i) Phagocytosis:

It is the process through which some specific types of WBCs take-in and digest the foreign particle or microorganism. Among the WBCs, neutrophils, macrophages (monocytes)and dendritic cells perform such phagocytosis.

**Neutrophils:**

These are the most abundant WBCs (50%-70% of all leukocytes) and are specially adapted to phagocytize bacteria. The mature neutrophils have multi-lobed (3-5 lobed), non-spherical nucleus. They are usually short-lived. Upon maturation, majority of them migrate from the blood into our tissues. Through specific receptors on their surface, the neutrophils (figure, 13.5)can recognize various bacterial molecules such as peptidoglycans, flagellin protein of flagella, lipopolysaccharides, lipopeptides, etc.

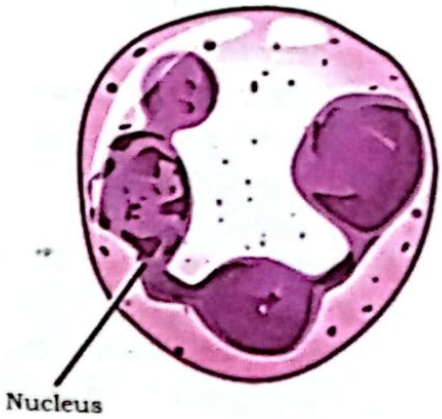



Fig: 13.4 A neutrophil

Upon recognition as foreign, the intruder is internalized by neutrophils and digested to destroy through its lysosomal hydrolytic enzymes.

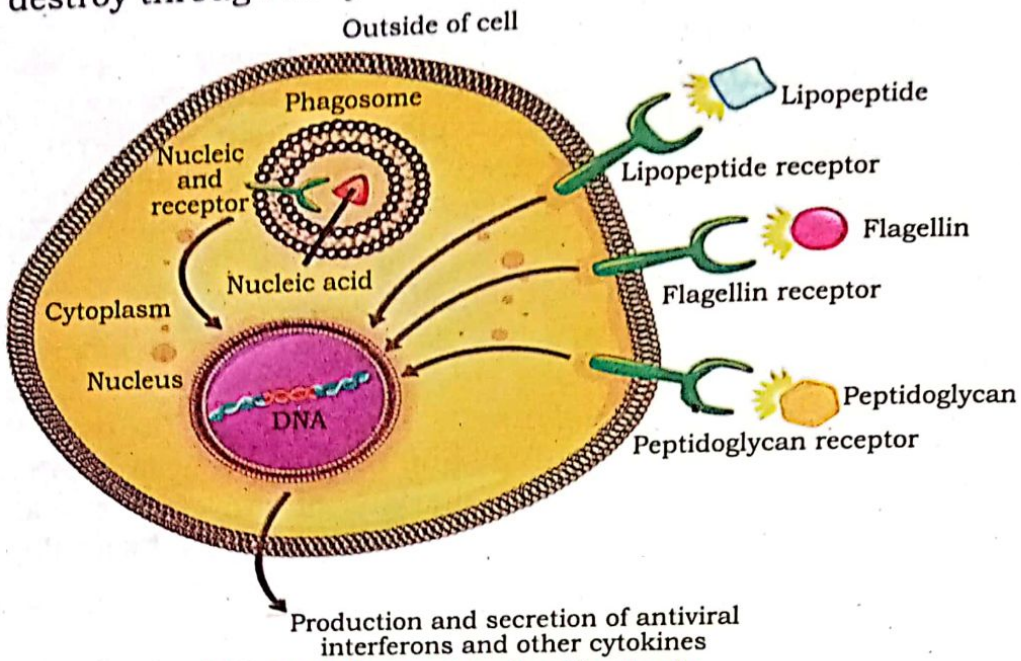



**Fig: 13.5 Phagocytosis of bacteria**

**Monocytes:**

They have a single bean shaped nucleus. The cytoplasm is non-granulated. They constitute about 2-8% of our total W.B.Cs. Like granulocytes, they originate from the myeloid stem cells. Although, the average life span is about 2 to 5 days in blood circulation, they can migrate from the blood into the tissue where they grow in size and become either **macrophages dendritic cells** and can live for months to years. Monocytes are involved in our innate immunity.

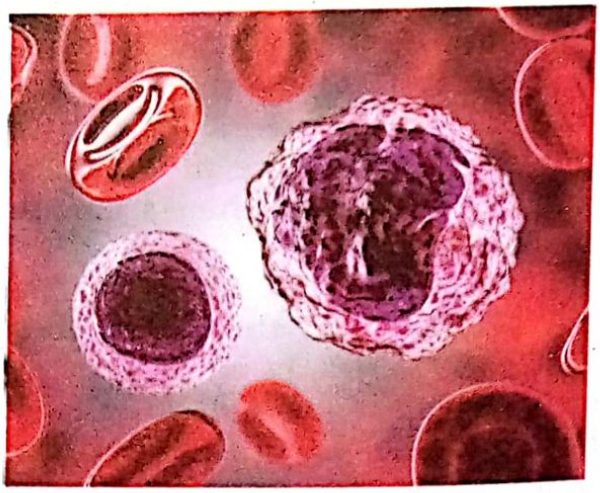


**Fig: 13.6. A monocyte**

**Macrophage:**

The leukocytes other than neutrophils involved in phagocytosis of foreign cells, worn-out cells, etc. are macrophages. They are derived from monocytes which are categorized as a type of agranulocytes because they lack any kind of pigments in their cytoplasm. They are the largest among all leukocytes. Unlike granulocytes, they have a large indented, horse-shoe shaped, nucleus. Circulating monocytes, after sometimes leave blood and

enter into lymphoid as well as non-lymphoid tissues where they grow in size and turn into macrophage dendritic cells. Macrophages have ability to adapt the specific tissue conditions so they are also named such as Alveolar macrophages in alveoli of lungs, Kupffer cells in liver, Microglia in Central Nervous System, etc. accordingly.

Macrophages not only phagocytize the pathogenic microorganisms but also remove and present their antigens to T-Cells (a type of lymphocytes), hence they are also termed as **Antigen Presenting Cells (APCs)**. They do release specific signaling molecules called **cytokines** to activate other immune cells. They also initiate the process of inflammation which we will discuss in the proceeding text. In addition to above mentioned activities, macrophage secrete nitric oxide which kills phagocytized pathogenic organisms.

**Dendritic Cells:**

The dendritic cells, another type of WBC, are also involved in presenting antigens of the phagocytized pathogen to the T-Cells. They were named so due to the presence of long cytoplasmic projections or dendrites. Upon activation through specific inflammatory cytokines secreted by macrophages, the dendritic cells migrate to the secondary lymphoid tissues such as tonsils, Peyer's Patch, spleen, tonsils, etc.). As soon as their task of activation of T cells achieved, unlike macrophage they die.

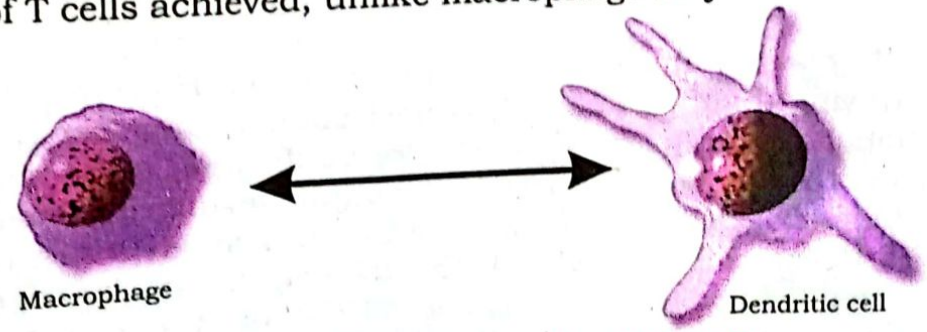



**Fig: 13.7 Macrophage vs Dendritic Cell**

**(ii) Cytotoxicity:**

It refers to the ability of a substance or certain cell, either to damage or cause death of a target cell. It is one of our protective response is exhibited against virally infected cells, cancer to tumor cells as well as our cells which are being infected by some pathogenic microorganism. The process of cytotoxicity could be a consequence of either Natural Killer (NK) Cells or Cytotoxic T ($T_c$) Cell. Although both NK Cells as well as Tc Cells are lymphoid in cell lineage and originate in the bone marrow, yet they differ in their mode of activation against their target cells.

**Natural Killer Cells (NK Cells):**

NK Cells are one of the types of lymphocytes involved in detecting and eliminating virally infected cells as well as cancer cells. In such cases, unlike $T_C$ cells, they do not need any prior activation by antigen presenting cells.

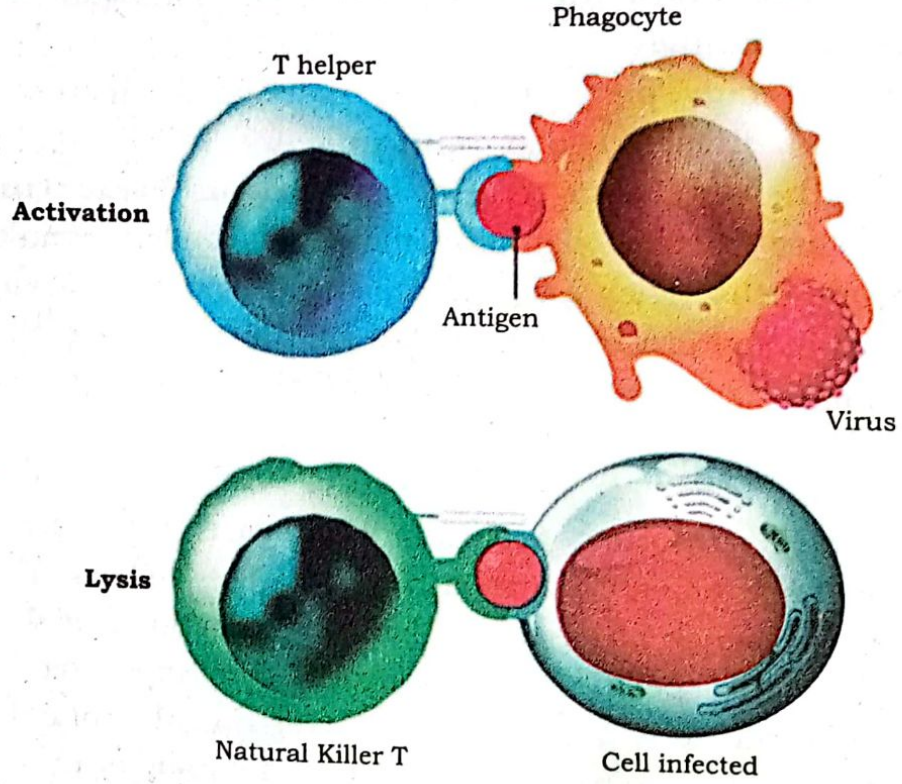



**Fig: 13.8. Response of NK Cell against a normal vs infected cell. In case of infected cell it is activated to cause lysis of the target cell.**

Hence they were named as Natural Killer Cells. However, the mode of action in destroying the target cells is almost similar. Just like a policeman checking national Identity card of person for verification of his identity, the NK Cells do check on the cell surface, a conjugate molecule called Major Histocompatibility Complex-I (MHC-I), which serves as identification card of cell as "self". In case of intact MHC-I, the NK cell remain inactive while in case of any modification or absence of MHC-I on the target cell, it is activated to destroy the target cell. The lysis of the target cell is brought about by releasing cytotoxic granules having **perforin** protein and **granzyme**. The former forms pores in the plasma membrane of the target cells while the later enters the target cell and causes its lysis.

**Cytotoxic T Cells (Tc Cells):**

Cytotoxic T Cells are another group of immune cells which belong to Lymphocyte family of our W.B.Cs. As the name suggests, they recognize virally infected cells as well as tumor cells. Though they are produced in the bone marrow but they migrate to thymus where they mature and then released into the blood. During their maturation process, the nive T Cells

which develop CD8 type of co-receptor along with their T Cell Receptor (TCR) on their surface, turn into Cytotoxic T Cells. Through their CD8 co-receptor and TCR, the Cytotoxic T Cells bind with **Major Histocompatibility Complex-I (MHC-I)** present on all of their own nucleated cells of our body except macrophages because they have another **Major Histocompatibility Complex-II (MHC-II)**. For the activation of $T_C$ cells, several chemical signals are required from other cells like dendritic and T helper cells.

