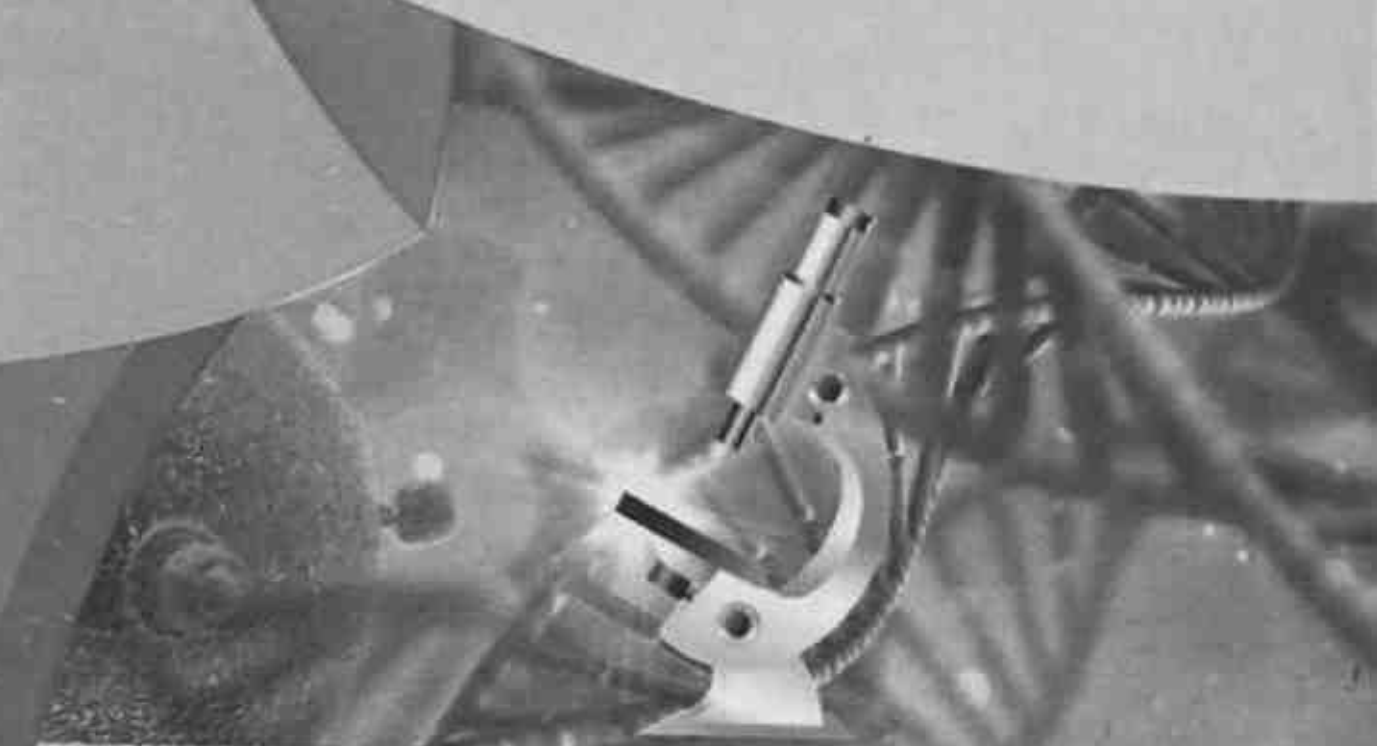
A Textbook of

BIOLOGY

Grade 11



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We would have never been able to produce this manuscript without the blessings of Allah Almighty. Thanks Allah for enabling and guiding us in completion of this noble task.

Authors

Preface

Biological Research is in the midst of a revolutionary change due to the integration of powerful technologies alongwith new concepts and methods derived from inclusion of Physical Sciences, Mathematics, Computational Science and Engineering.

We are living in the 21st century where the role of science and technology cannot be denied. Biology as subject is playing a pivotal role to explain the complex nature of life. Now, there is a need for every individual to know the worth of scientific saturations, and in this regard it's Biology which is going to help every individual of a society in today's world.

It is essential that we learn the Morphology and Physiology of all living things. How to live in harmony with the other residents of earth. Thus study and teaching of Biological Science at each and every level of education has become inevitable.

The text for class XI has been developed in accordance with the demand of national curriculum 2006, which is based on attainment of standard benchmarks and learning outcomes.

The special features of this book are:

- Each chapter begins with the brief introduction of topic.
- The headings and sub-headings of each topic is written in different colours which help the students to differentiate between topics and sub topics.
- For the first time new informative pattern is introduced e.g., tit bits, data/information, tables or boxes, critical thinking, activities etc.
- The exercise of each chapter is written according to the pattern of paper as prescribed by educational board that is section 1 is comprising of objective questions which include MCQs and completion of blank spaces. Section 2 includes short questions and section 3 includes long questions.
- SLOs of each chapter are given in the beginning of the chapter while summary is given at the end of each chapter in order to assist students recall their knowledge about said chapter.
- Biological names of organisms are written in italics letter.

At the end of this book:

- Commonly used Greek and Latin words and their meanings are given at the end for the convenience of students and teachers.
- Glossary has been provided to understand the biological terms.
- Index is also given for the convenience of students to locate different topics.

Your kind guidance will be appreciated:

- Despite our earnest efforts there can be certain errors and omissions in this book as human limitations, suggestions and positive criticism, therefore, from our colleagues, teachers and students will definitely inculcate a new spirit in us for further improvement of the textbook.

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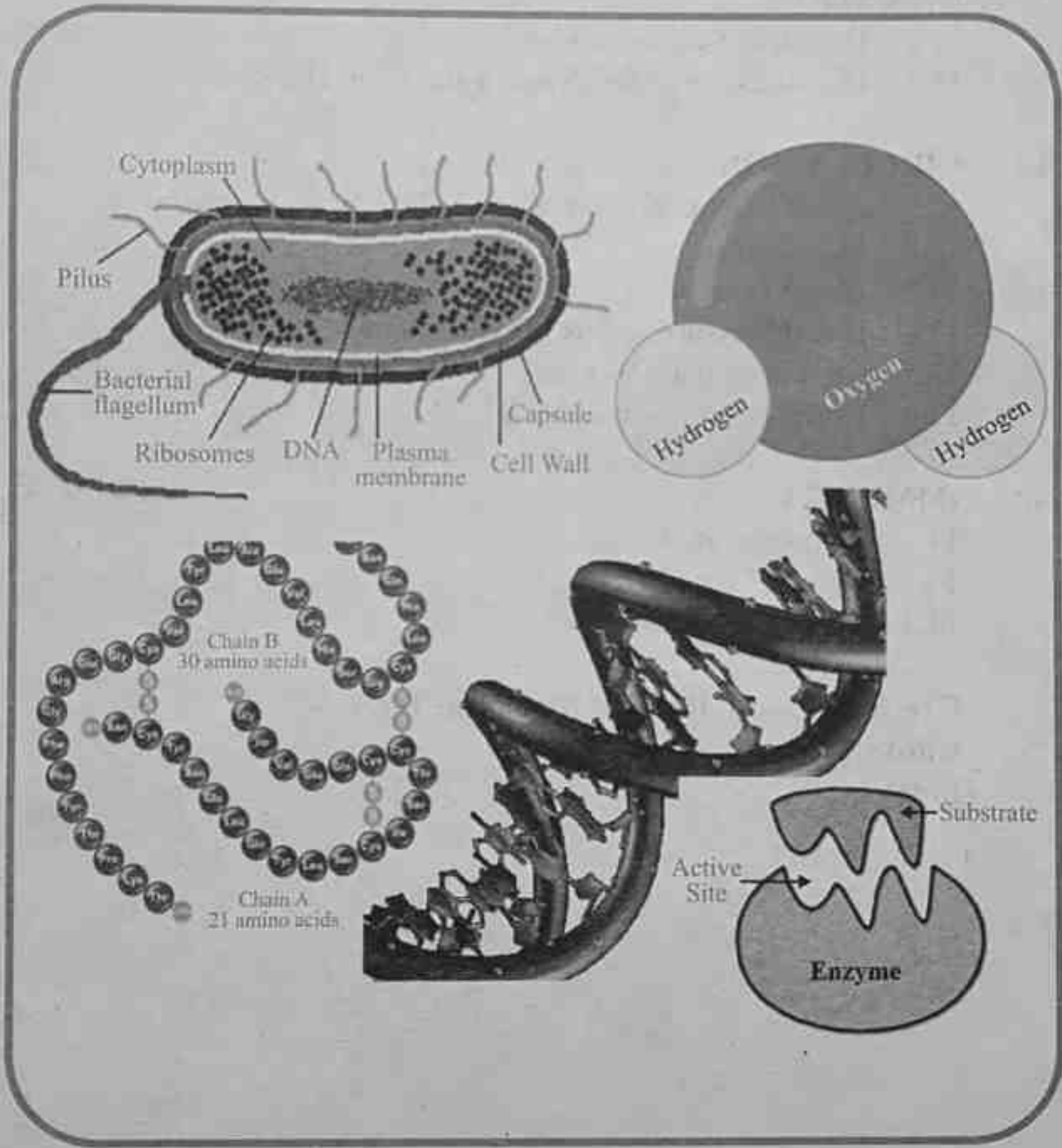
Section 01