Whenever the $T_C$cells encounter virally infected cells, they recognize them immediately through the viral antigens expressed on the MHC-I of the infected cells. Their programming, in such case, is to release some protective proteins or cytokines such as Tumor Necrosis Factor – alpha (TNF-α) and Interferon-gamma (IFN-γ) which act on other immune cells such as macrophage and dendritic cells to enhance immune responses. Like NK Cells, they release **perforin** proteins and **granzyme** to cause lysis of the infected target cell. Unlike NK Cells, the $T_C$cells then proceed towards other infected cells to cause their lysis. In this way, they serve the role as "serial killer".

### 13.2.2. Protective proteins:

In our body fluids, there circulates different proteins which help us in the protection of the body against microorganisms such as pathogenic bacteria, etc. Such proteins are termed as complement protein. Upon recognition of bacteria as foreign organism (non-self), complement proteins are activated through a series of reactions. Some of them damage the plasma membranes of their target cells while the others attract other cells of the immune system such as mast cells, neutrophils and macrophages to enhance the immune responses.

### 13.2.3.Inflammatory response:

Inflammation (to set on fire) is one of the non-specific immune responses which is usually a consequence of infection. However, it may be due to other factors like tissue damage, irritants or autoimmune disorders. It is classically categorized as two types, acute and chronic. The acute type is a short term inflammation and characterized by redness, hotness, pain, swelling and loss of the function of the affected organ. The chronic one is of long term duration and is usually a consequence of diseases like Cardio-Vascular Disorder (CVD), allergy, etc.

Whenever, damage to our tissue takes place either through an accident or a pin prick to skin, the harmful bacteria are introduced in our tissues. As a result, the damaged tissue releases specific complex proteins such as Histamine and Prostaglandin which dilate the nearby blood vessels and attract neutrophils and macrophages to the site of infection so that the intruder bacteria may be eliminated through phagocytosis. It may result in abscess. Since it is a sort of war is going on in the infected tissue, our own

cells may die forming a thick paste-like, white, yellow, orange or greenish fluid, Pus is formed. The pus may have bad smell.

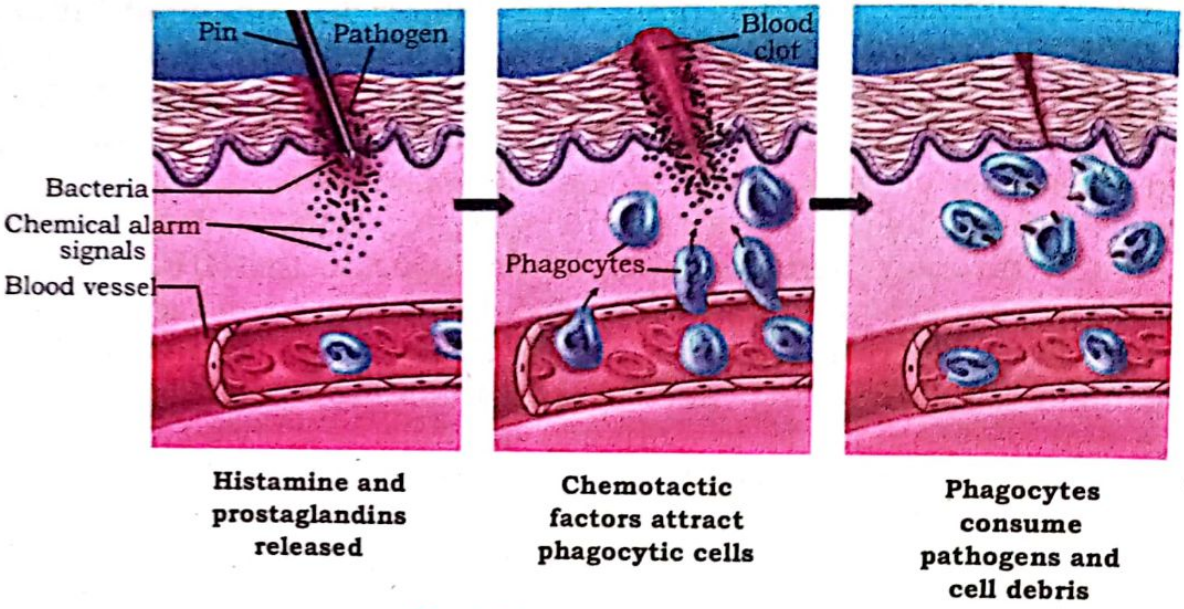


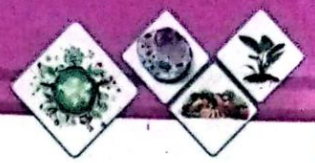

**Fig:13.9. Inflammatory response**

**Justify the inflammatory response in arthritis as an example of a misdirected immune response:**

Normally the immune cells respond to the foreign cells, or particles such as bacteria, viruses, etc. only. However, in few cases like autoimmune disorder such as Rheumatoid Arthritis, the immune cells responds against their self (own) cells/antigens. The exact reasons for this misdirection are not certain in many specific cases. In case of rheumatoid arthritis, there is inflammation of the synovial membranes of the joints that progresses to swelled and painful joint, ultimately leading to their deformity. It may damage other parts of the body also.

### 13.2.4 Temperature response or fever (Pyrexia):

Whenever the body temperature rises above the normal, it is clinically termed as fever. It is a symptom rather than a disease. It is one of the non-specific type of our immune system which could be a sign of infection. It may also be caused by heat-stroke, brain tumors, toxins affecting brain, some medicines, etc. Substances that induce fever are termed as **Pyrogens**. They may be endogenous (body's own cells secretions) or exogenous (external source). The endogenous pyrogens are released by our immune cells in response to the presence of pathogenic organisms like bacteria, viruses, etc. They are released in the blood stream from actively phagocytizing macrophages. The important pyrogens are Interleukin-1 (IL-1) and Interleukin-6 (IL-6), Tumor Necrosis Factor (TNF) and Interferons (INF-alpha), respectively. Through the blood, the pyrogens are transported to the brain where they act upon hypothalamus, the thermostat of the brain. As a



consequence, the hypothalamus produces lipid like signaling molecules, **prostaglandin** due to which the thermogenesis is increased and heat loss is decreased. This causes rise in the body temperature or fever.

Because of the fever, many fungi and bacteria cannot grow and multiply properly so that our immune cells can handle them easily causing their death, e.g. facilitates the phagocytosis. As mentioned earlier, the exogenous pyrogens are coming from external source such as bacteria. Such toxins are recognized by brain as pyrogens and can induce fever.

Although fever in the above sense is beneficial to us, yet it has following harmful effects also:

i) A considerable amount of energy is lost as heat.
ii) It causes fatigue, dehydration, body ache and seizures also.
iii) Temperature higher than 105° F denature our enzymes and other proteins also.
iv) It can denature our own cells. It can cause death also.

**Justify why physicians prescribe antipyretic drugs, when fever is non-specific defense against microbial infections.**

**Antipyretic Drugs:** Those drugs which reduce or control fever are called antipyretic. The antipyretics can inhibit the prostaglandin secretion by the hypothalamus thereby reducing fever. The antipyretics can be categorized into 3 groups, viz., i) Salicylates, e.g. Aspirin, etc. ii) Acetaminophen, e.g. Paracetamol, etc. and iii) Non-steroidal anti-inflammatory, e.g. Ibuprofen, etc. Most of the antipyretics inhibit enzyme, cyclooxygenase which reduces the level of prostaglandins from the brain.

## 13.3 THIRD LINE OF DEFENSE (The Specific Defenses):

The non-specific second line of our defense is supported simultaneously by third line of defense. It is very complex and specific in nature. This part of the immune system is termed as Acquired or Adaptive Immune System and its response varies from person to person and is the most powerful means of resisting infection.

### Recognition of self vs non-self:

For the adaptive immune response to work, it is first necessary to recognize the foreign organism as "non-self" by the immune cells. It is made possible by the identification of **Antigens** of invading organism. The antigen could be any foreign macromolecule, especially proteins which can elicit immune response. In response to the particular antigens, B-lymphocytes produce a small, soluble and specific protein called **antibody** which combines with specific antigen and helps to destroy the antigen displaying pathogenic organisms. The immune system of a vertebrate can produce billions of different antibodies. Not only the immune system destroys in this

way the pathogenic organism but it also memorizes it and can produce antibodies against the same pathogen in case of reinfection. The distinction between the self and non-self is the hallmark of immune system.

As you have already learnt about the Major Histocompatibility Complex (MHC) Class-I & Class-II as our cell surface marker or Cell Identification Cards which are to be displayed on cell membranes of each and every cell of our body. Being codes by a specific set of genes, MHC proteins are found in all vertebrates. In humans, they are also termed as Human Leukocyte Antigens (HLA) system. As you can see in (Figure 13.10) that the MHC-I is composed of three alpha sub-units and a beta microglobulin. In between alpha 2 and alpha1, there is groove termed as binding groove for interaction with NK Cells through its inhibitory receptor. On the other hand, the MHC-II is comprised of 2-unit alpha chains and 2-unit beta chains (Heterodimer). The binding groove is shallow and open at each ends.

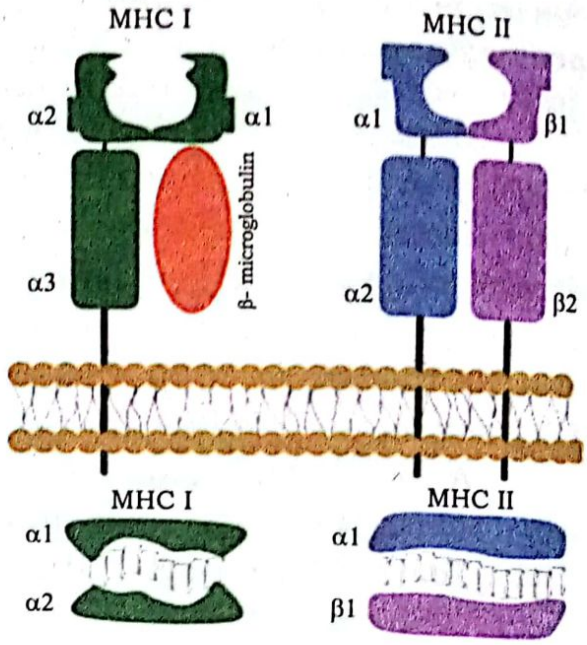



**Fig: 13.10. MHC peptides expressed on the cells surface.**

MHC-I is present on the plasma membrane of our all nucleated cells and platelets. It interacts with $T_C$ cells and NK Cells. In case of intact MHC-I, the patrolling cells take it as "self-cells" and no adverse response is shown against them. In case of any kind of alteration/modification/loss in MHC-I, the target cell is taken as non-self and subject to be terminated. Thus altered MHC-I serves as a global alarming system in our body's immune system.

MHC-II is displayed on the cell surface of antigen presenting cell such as macrophage, dendritic cells and B cells. The MHC-II interacts with CD4 T cell, i.e., Helper T Cell and is essential for our adaptive immune system so as to develop

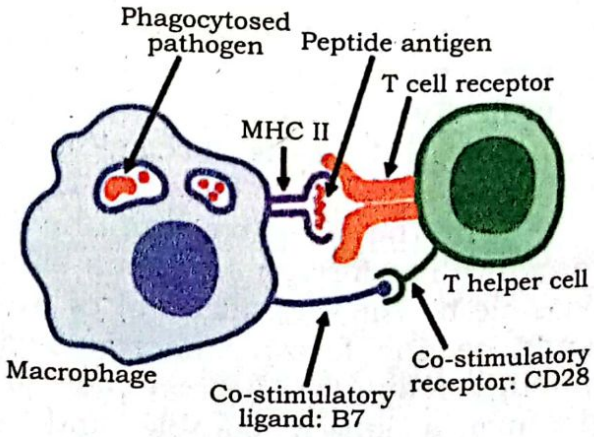



**Fig: 13.11 Interaction of an antigen presenting cell with T helper cell**

specific immune response. If no peptide antigen is displayed on MHC-II of macrophage, the $T_H$ cell remain inactive. However, in case of such antigen displayed on MHC-II of APC, the naïve TH cell activates and releases number of lymphokines to activate other immune cells.

### 13.3.1 In-born and acquired immunity:

There are two basic types of immunity, Innate Immunity and Acquired Immunity.

**Inborn or Innate Immunity:**

The Inborn or innate immunity provides the non-specific, natural defense of our body against pathogenic organisms. It is conferred upon us through physical barriers (e.g. skin, etc.), cellular barriers (e.g. macrophage, neutrophils, mast cells, eosinophils, and basophils), biochemical barriers (e.g. cytokines, interferon, interleukins etc.). This kind of immunity is a consequence of genetic make-up of an individual so it exists before the infection is acquired.

**Acquired or Adaptive Immunity:**

After the breach of the Inborn immunity, the acquired or adaptive immunity comes in action against pathogenic or foreign organisms. It is specific in nature and the pathogen is death with T and B lymhocytes. Although the resistance offered is slower, it is long lasting due to existance of memory, and in few cases life long against particular pathogens. In this case the resistance offered by individual varies from person to person.

There are two types of acquired immunity: i) Active Immunity, and ii) Passive Immunity. Both of these could be natural or artificial. If immunity develops as a consequence of natural infection, it is termed as Natural, and if it is a consequence of artificially inocculation of pathogenic organism, it is termed as Artificial, as shown in the table number 13.2). Artificial immunity is also termed as Immunization.

**Table: 13.2 Innate and Artificial Immunity**

| | Active Immunity | Passive Immunity |
|---|---|---|
| **Natural** | Clinical, sub-clinical infection | via breast milk, through placenta |
| **Artificial** | Vaccination: Live attenuated, killed pathegens; purified antigen vaccine | Inocculation of immune serum, immune cells from other individual or other organisms. |

**(i) Active Immunity:**

It is a consequence of individuals' own immune response. If it is due to natural infection, it is called Natural Active Immunity. In case of artificially inoculating individual with vaccine, it is termed as Artifial Active Immunity or Vaccination.

**Vaccine:**

A vaccine is either a pathogen (live attenuated, or killed) or its product that is introduced in our body to induce a state of immunity for protection against natural infection with the same pathogen. Vaccines are of following four types:

i) Live Attenuated Vaccines,
ii) Inactivated Vaccines,
iii) Toxoid Vaccines, and
iv) Sub-unit, Recombinants, polysaccharide and Conjugate Vaccines.

**(ii) Passive Immunity:**

In this kind of immunity, antibodies or immune cells produced by one individual (donor) are transferred to another individual (recepient) to develop immunity. For example, a pregnant woman passes her antibodies to her foetus through placenta. Similarly, an infant receives antibodies of his/her mother through breast feeding. This kind of passive immunity is termed as Natural Passive Immunity. There could be another case of passive immunity in which immune cells or immune serum from an immune person are transferred to non-infected person. This is termed as Artificial Passive Immunity.

### 13.3.2 Cell mediated immunity and antibody mediated immune responses:

The third line of defense is based upon our specific W.B.Cs. known as Lymphocytes. They are of two types, i.e., T cells and B cells, respectively. Although both are morphologically indistinguishable from each other, yet they differ a lot biochemically and functionally.

B cells mature in bone marrow and then are released into the blood circulation while the T cells are released in immature-form from the bone marrow, from where they migrate to thymus and become mature. After maturation they are released into the blood circulation. Since they mature in thymus, they are termed as T cells. B cells were named as they were discovered in a glandular sac opening called Bursa of Fabricus into the cloaca of chicken. The third line of defense or Adaptive Immune System provides us immunity in two different ways, i.e., Cell Mediated Immunity (CMI) through T cells and Antibody Mediated/Humoral Immunity through B Lymphocytes, respectively.

**(i) Cell mediated immune (CMI) response:**

It is a consequence of T-Lymhocytes which do not secrete antibodies. The CMI is particularly important against viruses, parasites that hide within the host cells, tumors cells and fungi.

### (ii) Antibody mediated immune response (Humoral Immunity):

It takes place due to the activity of another group of lymphocytes, the B-Cells. It was once called "humoral" because the antibodies are secreted in the blood stream or humours.

In order to learn about CMI & Antibody mediate Immunity, we will some structural, biochemical and functional details about lymphocytes.

**Lymphocytes:**

The lymphocytes are very important group of W.B.Cs which originate from lymphoid stem cell series. They constitute 20-40% of the circulating W.B.Cs and play crucial role in adaptive immune system. They are found in blood as well as tissues. There are two types of lymphocytes, T Cells and B Cells. Both are antigen-specific and have special receptors called T Cell Receptors (TCR) and B Cell Receptors (BCR) on their plasma membranes, respectively. Their average life span is about a week to few months but a few may live for years. The long-lived lymphocytes are actually those which confer immunological memory for particular infectious pathogens.

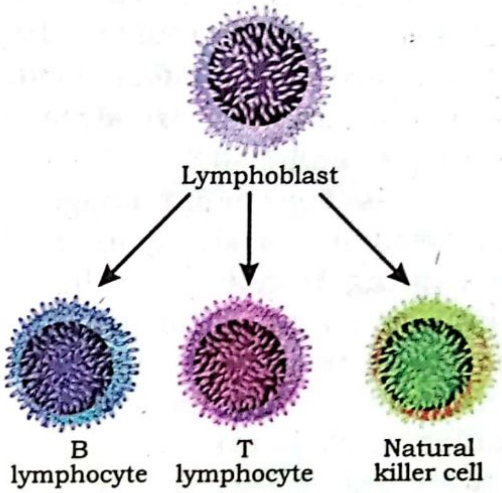



**Fig: 13.12 Origin of different types of Lymphocytes from Lymphoblast (stem cell)**

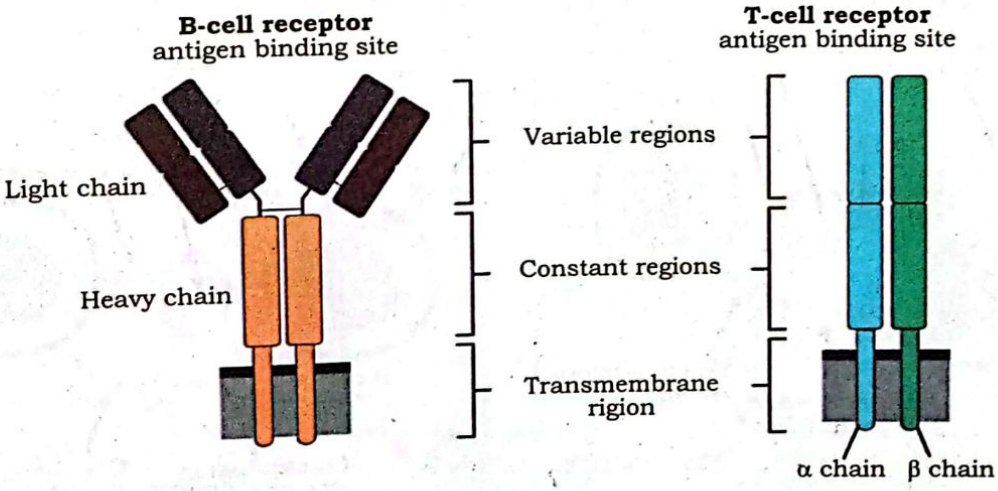



**Fig: 13.13 Structure of B-Cells Receptor and T-Cells Receptor**

**T-Lymphocytes:**

They are formed in bone marrow and then migrate to thymus to attain maturity. For this reason, they were named as T cells (T stands for thymus). A naïve T cells (inactive), in order to become an effector T Cell,

requires interaction with antigen presenting cell. They require essentially three signals; i.e., TCR, BCR and cytokines. According to the function and cell surface markers, T cells differentiate into four main types, i.e., T helper cells, T cytotoxic cells, T memory cells and T suppressor or regulatory cells.

**T cytotoxic cell ($T_c$):**

The T cells having CD8 markers (co-receptor) are termed as $T_c$. They are programmed to kill the target cells (apoptosis) that bears specific antigens. For this reason, they are termed as **Cytotoxic cells**. Their specific targets are virally infected cells, bacteria and tumor cells. The details of their activation and role are already discussed.

**T helper cell ($T_H$):**

As the name suggests, these cells upon activation by APCs, are involved in signaling by releasing various cytokines and thus ultimately activating B cells, $T_c$ cells and other macrophages to destroy the specific antigen carrying pathogen. They play very important role our adaptive immune response. The $T_H$ cells bear CD4 type (co-receptor) cell surface markers on their plasma membranes. Upon activation of T cells, it further differentiates into its sub-types which release different cytokines like Interleukins, INF, etc. for activation signals to other WBCs.

**T suppressor or regulatory cell (Ts):**

The Ts cells play vital role to suppress the activity of the activated Tc, $T_H$ cells and B cells after they get rid of the specific antigen bearing pathogen, otherwise they may harm their own normal cells of the body. Ts cells have CD4, CD and TCR receptors on their surface.

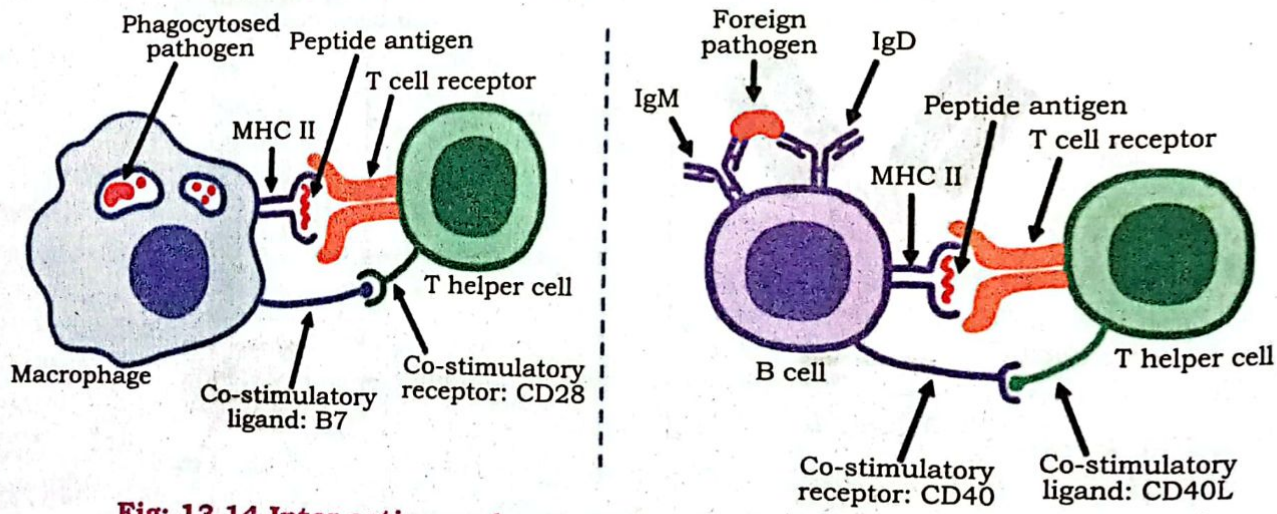



**Fig: 13.14 Inter action and activation of TH cell with B-Cell and antigen presenting cell (macrophage)**

**T memory cell ($T_M$):**

A group of T cells that are antigen specific and capable to survive for years even after the elimination of infectious organism. As soon as they are re-exposed to the same antigen bearing organism, the T memory cells

rapidly proliferate and become effector T cells. In this way, they play extremely important role in controlling the reinfection. The process of vaccination is greatly benefitted by the presence of $T_M$ cells.

**B Lymphocytes:**

These are formed and mature in the bone marrow. They confer upon us the most important aspect, the antibodies for our specific immunity. B Cells activation into effector cells called Plasma cell occurs either T-dependent mechanism or through T-Independent mechanisms. The former occurs when an activated $T_H$ cell displays peptide antigen along with its MHC-II. Thus activated $T_H$ cell releases the alert signals to naïve B-cell which then grows in size and starts producing and releasing antibodies actively. Such antibody secreting B-cells are termed as **Plasma cells**. Some of the B-cells meanwhile turn into **B Memory cells** or ($B_M$). The latter, records all the data of the antigen for controlling future reinfection. They do play very important role as far as the immunization is concerned.