CELL BIOLOGY

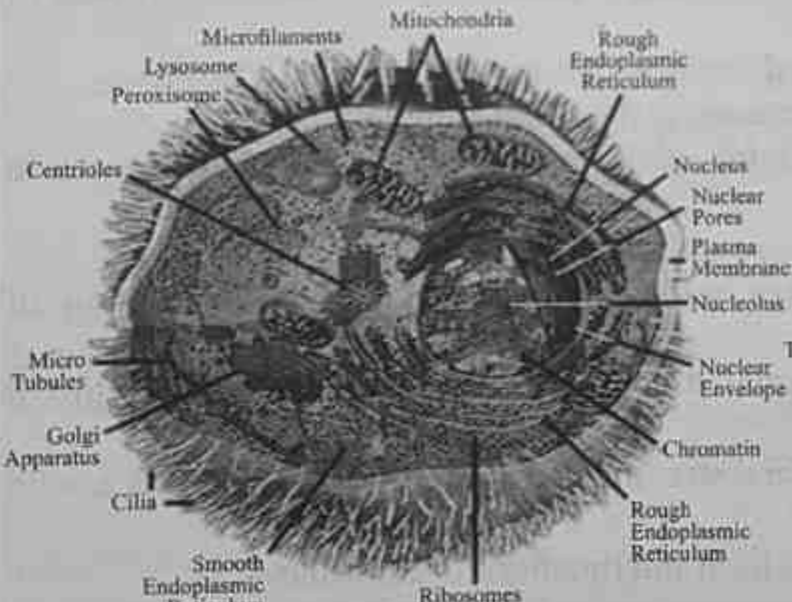


UNIT 1

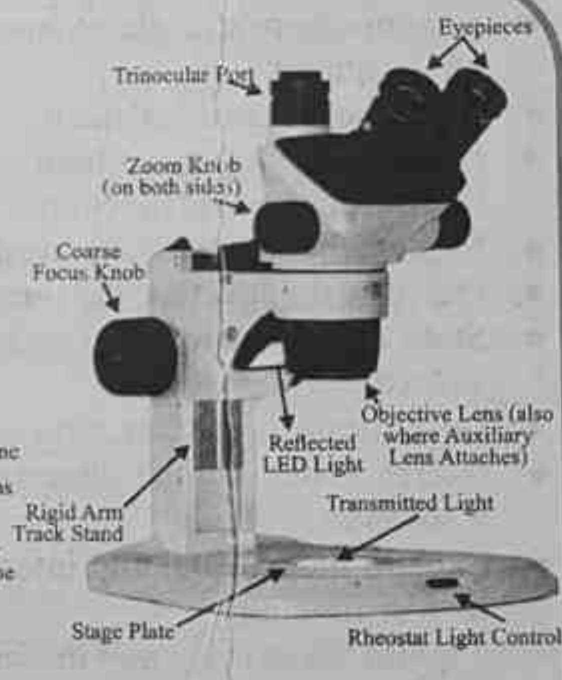
CELL STRUCTURE AND FUNCTION

Major Concepts

1.1 Techniques used in Cell Biology
1.2 Cell wall and Plasma Membrane
1.3 Cytoplasm and Organelles
1.4 Prokaryotic and Eukaryotic Cells



Anatomy of the Animal Cell



Dissecting Microscope

Students Learning Outcomes

On completion of this unit students will be able to:

- List the principles and identify the apparatus used in the techniques of fractionation, differential staining, centrifugation, microdissection, tissue culture, chromatography, electrophoresis and spectrophotometry.
- Describe the terms of resolution and magnification with reference to microscopy.
- Explain the use of graticule and micrometer and define the units used in micrometry.
- Describe the locations, chemical compositions and significance of the primary and secondary cell walls and of middle lamella.
- Explain the chemical composition of plasma membrane.
- Rationalize the authenticity of the fluid mosaic model of plasma membrane.
- Relate the lipid foundation and the variety of proteins of the membrane structure with their roles.
- Identify the role of glycolipids and glycoproteins as the cell surface markers.
- Explain the role of plasma membrane in regulating cell's interactions with its environment.
- Describe the chemical nature and metabolic roles of cytoplasm.
- Distinguish between smooth and rough endoplasmic reticulum in terms of their structures and functions.
- Explain the structure, chemical composition and function of ribosome.
- Describe the structure and functions of the Golgi complex.
- State the structure and functions of the peroxysomes and glyoxysomes in animal and plant cells.
- Describe the formation, structure and functions of the lysosomes.
- Interpret the storage diseases with reference to the malfunctioning of lysosomes.
- Explain the external and internal structure of mitochondrion and interlink it with its function
- Explain the external and internal structure of chloroplast and interlink it with its function.
- Describe the structure, composition and functions of centriole.
- Describe the types, structure, composition and functions of cytoskeleton.
- Explain the structure of cilia and flagella and the mechanisms of their movement.
- Describe the chemical composition and structure of nuclear envelope.
- Compare the chemical composition of nucleoplasm with that of cytoplasm.
- Explain that nucleoli are the areas where ribosomes are assembled.

- Describe the structure, chemical composition and function of chromosomes.
- List the structures missing in prokaryotic cells.
- Describe the composition of cell wall in a prokaryotic cell.
- Differentiate between the patterns of cell division in prokaryotic and eukaryotic cells.
- Relate the structure of bacteria as a model prokaryotic cell.

Introduction

As we know that the cell is the structural and functional unit of living organisms. The branch of biology which deals with the study of different aspects of cell is called **cell biology or cytology**. As most of the cells are microscopic, therefore, to study cell at organelles level and molecular level, different techniques are used. In this chapter we will study about these techniques and detailed structure and function of cell organelles.