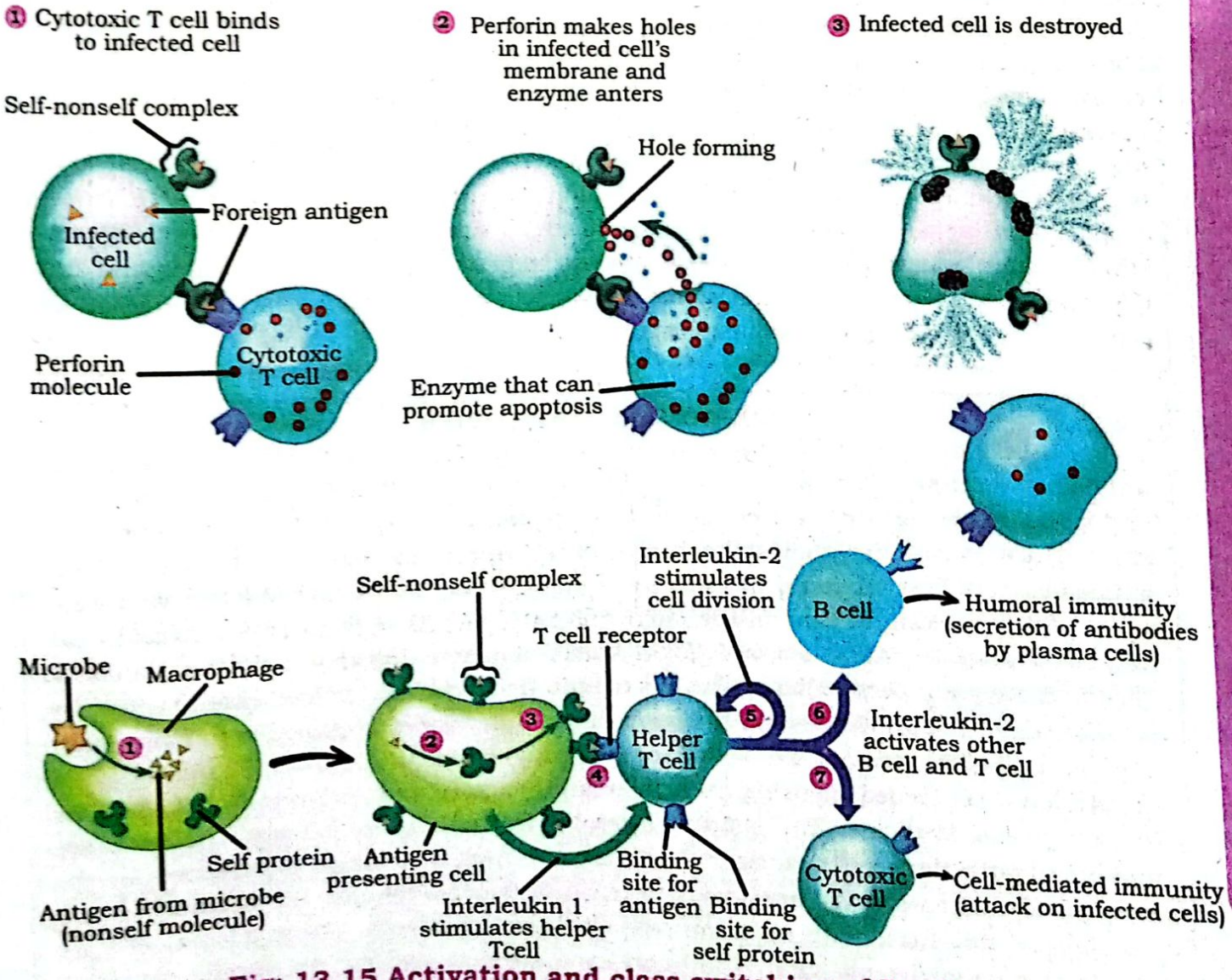
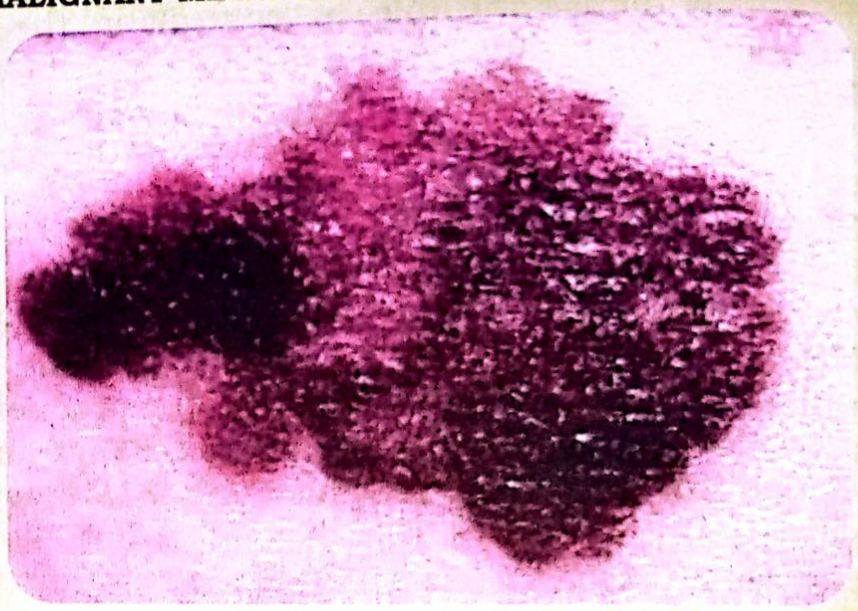



**Fig: 13.15 Activation and class switching of B-cell**

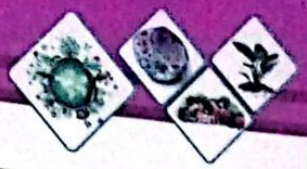
## MALIGNANT MELANOMA



Malignant melanoma is a type of skin cancer of the melanin producing skin cells, the melanocytes. It is one of the most dangerous form of skin cancer. The usual cause for the development of melanoma is exposure to Ultra Violet radiation. However, genetic causes are also reported. In the early stage of melanoma development, the melanocytes show abnormally high, uncontrolled growth rate so spread radially in basal epidermis. Then it starts moving upward in epidermis and this stage is the beginning of invasive stage when the cancerous cells may spread through body fluids to different parts of the body. At this stage, the Tumor Infiltrating Lymphocytes (TILs)recognize the abnormal behavior of the tissue and initiate immune response. TILs comprised of both T and B Lymphocytes along with NK cells, macrophages, dendritic cells, mast cells, basophils, eosinophils and neutrophils. The main proportion of TILs consists of $T_C$. In case of malignant melanoma TILs response is not strong enough to eliminate the cancerous cells. In such malignant melanoma micro-environment, number of molecules and cells have been shown to suppress immune response through cell interaction and/or the production of immune suppressing molecules.

## MONOCLONAL ANTIBODIES

Antibodies derived from the clone of a single W.B.C. are termed as monoclonal antibodies or mAb. They bind only to the same epitope of the antigen. Monoclonal antibodies are being used to treat some types of cancer. They can be used alone or to carry drugs, toxins, or radioactive substances directly to cancer cells. Monoclonal antibodies were first produced in 1975 by Georges Köhler and César Milstein who were successful in making fusions of myeloma cell lines with B cells to create hybridomas that could produce antibodies, specific to known antigens and that were immortalized. They and Niels Kaj Jerne shared the Nobel Prize in Physiology or Medicine in 1984 for the discovery. George Winter and his team in 1928 developed techniques to make non-human antibodies compatible with human body. In 2018, James P. Allison and TasukoHonjo succeeded in using mAb in treating cancer and awarded Nobel Prize for Physiology and Medicine. The simplest protocol for mAb is as follows: The mice are immunized with the desired antigen and after few days their blood is screened for the presence of antigen-specific antibodies. In case of positive results, the splenocytes are isolated and then fused with myeloma cells to make hybridoma. The myeloma cells are capable of unlimited replication. The hybridoma are screened for the specific-type and



class of antibodies they produce. The desired antibody producing clones are selected for further propagation. Thus the mAb are produced from cell culture techniques. In addition to the treatment of cancer, mAb are not only used for diagnosis of different diseases (e.g. hepatitis, etc) as they can identify particular antigens but also for therapeutic purposes as they can block the targeted substances inducing apoptosis of the target cells. They can also be used to prevent autoimmune diseases such as rheumatoid arthritis.

### 13.3.3 Disorders Of Immune System:

**Allergies:**

Sometimes, our immune system responds to certain normally harmless substances (e.g. pollens, molds, pet dander, certain drugs, some food, etc., called allergins. Such response is termed as allergy. It is considered to be an exagerrated response of the immune system against the normal substantces taken by the WBCs as antigens. The common allergies of man are rhinitis, asthma, eczema, dermatitis, hives, anaphylaxis, food allergies, etc.

When allergins enter our body, a type of allergin specific antibody, IgE is produced by the plasma cells. These antibodies upon secretion into the blood bind to the allergin and then to the receptor on the mast cells or basophils. Being granulocytes, mast cells and basophils upon activation through IgE-allergin complex, release histimine to produce inflammatory response causing symptoms like itching, rashes, runny nose, sore throat, sneezing, cough, etc. The treatment of allergies usually employs anti-histamine and steroids.

**Autoimmune Diseases:**

It is the abnormalilty of the immune system in which immune system fails to recognize one or more own tissues as "self". As a result, it initiates immune response agaisnt its own cells. Diabetes mellitus type-I, rheumatiod arthritis, psoriasis, etc are some of the examples of autoimmune diseases in human. In such cases, misdirected self-antibodies are produced which destroy own tissue.

Autoimmune diseases can develop from a variety of factors with no known definitive cause for the onset of the disease. Some suspected sources are some bacterial or viral infections, effects from certain drugs, toxins and pollutants. In human, some of the common affected tissues are muscle, joints, blood vessels and connective tissues.

The common symptoms are malaise (sick feeling), low fever, fatigue, muscle ache and rashes on different areas of the body.

**Justify why physicians prescribe antihistamine therapy to the patients of runny nose or skin rashes.**

As you have already learnt that during the allergic reaction, mast cells and basophils release histamine to induce inflammation. In order to reduce inflammatory response,

antihistamine drugs are used to block the histamine receptors of mast cells, muscles, endothelial cells, etc. and ultimately the allergy is controlled. Itching, sneezing, runny nose, skin rashes are thus reduced in this way.

**Transplant rejections:**

Whenever some of the body organ either loses its function or lost due to some accident or incident, it is desired to replace it from corresponding healthy organ from a donor. Commonly transplanted organs are liver, kidney, skin and heart. However, trasnplanted organ is always subject to some degree of rejection because of fact that genetically donor and recepient are not identical. Thus the transplanted organ is subject to the attack of immune cells of the recepient, the response is termed as transplant rejection. It has been observed that different types of transplanted tissues encounter different rejection mechanisms of the host's immune system. It could be the consequence of CMI or humoral immunity.

**Role of T-cells in transplant rejection:**

In this case of transplant of solid organs from individual of the same species or allograft, the major threats are the T cells of the recepient. Initially, the dendritic cells of the donor tissue migrate into the recepient lymphoid tissue where they are recognized bythe recepient's $T_H$ cells through APCs. Once activated, $T_H$ cells, proliferate and activate NK cells and $T_C$ to attack the grafted tissue.

**Role of B-cells in transplant rejection:**

The activated $T_H$ cells signal the B-cells to transform into specific antibody secreting Plasma Cells. The antibodies thus produced play very important role in destroying the grafted tissue.

**Skills: Initiating and Planning**

***Explain why a transplant recipient is give immune suppressant drugs and determine what implications do this have on his life.***

People having organ transplant are given immune suppressant drugs because of the threat of organ rejection by the immune cells of the recipient. These drugs suppress or inhibit the activity of the immune system. Different types of immune-suppressants are used for this purpose decided by the physician. There are no doubt, side effects of such drugs such as fatigue, headache, nausea, vomiting, acne, diabetes, hypertension, hair loss, mouth sore, sepsis, osteoporosis, etc.

## SUMMARY

- Immune system is the defence system of an organs consists of cells and proteins.
- Study of functioning and disorders of immune system is termed as immunology.
- The non-specific type of immune system against any pathogen which tries to enter in the body called innate-immune system.
- Adaption immune system is the specific types of immune system develop against specific foreign body called antigen.
- Innate immune system is consist of 1st line of defence and 2nd line of defence
- 1st line of defence is consist of skin, mucous membrane, ciliated epithelium, saliva, tears, mucous, gastric juice etc.
- 2nd line of defence consist of phagocytes (neutrophils monocytes), dendritic cells, cytoxic T cell, natural kill cells (N.K.C) perforin protein and granzyme.
- 3rd line of defence consist of lymphocyte T and B antibodies proteins.
- Active immunity is the consequence of individuals own immune response.
- Passive immunity is the kind of immunity. Where antibodies on immune cells produced by one individual are transferred to another individual to develop immunity.
- Allergies, auto immune diseases, transplant rejections are the disorder of immune system.

## EXERCISE

**1. Encircle the correct choice**

(i) The study of functioning and disorders of immune system is termed as:

(a) Immunity (b) Immune response
(c) Immunology (d) all of these

(ii) It is responsible for specific immune response:

(a) Innate Immune system (b) First line of defense
(c) Second line of defense (d) Third line of defense

(iii) Following serves as physical barrier:

(a) Macrophage (b) Mucous membrane
(c) HCl (d) Saliva

(iv) Our digestive tract consists of what kind of barriers?

(a) Physical barriers (b) Biochemical barriers
(c) Both a & b (d) None of these

(v) Which of the following is involved in phagocytosis of bacteria?
(a) Neutrophil (b) Macrophage
(c) Both a & b (d) None of these

(vi) It is not involved in antigen presentation:
(a) Macrophage (b) Dendritic cell
(c) Neutrophil (d) Both a & b

(vii) The type of receptor exhibited by all nucleated cells other than macrophages is:
(a) MHC-I (b) MHC-II (c) Both a & b (d) TCR

(viii) Any foreign substance that can elicit immune response is called:
(a) Antibody (b) Antigen
(c) Both a & c (d) Antihistamine

(ix) The type of immunity through the transfer of antibodies from mother to her fetus is:
(a) Natural Active Immunity (b) Natural Passive Immunity
(c) Artificial Active Immunity (d) Artificial Passive Immunity

(x) Antibodies are secreted by:
(a) T cells (b) B cells
(c) Plasma cells (d) Macrophages

**2. Write short answers of the following questions:**

1. List out any six biochemical barriers.
2. How the tumor cells are dealt with by our immune system?
3. Differentiate between NK Cell and $T_C$ cell.
4. List out the ways of second line of defense.
5. Even though the core proteins are the same, how antibodies differ from each other?
6. What is antipyretic therapy and why it is used?
7. List out four autoimmune disorders of man.
8. What is phagocytosis? Name some WBCs acting as phagocytes.
9. What is inflammation?
10. Outline the harmful effects of fever.

**3. Write detailed answers of the following questions:**

1. State and explain how a bacterium is identified as non-self by our immune system.
2. What is cytotoxicity? Compare and contrast the mechanisms of NK cell and $T_C$ cell.
3. What is inflammation? Why it is developed and how it is controlled?
4. Explain the underlying mechanism of the fever. State and explain its protective role as well as harmful effects.
5. Discuss the structural features of antibody? How it is helpful in getting rid of pathogenic organisms.
6. What do you understand by autoimmune disorder? Explain the role of T cells and B cells in transplant rejection.

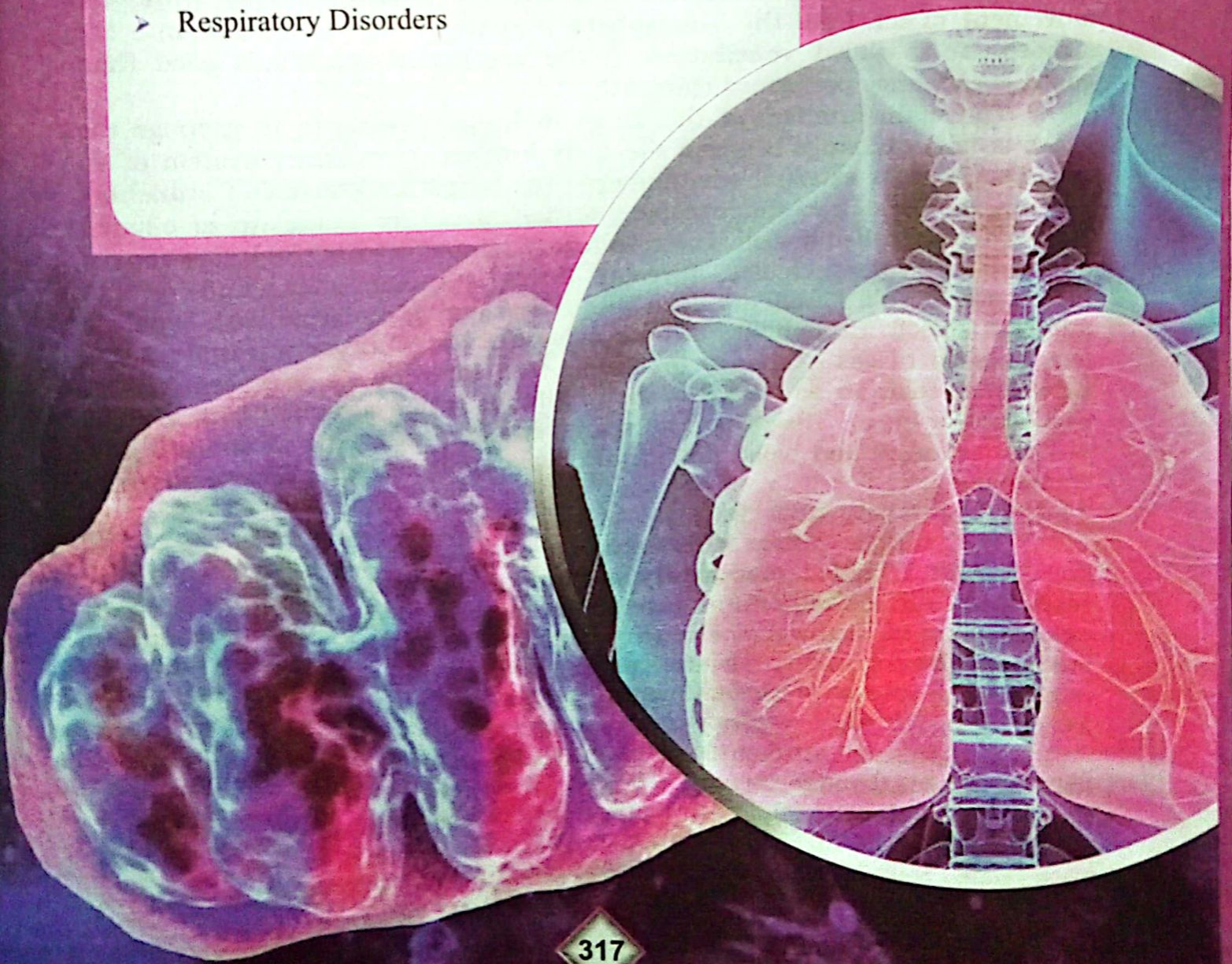
# GASEOUS EXCHANGE

Chapter 14

## Major Concept

**In this Unit you will learn:**

- Respiration and Respiratory System of Man
- Mechanism of Transport of Gases
- Respiratory Disorders



## 14.1 RESPIRATION

**Respiration** is a very important process in which the cell or cells of an organism (s) gain energy (ATP) rich molecules by oxidizing food molecules. In human being the food molecule is chiefly used for this purpose. During aerobic respiration glucose in our cells oxidized with the help of oxygen, the energy is released along with by-products carbon dioxide and water. Therefore, the many of cells in an organism body require abundant amount and continuous supply of oxygen ($O_2$) to perform the bodily functions. We can't live without oxygen for more than a few minutes.

### 14.1.1 Ventilation and Gaseous exchange

As you already learnt that we provide glucose to our cell through nutrition process. However, in order to supply oxygen to our cells, we have to bring air in to our lungs through the air passage ways. Thus, the movement of air from the atmosphere into the lungs and back into the atmosphere is called **ventilation**. If the ventilation quality is good than gaseous exchange performed efficiently.

The main function of the lungs in human being is to manage the gaseous (air) exchange between the body internal circulatory system of an organism and its external environment. The lungs are consist of branching airways that end into microscopic sac like structure made up of ciliated epithelial cells called alveoli. The respiratory related area of the lungs consist on respiratory bronchioles, alveolar ducts, alveolar sacs, and a thin membrane alveoli. Alveoli are lined with a thin film of moisture with separate adjacent alveoli. Bronchioles of both sides and large airways transvers gas (air) to sites of gas exchange in alveoli. The interchange of gases (air) in between alveolar air and blood of the capillaries which attached with alveoli, occur in the lungs. The alveoli must be ventilated (the flow of air into and out of the lungs) and blood flow in alveolar capillaries for effective gaseous exchange.

### 14.1.2 Respiratory surface:

The surface where the exchange of gases take place with its environment is called **respiratory surface**. Each organism must need a respiratory surface to perform gaseous exchange with its environment. For example skin in earthworm, alveolar membrane etc. Our respiratory surface is alveoli. The respiratory surface should be moist, thin, permeable and large in relation to volume of the organism.

### 14.1.3 Characters of respiratory surface:

**Moist:** Respiratory surface (alveoli) must be moist which allow to pass dissolved gases through them.

**Permeable:** The permeability of respiratory surface should be permeable to gases ($O_2$, $CO_2$etc).

**Thin**: Being thin the respiratory surface reduce the diffusion distance.

**Large surface area:** The respiratory surface must be large in size in accordance to the body size of an organism. In our lungs we have millions of alveoli whose collective surface area is several folds larger in relation to our total volume.

In case of higher animal like human, the respiratory surface is facilitated by following:

**Significant blood supply:** The another character of respiratory surface is to initiating highly concentrated oxygenated blood is taken away from the lungs and carbon dioxide rich blood is taken to the lungs.

**A large diffusion gradient:** For the purpose of continuous breathing, oxygen concentration in the alveoli is higher than in the capillaries, so oxygen moves from the alveoli to the blood. Carbon dioxide diffuses in the opposite direction (Fig:14.1).

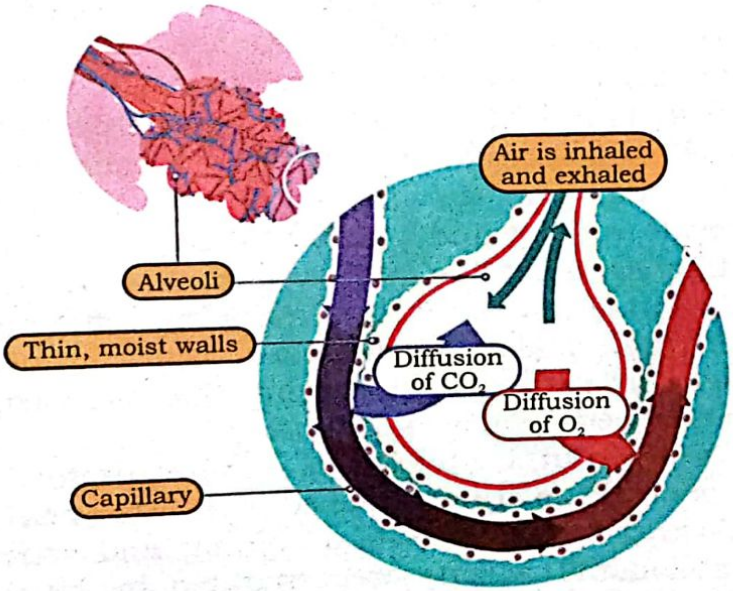



**Fig: 14.1 Respiratory surface: An alveolus**

### 14.1.4 Main Components of Human respiratory system

The human respiratory system consists of a complex set of organs and tissues. This system carries air from the environment to the lungs and vice versa. The human lungs are the paired, soft, spongy and highly vascularized organ in structure, located inside thorax (chest). Lungs are the primary organ of the respiratory system. However, the external nostril **(nose)**, **pharynx**, **larynx**, and **trachea** are the other respiratory accessory organs.