After the discovery of the cell in seventeenth century, a lot of informations have been collected by different researchers. These informations have been summarized in the form of cell theory.

The main points of **cell theory** are given below.

1. All organisms are composed of one or many cells and their products e.g. hair, nails, scales and horns etc.
2. Cell is the structural and functional unit of life.
3. All cells come from parent (pre-existing) cells.
4. Cell contains the hereditary informations, which are transferred from parental cells to daughter cells.
5. Most of the diseases are caused by malfunctioning of cells.

> **Do you know?**
> *An adult human contains more than 37 trillion cells.*

1.1 Techniques Used in Cell Biology

To study the cell, many techniques are used to examine various components of the cells and their functions in detail. These techniques are cell fractionation and centrifugation, differential staining, micro-dissection, tissue culture, chromatography, electrophoresis etc.

1.1.1 Cell Fractionation and Centrifugation

It is a procedure to separate cell components into parts and fractions without altering their shape and function.

For this purpose firstly the cell is homogenized (grind) in a suitable medium with correct pH, ionic composition and temperature. This process is called **homogenization** which is usually

> **Tit bits**
> *A centrifuge machine can be described as a machine with a rapidly rotating container that applies centrifugal force to its contents.*

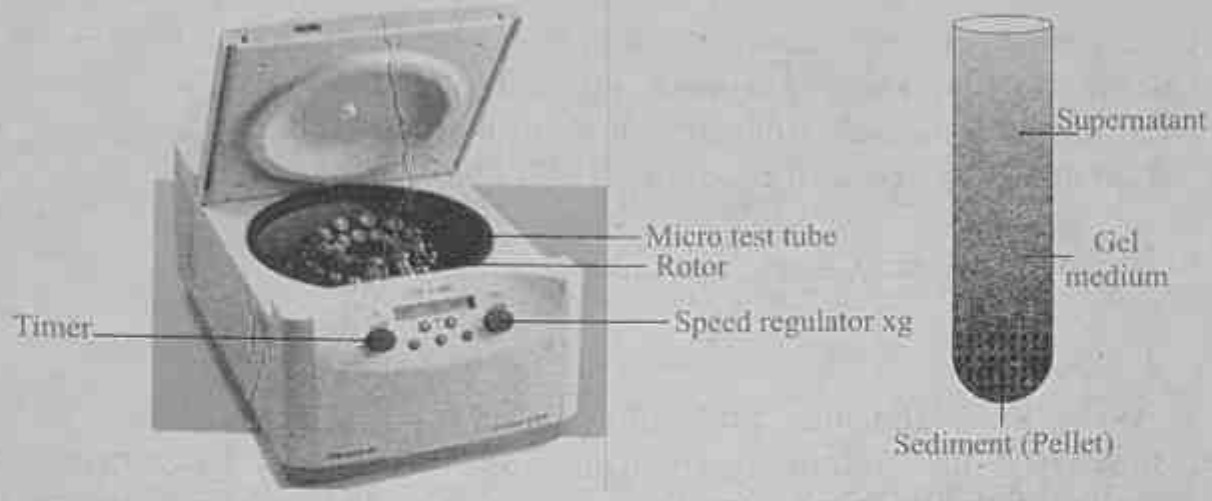


Fig. 1.1 Ultra Centrifuge Machine

done by a food mixer. The homogenate is poured in a test tube. The tube is then kept in a centrifuge machine and centrifuged for a fixed time at a specific speed. The faster the rotation of the centrifuge make the smaller particles well sedimented. A series of increasing speeds can be used for the separation of smaller components. After each speed a pellet is formed at the bottom of the test tube. Then **supernatant** (fluid above the pellet) is taken into another empty test tube and recentrifuged. Thus a series of different cell organelles are obtained in different test tubes. This is known as **differential centrifugation.** The detailed structure and function of these isolated cell organelles are studied under microscope.

> **Tit bits**
> *Ultra centrifuge is a type of centrifuge optimized for spinning a rotor at very high speed.*

1.1.2 Differential Staining

As most of the biological structures are transparent and colorless, therefore, cannot be seen clearly. Thus we stain these structures to observe them in detail. When only one stain is used, it is called **single staining** e.g., Borax carmine. When two stains are used, this is called **double staining** or differential staining. One stain for nucleus e.g., Haematoxylin and other that will stain cytoplasm e.g., Eosin.

1.1.3 Microscopic Dissection or Micro Dissection

It is a technique in which a microscope is used to assist in dissection. Laser or fine glass needles are used under a microscope to remove a portion of selected cell or chromosome etc. Large TV screens or monitors are used to view images.

> **Tit bits**
> *Tissues that take up stains are called chromatic. The term chromosomes refers their ability to absorb violet stain.*

1.1.4 Tissue Culture

The term tissue culture was introduced by an American pathologist Montrose Thomas Burrows.

It is a modern technique in which cells from a tissue of multicellular organism are grown *in vitro*. The cells for tissue culture may be isolated from donor organism "primary cells" or an immortalized cell line. The cells are bathed in a culture medium which contains essential nutrients and energy sources needed for tissue survival. The tissue culture is also called **cell culture.** This technique is used for both plant and animal cells. It is used to produce disease free plants without using seeds.

> **Tit bits**
> *Micro dissection is a useful method of collecting selected cells for DNA/RNA or protein analysis and to isolate cellular structures.*

> **Tit bits**
> *A complete plant can be grown from small pieces of plant tissue in a culture medium.*

Fig. 1.2 Procedure of Tissue Culture

1.1.5 Chromatography

It is a procedure used to separate different chemical compounds (Pigments) from a mixture.

There are different techniques are used for chromatography. However paper chromatography is simple, easy and widely used. The paper chromatography involves two phases i.e.,

> **Paper Chromatography**
> *This type of chromatography is used to separate coloured chemicals or substances and primarily used as a teaching tool.*

1. **Mobile Phase** which consists of the solvent and dissolved sample (pigment mixed in water).
2. **Stationary phase** which consists of filter paper.

Mechanism:- The mixture of mobile phase is passed through the stationary phase, as a result the molecules of mixture begin to separate as dots at different places on stationary phase (filter paper) according to affinity of molecule for the stationary phase. Now this filter paper is called chromatogram.

This procedure is usually performed to separate the mixture of protein and photosynthesis pigments.