The human respiratory system is anatomically differentiated into upper and lower respiratory air passages. The upper airways are consist of nose, nasal cavity, and Pharynx while the lower air passage are the larynx, bronchial branches and the pair of lungs. The respiratory system

starts from the nose. During respiration, air enters into the nose through the paired opening called **external nostrils** or nares. The nose is the only external part of our respiratory system. Interiorly nose consists of the nasal cavity, a bony partition that separates the nasal cavity into nasal chambers by a midline cartilaginous **nasal septum**. The hairs of nasal cavity and its ciliated cells trap the dust particle and decontaminate the gas (air).The nasal chambers run forward through internal nares into a tube like cavity at behind of the mouth. This cavity is called **pharynx**. The muscular tube pharynx is long about 13 cm, which serves as a common pathway for both the respiratory and digestive system. The external air enters from the nasal cavity to the pharynx. Then air move from pharynx to the upper portion, **nasopharynx** and **larynx** from **laryngopharynx**. Normally air enters the pharynx through the nose, but it may also enter by the mouth if the nasal sections are blocked. **Larynx** or **voice box**, is the component of lower respiratory track located at the entrance of the trachea. The flap like pairs of tissues called **vocal cords,** present in the larynx, which produce sounds when air expelled from it. From the pharynx, air enter into the **trachea** or windpipe. Trachea is the main airway to the lungs, it is a fibro-cartilaginous tube about 10-11 cm long. Trachea has about 16 to 20 "C" shaped cartilaginous ring, provide rigidity and prevent trachea collapsing. Before entering into lungs, trachea bifurcate into two bronchi. A singular right bronchus is broader, shorter and straighter than the left one bronchus. Each bronchi branches into smaller **bronchioles.** These bronchioles form the bronchial tree which terminates at the **alveoli**, the microscopic air sacs where gases are exchanged between air and blood.

The 12 pairs of ribs form the rib cage. It provides protection to lungs and heart. The wall of thoracic cavity is attached with **inter-costal muscles** which are associated with rib cage, vertebral column and sternum (chest bone). Thoracic and abdominal regions are separated by muscular sheet called **diaphragm**. The pleural membrane in thoracic region called **visceral pleura** wraps around each lung and separates from the thoracic wall. The other membrane is **parietal pleura,** lies the inside of the chest wall. The small space between the visceral and parietal pleurae is the **pleural cavity,** filled with serous fluid which serves as a lubricant to the **lungs** and allows optimal expansion and contraction during breathing mechanism.

### 14.1.5 Lungs

Lungs are the main respiratory organs. The left and right lungs are somewhat dissimilar in structure. The left lung is smaller than the right lung, because left lung is slightly displaced by the heart which occupies more space on the left side in thorax. Each lung consist on smaller units, called **lobes.** Three lobes are in right lung, called **superior, middle,** and

**inferior lobes**. Two lobes are found in left lung **called, superior** and **inferior lobes**. Each lobe is supplied by the secondary bronchi.

**(i) Right lung**

The three main lobes of right lung (fig: 14.2).

1.Superior lobe
2. Middle lobe
3. Inferior lobe

**(ii) Left lung**

The two main lobes of left lung (fig: 14.2).

1.Superior lobe
2. Inferior lobe

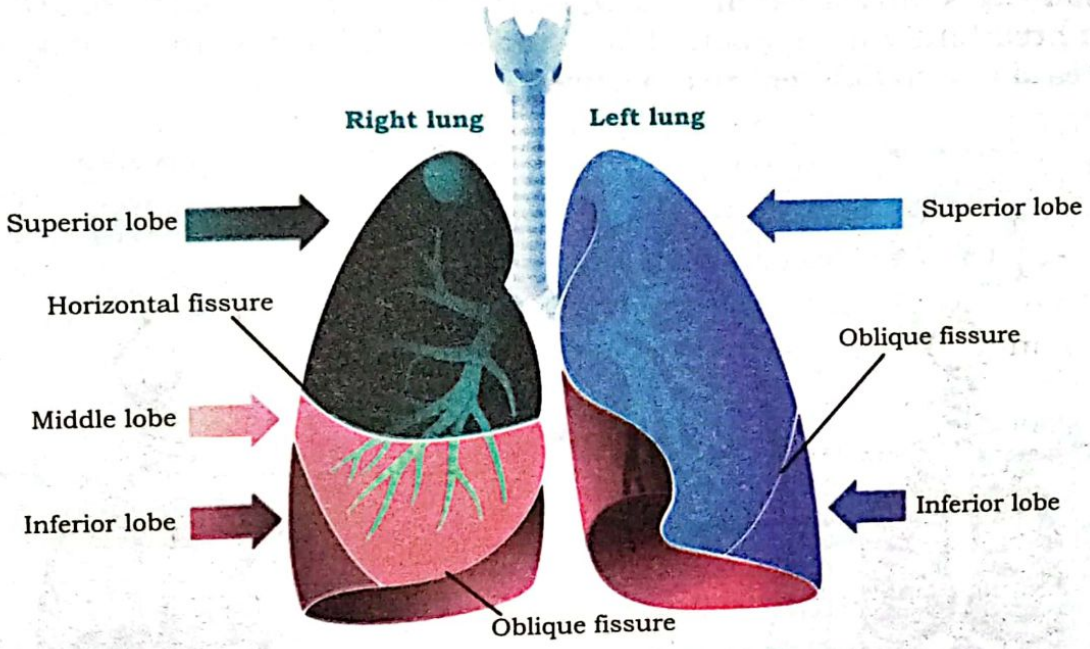



**Fig: 14.2 Different lobes in both lungs**

### 14.1.6.3 The major Functions of the respiratory system:

The respiratory system performs the following major functions:

**Oxygen supplier:**
It provides a continuous supply of oxygen to all tissues.

**Withdrawal:**
Removal of by-product, carbon dioxide ($CO_2$).

**Conversation of Gas:**
The mechanism of gas exchange between the internal and external environment of the body is regulate through respiratory surfaces.

**Humidifier:**
The respiratory system performs as a humidifier. It has the capability to humidify and keep the air warm which inhale from the external environment.

### 14.1.7 Ventilation (Breathing)

**Ventilation** is the process in which air (gases) goes in and out of the lungs. During this process, various respiratory organs are involved. This process goes on continuously throughout the life of an organism. The mechanism of movement of air from outside to deep inside and vice versa.

Ventilation (breathing) consist of two phases:

1. **Inhalation:** The taking in air from the atmosphere up to the alveoli.
2. **Exhalation:** Giving out of air from alveoli to the atmosphere.

Alive person breathes continuously. One breathing cycle comprises one complete inhalation and exhalation. The person breathes how much in every minute it's called breathing rate. Breathing rate varies upon a person's activity. It rises during running, walking or after a heavy exercise. The adult normal breathing rate is about 12-20 times per minutes and it may exceed or decrease due to different perspectives.

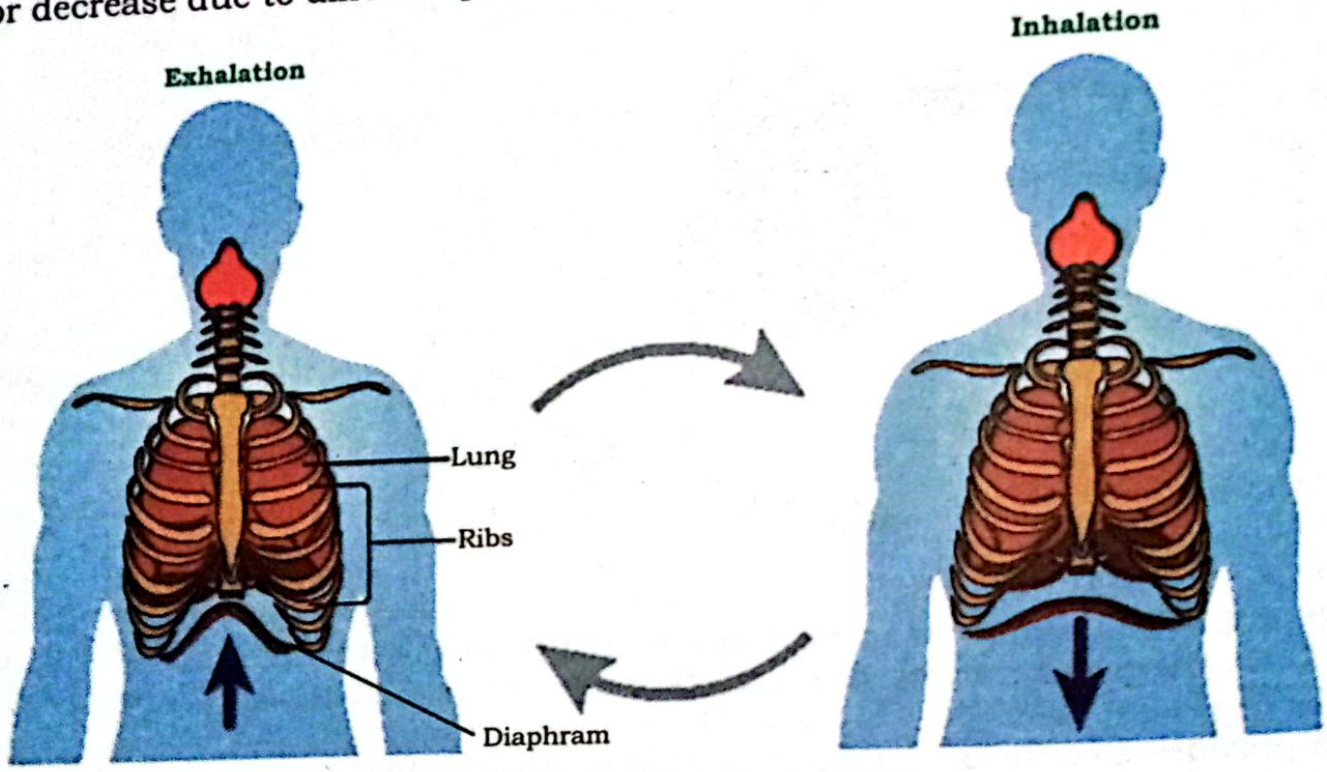



**Fig: 14.3 inhalation and exhalation**

#### 14.1.7.1Mechanism of ventilation (Breathing)

The pressure of lungs change when we breathe in and out. So essentially in the **inspiration**, there is a fall in gaseous tension of the alveolar sac which falls when the air launches into the lungs. In **expiration**, the pressure of alveoli is exceed than atmospheric pressure, the air is goes out from the lungs. This type of breathing mechanism is called **negative pressure breathing** (which is the decrease pressure in the region of thoracic cavity in relation to external atmospheric pressure).

### 14.1.7.2Inspiration (Inhalation)

Basically, the inspiration is the active process (energy consuming mechanism). During this process, the thoracic cavity is increased in its size (volume) due to the contraction of **external inter–costal muscles**, diaphragm and relaxation of **internal inter-costal muscles**. Contraction of external inter–costal muscles moves the ribs outward and as well as sternum also progressively move in upward direction while shrinkage of the diaphragm makes it levelled. Subsequently, the capacity is increased in thoracic cavity, so negative pressure is developed inside the thoracic and eventually in the lungs. The expansion of the lungs decreases the air pressure inside the lungs. So ultimately air rushes into the lungs up to the alveolar sac through the respiratory passage where gaseous exchange take place (Fig. 14.3).

### 14.1.7.3Expiration(Exhalation)

It is the passive phase of respiration. In this process gaseous exchange completed in the lungs and air is thrown out which is just reversed of inspiration. Expiration takes place due to the decreased volume of the thoracic cavity. It is due to the relaxation of external inter-costal and the contraction of internal inter-costal muscles, which move ribs and sternum inward and downward respectively. Comparably, diaphragm also relaxes which makes it dome shaped, thus the volume of the thoracic cavity is reduced. As an outcome, lungs are pressed so the air along with water vapours is expire outside through respiratory pathway (Fig. 14.4).

### 14.1.7.4 Lung volume and capacity

Respiratory volumes are also known as lung volumes. In Human adult, lung capacity is six liters of air. Measurement of lung volume is an essential part to observe pulmonary function. These volumes vary due to some factors: race, gender, age, body composition and respiratory diseases etc. Lung volume measures by a special instrument, **spirometry**. The lung capacities of human can be describe by the following manner.