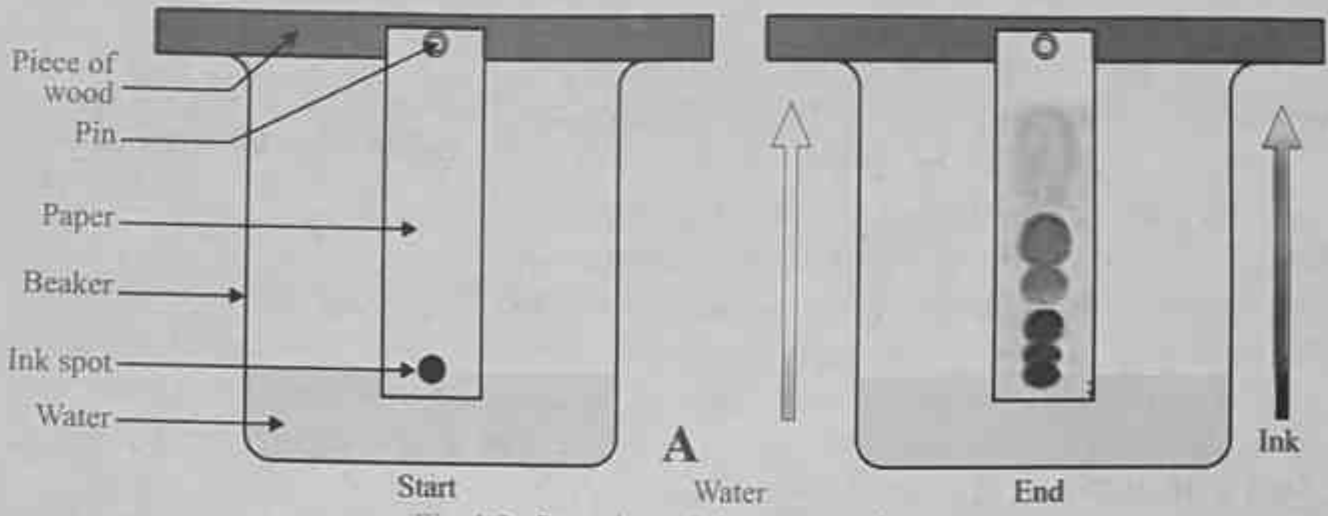


Fig. 1.3 Procedure of chromatography

1.1.6 Electrophoresis

It is a procedure to separate molecules (DNA, RNA, protein) according to their size, shape, molecular weight and surface charge. It is called gel electrophoresis because medium (Agrose or polyacrylamide gel) is used to separate the fragments under the influence of electric field.

A viscous slab of gel is formed between two glass or plastic plates. The samples are loaded in the slots of gel by micropipette. The two ends of slabs are suspended in salt solution and connected by electrodes to a power source (electricity). As a result the molecules present in the gel migrate through the electric field towards opposite terminal i.e., from negative to positive terminal. The smaller molecules will move faster than larger molecules.

Fig. 1.4 Gel Electrophoresis

Applications:- This procedure is used in forensic science to identify criminal cases (murder, rape, parentage). It is also used to diagnose infectious diseases, genetical disorders and cancer. Moreover this procedure is also used to determine the genetic similarities and evolutionary relationship among different organisms.

1.1.7 Spectrophotometery

This technique is used to measure the amount of light that passes through the sample, the amount of light absorbed at each wave length is plotted in a graph called absorption spectrum. The instrument used for this purpose is called **spectrophotometer** and the procedure is called spectrophotometery. For example it can be used to determine the wavelengths of light that take part in photosynthesis.

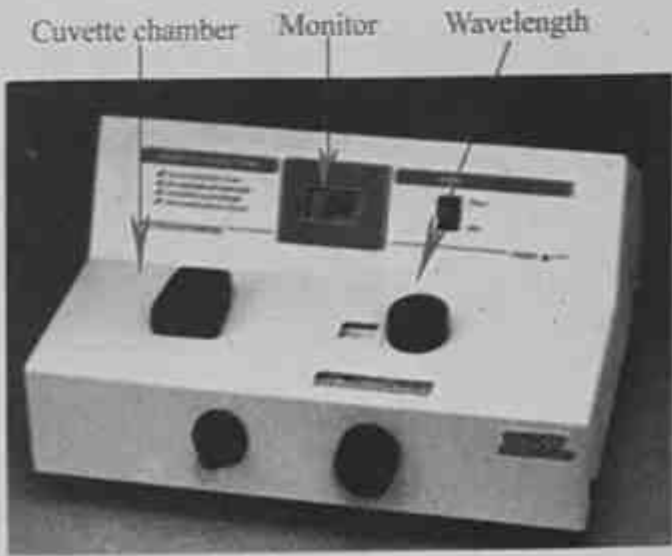


Fig. 1.5: Spectrophotometer

1.1.8 Microscopy

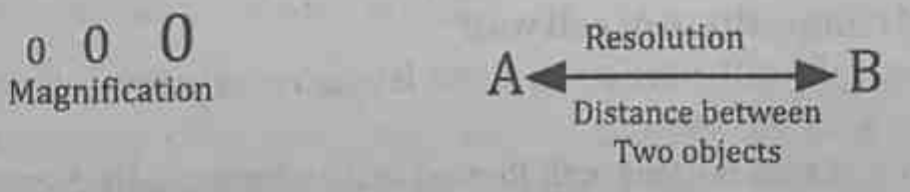
Microscopy is the procedure of using microscopes to view samples and objects that cannot be seen with naked eye. Of all the techniques used in biology microscopy is probably the most important. The cells of living organisms mostly range in size from 1-100 µm.

Tit bits

Magnifying glass, telescope, slide projector etc are some magnifying instruments.

Resolution and Magnification in Microscopy

The microscope has two abilities. i.e., resolution and magnification. The ability of a microscope to view two close objects by separating them from each other is called resolution power. The **resolution** of a compound microscope is about 200 nm times while resolution power of electron microscope is 0.5 nm. **Magnification power** is the ability of microscope to view an object by enlarging it from its real size. The magnification power of compound microscope is about 1500 times while electron microscope is about 1 million times. It depends on resolution power.



1.1.9 Graticule and Micrometer

The measurements of microscopic objects is called **micrometery**. This can be done by using specially designed scales on glass. One of the scales is placed in the eye piece called **graticule** (glass scale) or **ocular micrometer**. It is used as a ruler.

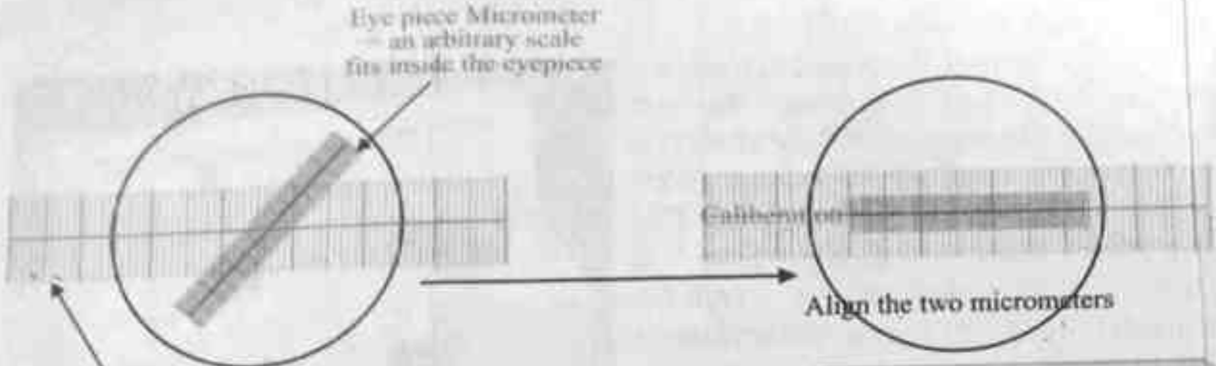


Fig. 1.6 Graticule

> **Activity**
> *Make a list of units used in micrometery.*

The stage micrometer is a glass slide on which a series of vertical lines are present (100 divisions). Its total length is 1mm.

1mm = 100 divisions
100 divisions = 1000 micrometers
1 division = 0.01mm (10μm)

> **Do you know?**
> A micron is an abbreviated term for micrometer. This is about 0.00004 inches or 1/1,000,000 meter.

1.2 Cell wall and plasma membrane

Structure of Cell

The cell consists of following parts.

> **Tit bits**
> *The plasma membrane is outer living membrane of all the cells. Many cells have rigid or semi rigid dead covering outside the cell membrane called cell wall.*

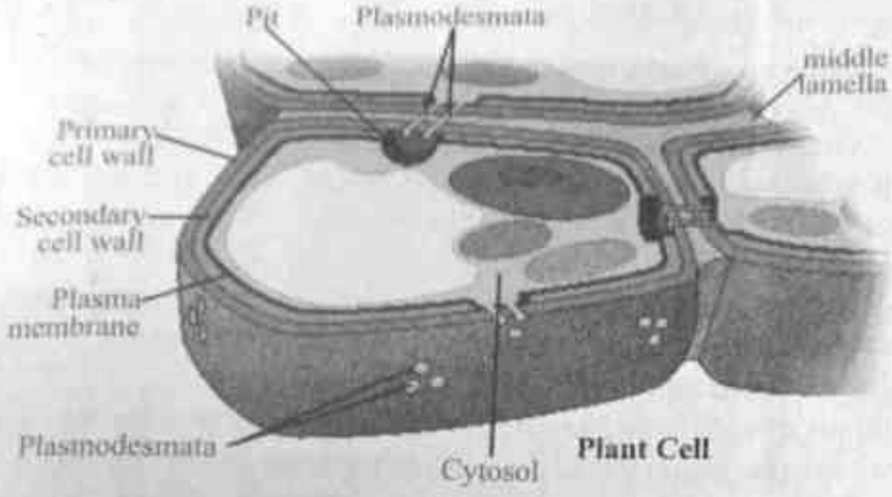
1.2.1 Cell wall

Cell wall is the outer most nonliving covering present in Plants, Algae, Fungi and Prokaryotes. It is secreted by the protoplasm of the cell. Its thickness and composition varies in different groups of organisms. Here we will discuss the detail of plants cell wall.

Structure and composition of cell wall

The plant cell wall consists of three layers i.e primary cell wall, middle lamella and secondary cell wall.

Primary cell wall is a true wall formed in developing cells. Some plant cells possess only primary cell wall such as leaves, storage cells and young growing cells. Primary cell wall is composed of **cellulose, hemicellulose** and **pectin**. The outer part of primary cell wall of plant epidermis is usually impregnated with cutin and wax, forming a permeability barrier known as plant cuticle. The cellulose microfibrils are arranged in criss cross manner. The microfibrils are held together by hydrogen bond to provide high **tensile strength.**



Plant Cell

Cellulose Fibrils

Fig. 1.7 Plant Cell Walls

Middle lamella

It is the first layer that is deposited at the time of cell division between two adjacent cells. It is formed of sticky gel like magnesium and calcium salts of proteins which help to stick the neighbouring cells together.

Secondary cell wall is thick layer formed between the primary cell wall and plasma membrane. The secondary cell wall is formed when the cell is fully grown. It is composed of cellulose, hemicellulose and lignin which is used to strengthen the wall. In the secondary cell wall the microfibrils also show criss cross arrangement. Cells with secondary cell walls are rigid.

1.2.2 Plasma Membrane

It is outer most living boundary of animal cells while in plant cell, it is always present after the cell wall. There are many other membranes bounded organelles, like mitochondria, Golgi bodies, Endoplasmic reticulum. All these membranes are chemically composed of 60- 80% proteins, 20 to 40% lipids and small amount of carbohydrates.

Tit bits

Cellulose, the main constituent of cell wall, is used in the manufacturing of paper, cotton goods, sellotape, ropes etc.

Do you know?

Cell wall provides mechanical strength shape, support and protection to cell.

Do you know?

Plant cells are communicated with each other by microscopic channels known as

Tit bits

The plasma membrane consists of 3 classes of amphipathic lipids, phospholipids, glycolipids and sterols. The amount of each depend on the type of cell. Usually phospholipid is most abundant.

Fluid mosaic model:

This model of plasma membrane was developed by **Jonathan Singer** and **Garth Nicolson** in 1972. According to this model plasma membrane is fluid mosaic of protein, floating within bilayer of phospholipid and cholesterol. The phospholipid molecule contains a hydrophilic head and two hydrophobic tails. The hydrophobic tails face each other while hydrophilic heads are directed towards water which is present outside and inside the cell.

The cholesterol molecules are embedded in the interior of the membrane which makes the membrane less permeable for water soluble substances. It also provides stability to plasma membrane.

There are two kinds of membrane proteins, **extrinsic** or surface protein and **intrinsic** or embedded proteins (either wholly or partially embedded in bilayer).

Some amount of carbohydrates are also present in plasma membrane. These may either attach with protein as glycoproteins or attached with lipids as glycolipids.

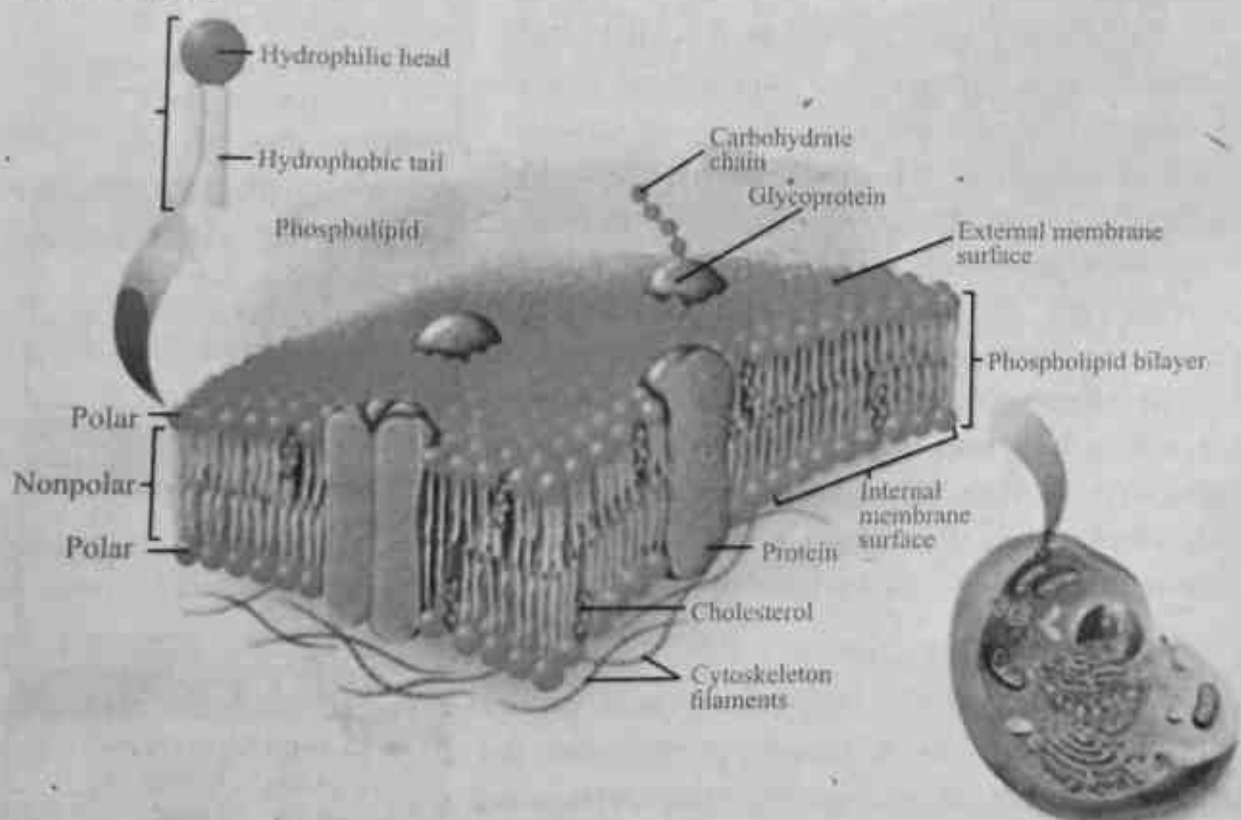


Fig. 1.8 Fluid Mosaic Model of Plasma Membrane

The role of glycoproteins and glycolipids:

They provide receptor sites for hormones, nerve impulses, recognition of antigens and also responsible for endocytosis. Therefore, these are called as cell surface markers. Cell to cell recognition, sticking, correct cell together. They are just like signboard on a shop.