**Total lung volume** of air is about 5000 milliliters (6 liter), which generally enters in the lungs during breathing. In normal breathing, human takes in and gives out air approximately 450 to 500 milliliters. This volume is called **Tidal volume**. On other hand, **vital volume** is the maximum air inspired and expired during deep breath. This volume is regarding 5000 milliliters (ml). **Expiratory reserve volume** is the valuable quantity of air which energetically respire up to 1200-1500 milliliters. **Inspiratory reserve volume** is the extra air volume which is 2000 milliliters. **Residual volume** that remains in the lungs is about 1000 milliliters and cannot allow the thorax to collapse. The amount of residual volume can be changed due to

the age and diseases. All these respiratory volumes can be describe according to the person's respiratory strength. (Fig: 14.4)

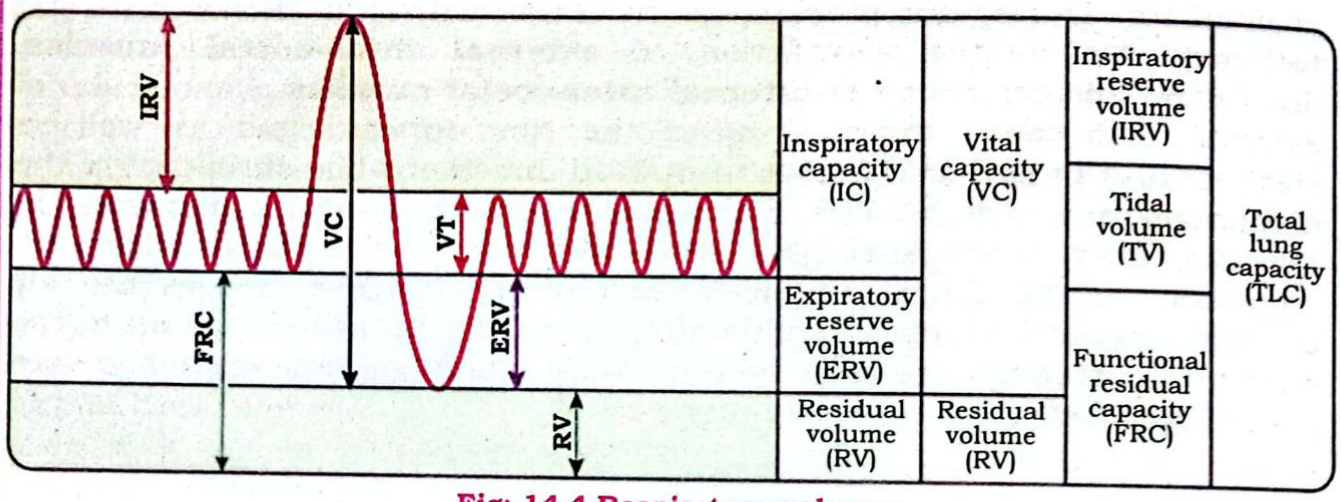



**Fig: 14.4 Respiratory volumes**

### 14.1.7.5Controlling mechanism of Breathing

Our breathing process can control for a very minimal duration or we can respire slower, faster and deeper at our will. This phase is called **voluntary control**. But generally our normal breathing is controlled automatically. This phase of breathing control is called **involuntary control**. The automatic breathing is maintained by the mutual association of respiratory and cardiovascular systems. It is observed that high concentration of carbon dioxide ($CO_2$) and $H^+$ in blood are stimuli to increase the rate of breathing. The accumulation of carbon dioxide ($CO_2$) and $H^+$ are monitored by specific chemoreceptors called **aortic** and **carotid bodies**. These bodies are found in aorta and carotid arteries, respectively. The lower part of brain medulla oblongata is responsible to detect any change in carbon dioxide and $H^+$ concentration in cerebro-spinal fluid. So this impulse (messages) sent to inter-costal muscles and diaphragm to increase the breathing rate, accordingly.

## 14.2 TRANSPORTATION OF GASES IN HUMAN

The exchange of Gases is the one of the vital process of respiration. Transportation of gases in all living creatures is a well-organized process. Oxygen ($O_2$) and carbon dioxide ($CO_2$) are the sources that transported in the human body by blood circulation and exchanged in the alveolar membrane by simple diffusion.

### 14.2.1 Transport of Oxygen

The inhaled air into lungs air passage has high concentration of oxygen which produces the concentration difference across the respiratory surfaces. So oxygen rushes into blood capillaries around the alveoli. Now the blood is oxygenated and converted into bright red colour. This oxygenated

blood is then transported to body cells. Around 97 percent oxygen is disperse by red blood cells and the remaining 3 percent oxygen gets dissolved and transported through blood plasma. Oxygen ($O_2$) molecules attached to haemoglobin molecules of RBCs and form compound, oxyhaemoglobin. Oxyhaemoglobin delivers oxygen molecule to all body cells for cellular respiration. At the level of cells, oxygen molecules detached from haemoglobin and diffuse into the cells. The diffused oxygen breaks down the glucose molecules to release $CO_2$, water and energy. The body utilizes the energy while tissues diffuse the carbon dioxide.

$$\underset{\text{Haemoglobin}}{Hb} + \underset{\text{Tissues}}{4O_2} \overset{\text{Lungs}}{\rightleftharpoons} \underset{\text{Oxyhaemoglobin}}{Hb\,(O_2)_4}$$

### 14.2.2 Transport of Carbon dioxide

Due to the high concentration of $CO_2$ is diffuses out from the tissues into the blood as a by-product. Now blood is deoxygenated and collected from all part of the body cells and returned to the lungs. The color of deoxygenated blood is dark maroon. There are three ways to transport carbon dioxide into bloodstream:

1. As bicarbonate
2. As carbaminohemoglobin (bound to hemoglobin or other proteins),
3. As dissolved gas.

About 70% of carbon dioxide is transported by RBCs water in the presence of **carbonic anhydrase** enzyme. This enzyme reacts with carbon dioxide and form carbonic acid ($H_2CO_3$). Later, carbonic acid dissociates into hydrogen ($H^+$) and bicarbonate ($HCO3^-$) ions. Bicarbonate ions combine with sodium and potassium ions to form sodium bicarbonate and potassium bicarbonate respectively.

$$CO_2 + H_2O \xrightarrow{\text{Carbonic anhydrase}} H_2CO_3 \rightarrow HCO^-_3 + H^+$$
$$HCO_3^- + K^+ \rightleftharpoons KHCO_3$$
$$HCO_3^- + Na^+ \rightleftharpoons NaHCO_3$$

Approximately, 20 percent carbon dioxide combines with hemoglobin in the red blood cell to form carbaminohemoglobin. This compound is dissociated into $CO_2$ and Hb and $CO_2$ move into alveoli which is later brought in the lungs where its concentration is lower but partial pressure of oxygen is high in alveoli. So dissociated carbon dioxide is exhaled.

$$CO_2 + Hb \rightleftharpoons HbCO_2$$

The remaining 10% carbon dioxide dissolves in the plasma water of the blood and then transported to the lungs.

### 14.2.3 Role of respiratory pigments

A respiratory pigment is a molecule which increases the oxygen carrying capacity of blood and tissues for example haemoglobin and myoglobin. All of these are iron bounded proteins which combine readily with oxygen.

**Haemoglobin**

**Haemoglobin** (Hb) is the respiratory pigment present in RBCs of all vertebrate including human beings. Haemoglobin is the conjugated protein molecule. Two pairs of polypeptide chains are constituted Haemoglobin. Each chain bears an iron-containing heme group. Each hemoglobin molecule is able to transport four oxygen molecules. That carries oxygen from the lungs to the body's tissues by forming a loose temporary compound called oxyhaemoglobin. This temporary compound is dissociates releasing oxygen, which enters in our tissues. Haemoglobin (Hb)brings back carbon dioxide from the tissues back to the lungs (fig: 14.5)

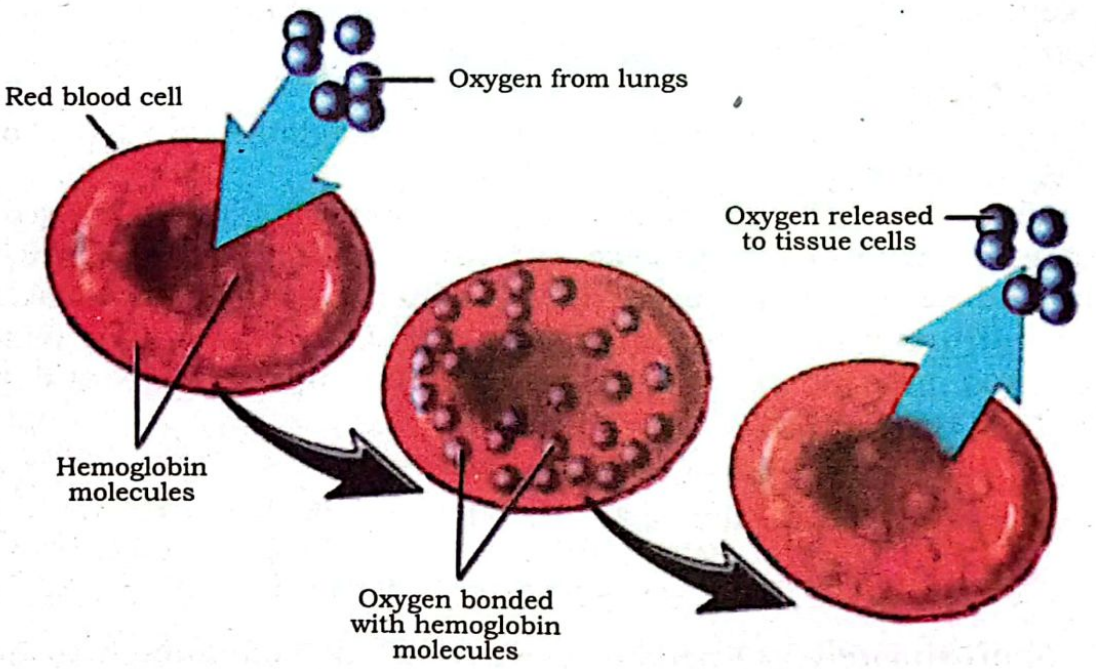



**Fig: 14.5 Formation and dissociation of oxyhaemoglobin**

### 14.2.3.2 Myoglobin

Myoglobin is a single-chain globular protein and smaller than haemoglobin. It is found in muscles and binds with oxygen more tightly than haemoglobin. It also consists of a heme group (an iron-containing organic compound). One hemebinds one molecule of $O_2$.

## 14.3 SINUSES

Sinuses are hollow air-filled cavities. These hollow cavities found in skull and linked to the nasal air passage. Human has four pairs of nasal cavities (Fig: 14.6)

1. **Frontal sinus**, in the forehead region
2. **Maxillary sinus**, in the behind cheeks
3. **Ethmoid sinus**, between the eyes
4. **Sphenoid sinus**, located in deep behind the ethmoids

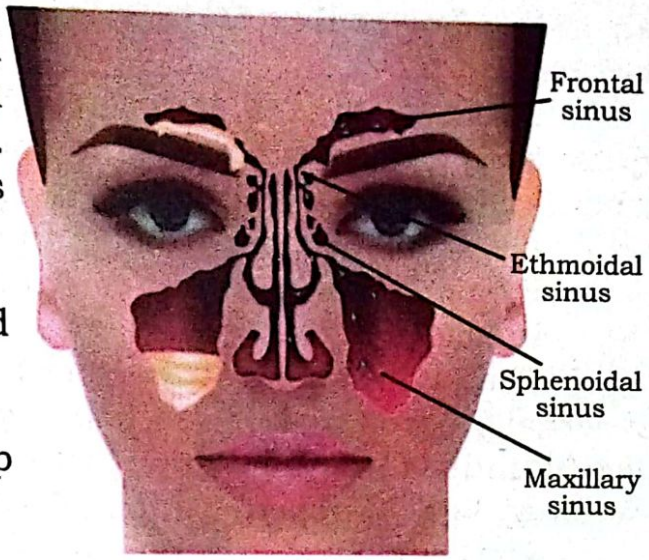



**Fig: 14.6 Nasal cavities**

## 14.3 RESPIRATORY DISORDERS

The respiratory disorder are broadly categorized into two groups on the basis of location of respiratory tract.

### 14.4.1 Upper Respiratory Tract Infections

#### (i) Sinusitis

Sinusitis is the inflammation of sinuses, which are filled with air normally, but in the sinusitis condition these sinuses are filled with fluid due to this it may harbor pathogens.

Following reasons that can cause sinus blockage include:

- Common cold
- Allergic rhinitis, swelling in the lining of the nose.
- Nasal polyps, nose lining show small growths.
- Nasal septum physical deviation of nose, involving a dislocation of the nasal septum.