Protein of plasma membranes:

Channel proteins and carrier proteins:

These are involved in the passage of molecules through the membranes. Some proteins have channels through which substances can move across the membrane while other molecules combine with carrier proteins to move across the membrane.

Enzymes:

Some proteins of plasma membrane act like enzymes, e.g., the epithelial cells lining, some parts of the digestive tract contains digestive enzymes on their cell surface membrane.

Receptor molecules:

Some proteins of plasma membrane act as receptors e.g., hormones are chemical messengers, circulating in the blood but only bind to specific target cells which have the correct receptor site.

Antigens:

Antigens are glycoproteins have different shapes, so each cell can have its own specific marker. e.g., foreign antigens can be recognized to defend the cell.

1.2.3 Role of plasma membrane with its environment

It regulates materials moving into and out of the cell. It secretes useful substances such as enzymes, hormones etc. It removes waste and toxic substances such as ammonia, urea, uric acid. It keeps a constant favorable ionic concentration within the cell for enzymatic activities and for nervous and muscular activities. The transport of substances across the plasma membrane takes place by endocytosis, exocytosis, osmosis, diffusion etc.

1.3 Cytoplasm and Organelles

The living contents of the eukaryotic cells are divided into nucleus and cytoplasm, these two together known as protoplasm. The word "cytoplasm" literally means "living gel of cell". It is liquid substance lying inside cell membrane and outside nucleus. The cytoplasm is a mixture of organic and inorganic materials and form a solution having all fundamental molecules of life i.e., amino acids, sugars, fatty acids, nucleotides, vitamins, salts and dissolved gases.

The soluble part of the cytoplasm is called **cytosol** which is about 90% water, the small molecules and ions form true solution and large molecules form **colloidal**

solution (Such as starch particles in plant cells and glycogen granules of animal cells). The colloidal solution may be in the form of a sol (non viscous) or gel (viscous) parts.

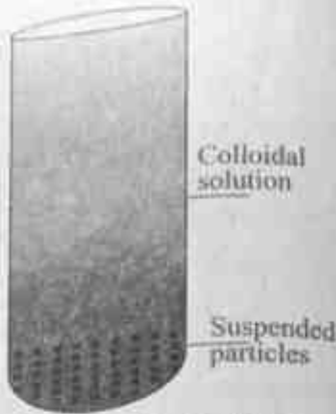


Fig. 1.9 Colloidal Solution

Tit bits

Colloidal solution is a type of solution which contain tiny particles of a substance suspended in it.

Cytoplasmic Organelles:

These are highly organized cellular bodies which perform specific functions. Such as endoplasmic reticulum, ribosome, Golgi bodies Mictochondria, plastid, centrioles, lysosomes etc.

Functions: Store House:

The cytoplasm serves as store house of vital materials, chemicals e.g., glycogen in liver cells.

Site for metabolic activities:

It is the site of certain metabolic pathways e.g., glycolysis.

Maintain the cell shape:

The cytoskeleton present in the cytoplasm, not only maintains the shape of the cell but also helps in the movement of organelles.

1.3.1 Endoplasmic Reticulum (E R)

Endoplasmic reticulum is a network of channels or tubules in contact and extending between nuclear membrane and cell membrane of all eukaryotic cells. The components of endoplasmic reticulum are:

Cisternae: These are long flattened and unbranched units arranged in stack

Vesicles: These are oval membrane bounded structures.

Tubules: These are irregular often branched tubes bounded by membrane. Tubules may be free or connected with cisternae.

Endoplasmic reticulum divides the intracellular space into two distinct compartments, i.e., luminal (inside) and extra luminal (cytoplasm).

Types: There are two types of endoplasmic reticulum, Rough ER and Smooth ER.

Modification of Endoplasmic Reticulum:

In skeletal and cardiac muscle cells SER is known as sarcoplasmic reticulum (SR). These store calcium ions in their lumen. If many ribosomes are attached on the small parallel cisternae of RER, then it is called **ergastoplasm.** In nerve cells the **ergastoplasm** is known as **Nissl's body.**

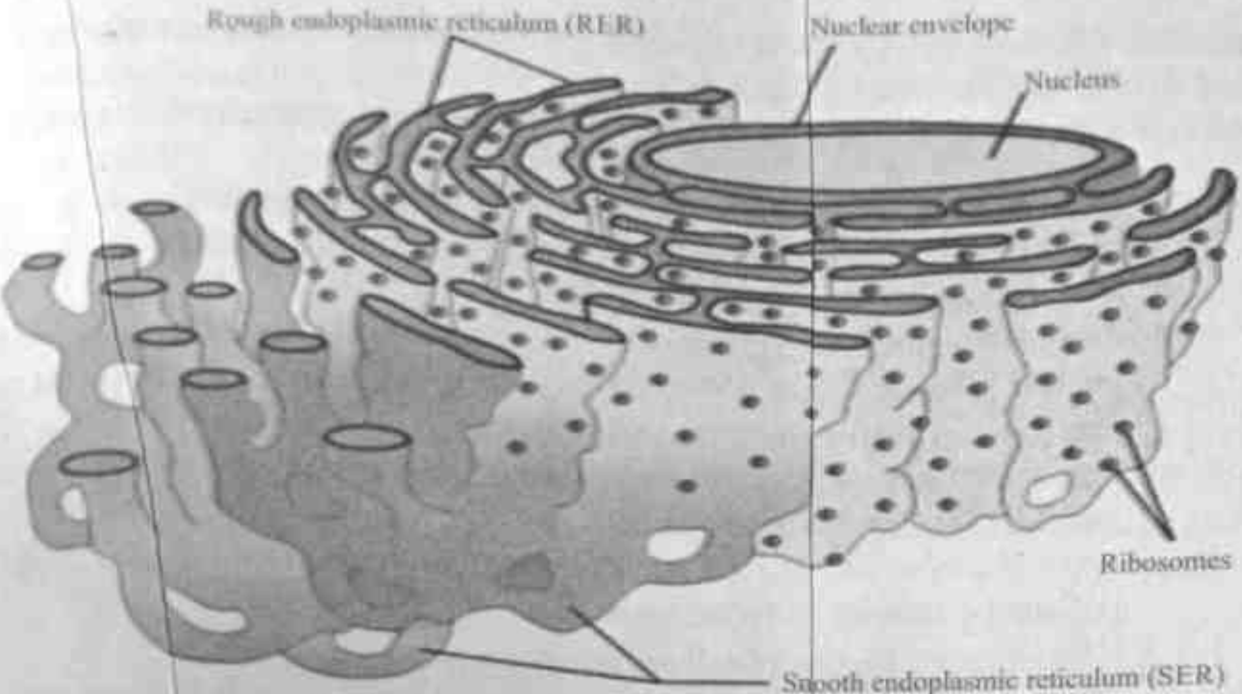


Fig. 1.10 Rugh Endoplasmic Reticulum (RER)
and Smooth Endoplasmic Reticulum(SER)