The main symptoms of sinusitis are:

Headache, fever, congestion (nasal stuffiness), cough, tooth pain, ear pain, eye pain and fatigue.

Use steam and saline nasal spray to wash nasal passage and consult your physician.

#### Otitis media

Otitis media is inflammation or infection in the middle ear. Cold, sore throat, or upper respiratory infection can cause this disease. This infection usually a result of a failure of the **eustachian tube**. This tube bridges the middle ear with the throat area and balance the pressure between the outer and the middle ear.

Fever, unbalancing, hearing problems, unusual irritability and ear painare the very common signs of otitis media.

The treatment of otitis media is depend on its type. Commonly antibiotic medicines by ear drops can be suggested by consultant.

### (ii) 14.4.2 Lower Respiratory Infections

**A(i) Pneumonia**

Pneumonia is a lower respiratory infection due to the number of virus, bacteria and fungi. In this infection air sacs filled with secretions and other fluid (Fig: 14.7).

- Lobar pneumonia occur in the lobes of lungs.
- Bronchial pneumonia (bronchopneumonia) patches appear on both lungs.

The symptoms of bacterial pneumonia are headache, lips and fingernails become bluish in color, fever with cough and yellowish green or bloody mucus may produce with cough, confused mental state, heavy sweating, Loss of appetite, rapid breathing and shortness of breath.

Viral and bacterial pneumonia have same symptoms in early stage which may causes shortness of breath, headache, muscle pain and weakness.

In Mycoplasma pneumonia symptoms are observed acute cough with mucus.

In most cases of bacterial pneumonia, oral antibiotics can use but antibiotic medications don't work on viruses. Patient should hot drinks. refreshments. Humidification and steamy baths also very helpful to open airways blockage and easy respiring.

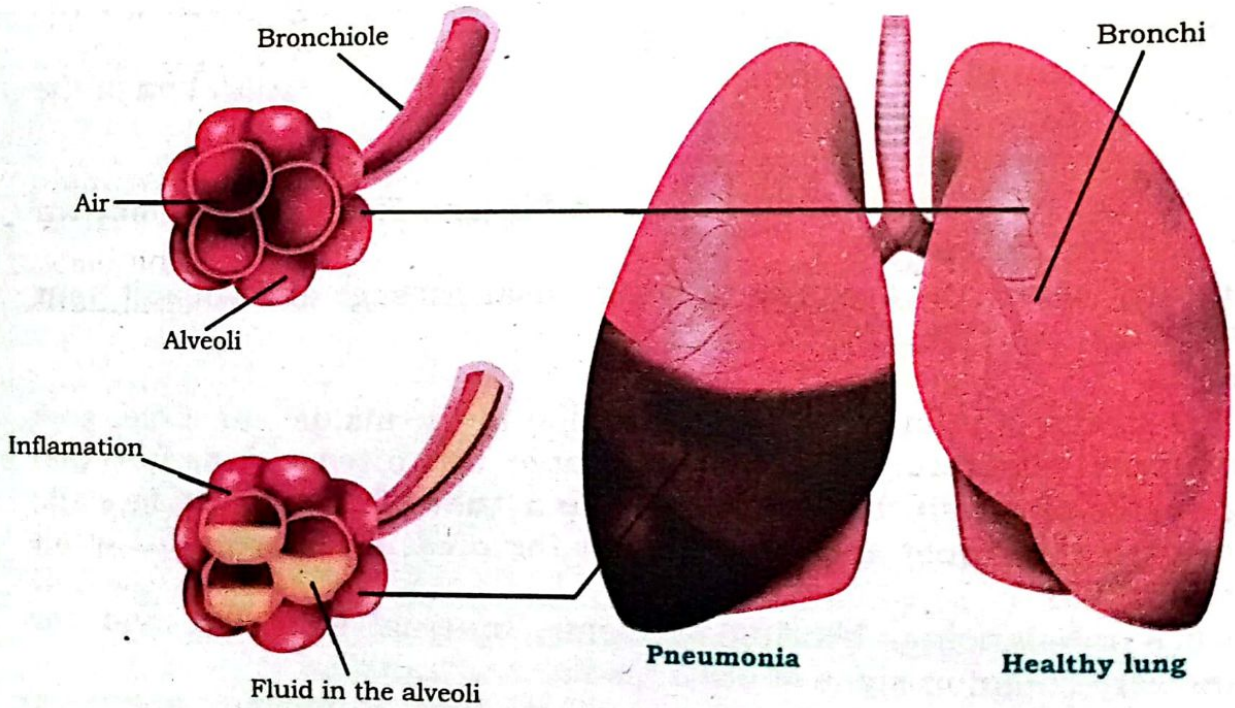



**Fig: 14.7 Pneumonia**

### (ii) Pulmonary tuberculosis

Pulmonary tuberculosis (TB) is a bacterial chronic infection of the lungs and caused by *Mycobacterium tuberculosis.* The treatment of Pulmonary TB is possible but late treatment or untreated patient may get life threatening situation.

Symptoms including coughing up mucus (phlegm), coughing up blood, low-grade fever, chest pain and weight loss.

Pulmonary TB is curable with an early diagnosis and antibiotic treatment.

### (iii) Emphysema

Emphysema is a condition of lung disease generally develops after many years of smoking. Emphysema is one of disease which belongs to group of chronic obstructive pulmonary disease (COPD).

In this condition wall of the air sacs become damaged. So, the alveoli cannot support the bronchial tubes. Due to the blockage of tubes too much air traps inside the lungs. There are fewer alveoli, less oxygen transport into bloodstream. It is irreversible condition.

Patient have no symptoms at the beginning but some specific symptoms can be observed in later stages like shortness of breath especially during physical activity, tightness in chest, frequent coughing or wheezing and mucus produces with cough. Some people with emphysema has respiratory infections such as cold and flu. In severe condition patient complains weakness in lower body muscles and weight loss.

Bronchodilators medicinal treatment recover the patient and relief from the coughing and short breathing. Antibiotics may be used for the remedy and steroid type drugs can also be inhaled like aerosol sprays which reduce swilling and may help in easy breath.

### (iv) Lung cancer

It is abnormal proliferation of affected tissues in the lungs. The main reason of lung cancer is Smoking. About 80% of **lung cancer** caused death.

Symptoms are coughing with blood, chest infections that keep coming back, pain when breathing or coughing, persistent breathlessness and continuous tiredness.

In lung cancer chemotherapy, radiation therapy, targeted therapy and surgery are acquires according to consultant.

### (v) Smoking is dangerous for respiratory system

The effect of tobacco smoking on respiratory system is the larynx and tracheal passage irritations. Tobacco smoke may cause swelling in air passage that produce the mucus which can block air ways. This cause lung infection and may damage the alveoli

# SUMMARY

- Breathing consist of inhalation and exhalation. Inhalation is the entry of air in lungs and exhalation is the removal of air from lungs.
- Air passage is nasal cavity → pharynx → trachea → primary bronchi → secondary bronchi → tertiary bronchi → bronchiole → alveoli.
- Barrier between air and blood is just 1μ in thickness.
- Exchange of gasses from air to blood cell at alveoli is due to moist and large surface area containing membrane.
- Lungs are pair left lung is 2 lobed i.e., superior and inferior lobs. While right lung is 3 lobed i.e. superior, medial and inferior.
- Sound producing organs i.e. vocal cord present in larynx.
- Inter coastal muscles, ribs, diaphragm help in breathing.
- A membrane also protect the lungs called pleural membrane, which secrete slippery secretin which makes the max: expansion and contraction to lungs.
- One complete inhalation and exhalation is called breath cycle breathing rate depends upon breathing cycles takes place in unit time. i.e. 15-18 time/ minute in adult and healthy person.
- Lung capacity is the amount of air filled in lungs i.e. 5 liter in dermal breathing.
- Tidal volume is the amount of air required for survival.
- Rate of breathing depends upon the concentration of $CO_2$ and $H^+$ present in blood which are monitored by specific chemoreceptors present in blood vessels called aortic and carotid bodies.
- 97% $O_2$ is transported in body by R.B.C and the remaining 3% is transported by blood plasma.
- $O_2$ molecule of air are attached with hemoglobins to form oxyhemoglobing.
- $CO_2$ as by product inhale from body by three different ways

$$CO_2 + H_2O \quad H_2CO_3 \quad HCO^-_3 + H^+$$

$$H_2CO_3 + K^+ \quad KCOH_3$$

$$H_2CO_3 + Na^+ \quad NaHCO_3$$

- Pneumonia, pulmonary tuberculosis and emphysema are disease of lower respiratory disorder.

# EXERCISE

**1. Encircle the correct choice**

(i) In which part of the respiratory system, gaseous exchange takes place?

(a) Alveoli (b) Pharynx
(c) Larynx (d) Trachea

(ii) Which of the following statements is true about involuntary breathing?

(a) It is controlled by the bronchioles
(b) It is controlled by the pulmonary arterioles
(c) It is controlled by the alveolar-capillary network
(d) It is controlled by the neurons, located in the medulla and pons

(iii) The tiny air sacs present in human lungs is called.

(a) Alveoli (b) Bronchus
(c) Bronchioles (d) All of the above

(iv) The exchange of gases between the external environment and the lungs.

(a) Respiration (b) External respiration
(c) Cellular respiration (d) None of the above

(v) The maximum volume of air contained in the lung by a full forced inhalation is called.

(a) Tidal volume (b) Vital capacity
(c) Ventilation rate (d) Total lung capacity

(vi) Which one of the following is correct regarding larynx?

(a) It houses the vocal cords
(b) It prevents the invading pathogens into the trachea
(c) It is an organ made of cartilage and connects the pharynx to the trachea
(d) All of the above.

(vii) Which of the following is the function of the trachea?

(a) Gaseous Exchange
(b) Filters the air we breathe
(c) Exhales the air from the body
(d) All of the above

(viii) Which of the following organs functions as an air conditioner?

(a) Larynx (b) Pharynx
(c) Nasal chambers (d) All of the above

(ix) Which of the following statements is true about the entry of air into the lungs?

(a) Air enters the body and travels to the lungs through the mouth and the nose

(b) Air enters the body and travels to the lungs through the esophagus and gullet

(c) Air enters the body and travels to the lungs through the windpipe and the pores

(d) Air enters the body and travels to the lungs through the nose and the nervous system.

## 2. Write short answers of the following questions:

1. When breathing process develop in animals?
2. What type of ventilation occur in human?
3. Why rate of breathing increases in human beings?
4. Why breathing of human being called negative pressure breathing?
5. How $CO_2$ from cell transport to lungs?
6. Which of the pigment is called respiratory pigment?
7. Draw a flow chart for the passage of air from external nares to alveoli.
8. Why hair and mucus glands are present in nostrils and trachea?
9. How exchange of gases occurs at the alveolar level?

## 3. Write detailed answers of the following questions:

1. What is respiration? Describe human respiratory system?
2. What are the 5 main functions of the respiratory system?
3. Draw labelled diagram of human respiratory system.
4. Describe the three regions of the pharynx and their functions.
5. What is the mechanism of inspiration and expiration?
6. Describe three ways in which carbon dioxide can be transported.

Prepared by **SINDH TEXTBOOK BOARD JAMSHORO.**
Reviewed by **Directorate of Curriculum Assessment and Research Sindh, Jamshoro**
Prescribed by the Board of Intermediate and Secondary Education Hyderabad, Sukkur, Shaheed Benazirabad, Larkana, Mirpurkhas and Karachi.
Approved by the **Education and Literacy Department, Government of Sindh.**

# قومی ترانہ

پاک سر زمیں شاد باد　　کِشورِ حسین شاد باد
تو نِشان عزمِ عالی شان　　ارضِ　　پاکستان

مرکزِ یقین شاد باد

پاک سَر زمین کا نِظام　　قُوّتِ اُخُوّتِ عوام
قوم، ملک، سلطنت　　پائندہ، تابندہ باد

شاد باد منزلِ مراد

پرچمِ ستارہ و ہلال　　رہبرِ ترقّی و کمال
ترجمانِ ماضی، شانِ حال　　جانِ　　استقبال

سایۂ خدائے ذوالجلال



| Serial No. | 13870 | | Publisher Code No. 1 |
|---|---|---|---|
| Month and year | Edition | Quantity | Price |
| August 2023 | First | 40,000 | 547.80 |