Table 1.1 Differences between smooth and rough ER

Rough ER	*Smooth ER*
• *Ribosomes are attached with their outer surface.*	• *Ribosoms are not attached with their outer surface.*
• *More stable structure*	• *Less stable structure.*
• *Mainly composed of cisternae and vesicles*	• *Mainly cmposed of tubules*
• *Abundantly occur in cells which are actively engaged in protein synthesis and secretion, such as in liver, pancreas and goblet cells.*	• *Abundanly occur in the cells concernel with glycogen and lipid metabolim, such as in adipose tissues, muscles, liver cells, and also remove toxins*

Functions of ER:

i) Mechanical Support: Along with microfilaments and microtubules, ER gives mechanical support to the cell.

ii) Intracellular Exchange: The ER forms intracelular connecting system and transports material of the cell from one part to aother part of the cell.

iii) Connection: The ER also helps in connecting nuclear material with plasma membrane.

iv) Protein synthesis: Rough ER helps in protein synthesis as ribosomes are attached with their outer surface.

v) Lipid Synthesis: Cholesterol and phospholipid are synthesized by smooth ER.

vi) Cellular Metabolism: The membranes of ER increase surface area for metabolic activities also contains some enzymes like, sucrases, glucose 6 phosphatase, NAD diphosphatase etc.

vii) Formation of Nuclear membrane: Fragmented elements of disintegrated nuclear membrane and E.R elements arrange around the chromosomes to form nuclear membrane during cell division.

viii) Formation of Organelles: All membranous organelles except mitochondria and chloroplast are formed by ER.

ix) Detoxification: Smooth ER are concerned with detoxification of drugs, pollutants, steroids and other toxins.

1.3.2 Ribosomes (Engine of cell or factory for protein synthesis)

These are granular structures first observed by George Palade in 1953. Ribosomes are **non membranous organelle**, present both in prokaryotic as well as eukaryotic cells (except mammalian RBCs). It is one of smallest cell organelle and also called organelle with in an organelle.

Composition: They are also known as ribonucleoprotein particle of the cell because composed of proteins and rRNAs. In prokaryotic ribosomes the amount of rRNA is 60% while protein is 40%. In eukaryotic ribosomes, protein is 60% and rRNA is 40%.

Location: The ribosomes exist in two forms, either freely scattered in cytoplasm or attached to outer surface of RER and nuclear membrane. It is also present in mitochondria and chloroplast.

Number: Numerous in number, about half a million ribosomes in a common eukaryotic cell.

Site of Synthesis: The subunits of ribosomes are synthesized in nucleolus of nucleus then transported to cytoplasm via nuclear pores. Thus nucleolus is the factory of ribosomes while ribosomes are the factory of proteins.

Subunits of Ribosomes: A complete eukaryotic ribosome consists of two subunits, based on their sedimentation (S) rate. ''S'' stands for Svedberg unit. A larger sub unit of 60s and smaller sub unit of 40s. Both units collectively make 80s particle. These

Do you know?

Svedberg unit is a unit of time equal to 10^{-13} seconds used in expressing sedimentation coefficients subunits are attached with each other by means of Mg ions or forming salt bonds between phosphate group of rRNA and amino group of amino acids or both by Mg ions and salt bonds. In prokaryote ribosome is 70s, larger unit is 50s while smaller unit is 30s.

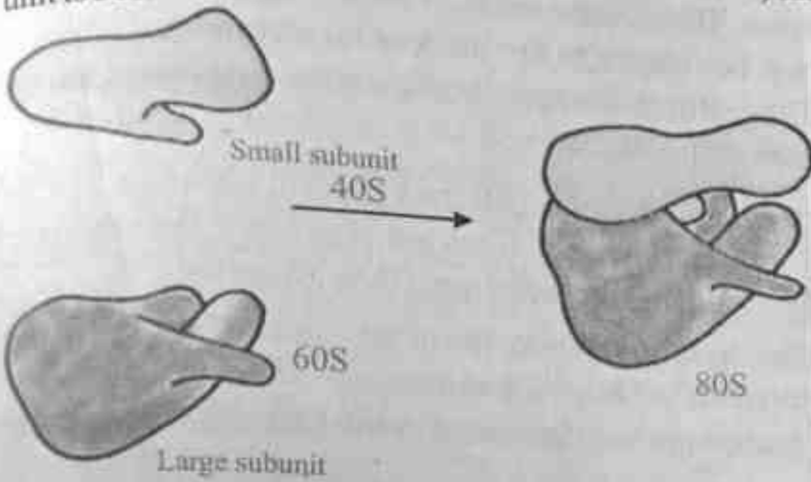


Fig. 1.11 Ribosome

> **Tit bits**
>
> *Mitochondrial ribosomes of eukaryotic cell are produced from mitochorndrial genes and functionally resemble many features of bacteria reflecting the likely evolutionary origin of mitochondria.*

Polysome

When many ribosmes attached to one mRNA strip, it is called polysome or polyribosomes. This happens during protein synthesis.

Function: Ribosomes are involved in protein synthesis which is facilitated with the help of three types of RNA and under the instructions of DNA.

> **Tit bits**
>
> *Golgi apparatus is a major collection and dispatch station of protein products, received from endoplasmic reticulum and known as post office of cell.*

1.3.3 Golgi Complex

They were discovered by Camillo Golgi in 1898, so called as Golgi complex or Golgi apparatus. In plants they are known as dictyosome.

Structure: The term Golgi apparatus refers to a set of smooth membranes that are stack into flattened, fluid filled sacs or cisternae, containing proteins, carbohydrates, glycoproteins and specific enzymes.

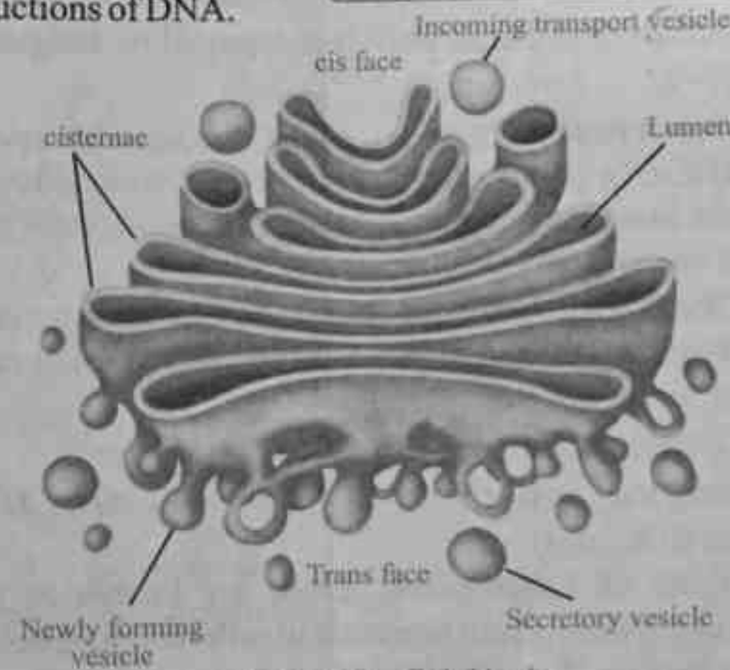


Fig. 1.12 Golgi body

Most of the Golgi apparatus is formed of flattened sacs or cisternae but some tubules and vesicles may also participate in the formation of Golgi complex. The number of cisternae ranges between 3-7 in most of animals but in lower organisms may have up to 30 flattened sacs. These flattened sacs are arranged in a concentric fashion, the convex face or sac lies closer to the nuclear membrane and called as Cis-Golgi or forming face. The farthest concave sacs are named as trans Golgi or maturing face.

Function: Golgi bodies perform number of functions e.g., Cell secretion: It is the main function of the Golgi complex. The secretions are processed and converted into finish products and are packed inside the membrane then exported.

Storage of proteins: Proteins synthesized by the ribosomes are passed to the endoplasmic reticulum and stored in the Golgi apparatus.

Cell wall formation: Golgi bodies are also involved in the formation of new cell wall by the plants.

Formation of Lysosomes: An important function of Golgi apparatus is the formation of primary lysosomes.

Formation of acrosome during spermiogenesis

Formation of vitelline membrane of egg is also secreted by Golgi bodies.

1.3.4_Lysosomes

Lysosomes (Gk. lyso: splitting, soma: body) are sac-like single membrane bounded organelles which break macromolecule in the cells.

Discovery: These were first reported by Belgian biologist Christian De Duve in 1949.

Occurrence: These are found in almost all eukaryotic cells except mammalian RBCs. In plants central vacuole functions as lysosome, therefore, lysosomes are less in number in plants. All fungi contain many lysosomes. The periplasmic space of bacteria may function as lysosome.

Chemical Composition: Lysosomes contain many enzymes like acid phosphatases and all types of hydrolytic emzymes, like carbohydrases, lipases, nucleases and proteases.

Shape: They are roughly spherical in shape.

Size: Vary in size from 0.1-0.8μm in diameter. In phagocytic WBC it is largest in size (0.8-2μm).

Types of Lysosomes: These are known as polymorphic cellular organelles because during function exist in different morphological and physiological states.

Primary Lysosome: Enzymes are synthesized by ribosomes of rough endoplasmic reticulum and then taken to Golgi bodies where these are processed and budded off as Golgi vesicles, called primary lysosomes.

Secondary Lysosome: They are also called digestive vacuoles. They are formed by the fusion of primary lysosome with food vacuole known as phagosome (phagocytic food vacuole).

Residual Bodies or Tertiary Lysosome: Lysosome containing undigested materials after the absorption of digested food into the cytoplasm is called residual lysosome. In unicellular organisms these are removed outside of cell by exocytosis while in multicellular organisms these are retained in the cell as lipofuscin granules.

Autophagic lysosomes: Also called autophagosomes or cytolysosomes. When primary lysosome fused with dead cellular organelles such as mitochondrion which die after ten days to be digested are called autophagosomes, such as human liver cells recycle half of its macro molecules each week.

Functions of Lysosomes: Lysosomes perform many functions inside and outside of cells. Which are as under:

Intracellular digestion: Foreign substances received by the cells either by phagocytosis (solid molecules) or pinocytosis (liquid molecules) are digested by lysosome. This process is called heterophagy. The old or dead cell organelles are digested by lysosomes and stored food is also digested during starvation. This process is known as autophagy.

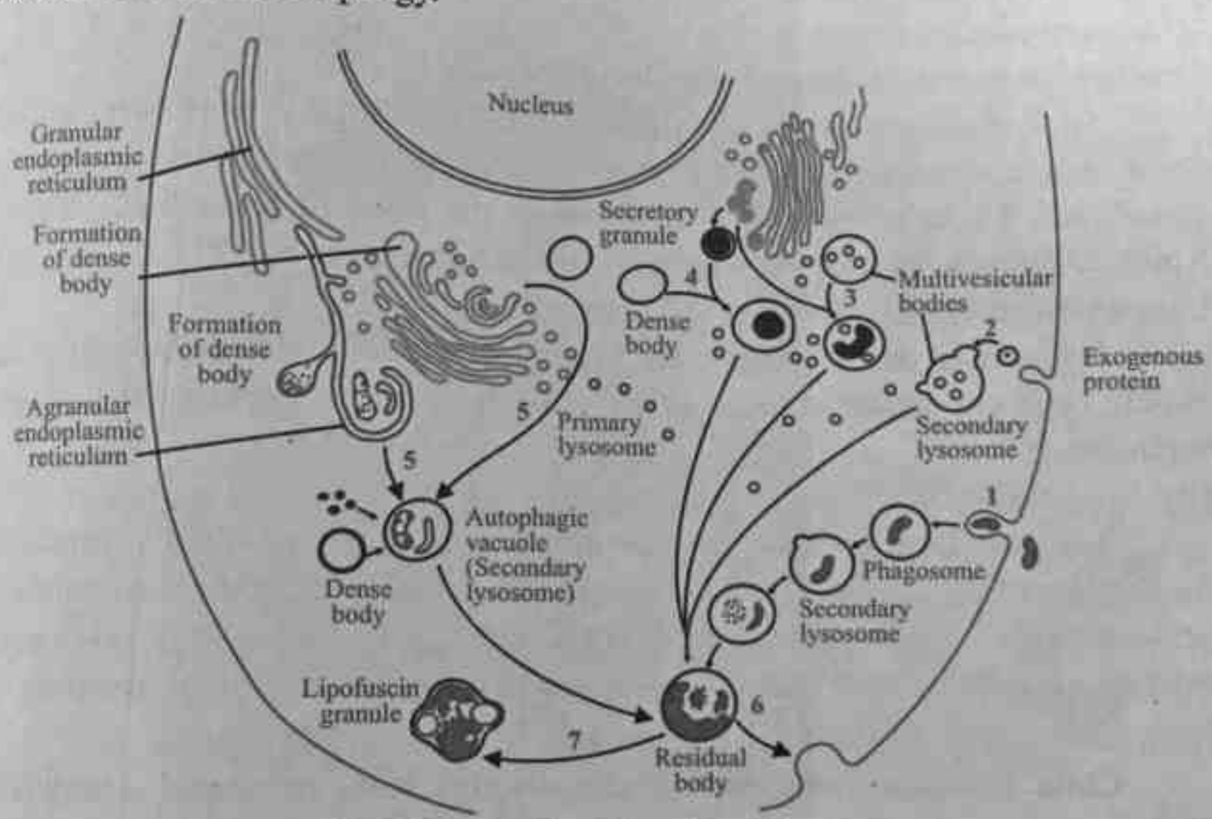


Fig. 1.13 Explained Function of Lysosome

Extra cellular digestion:

Lysosomes also help in extra cellular digestion by releasing enzymes. e.g., the lysosomes of osteoclast (Bone eating cells) dissolve unwanted parts of bone. Extracellular digestion also take place in fungi.

Autolysis:

Some time all lysosomes of cell burst to dissolve the cell completely. Thus also called suicidal bags because old cells like WBCs, platelets and epithelial cells are removed by autolysis. It also destroys unwanted organs of embryo such as tail of human embryo and tail of tadpole.

Crinophagy:

The excess hormones of endocrine gland may be digested by lysosome. This process is known as crinophagy.

Exocytosis or cell excretion:

Sometimes enzymes of primary lysosomes are released from the cell. This occurs during replacement of cartilage by bone during development. Similarly the matrix of bone may be broken down during remodeling of bone that can occur in response to injury.

> **Tit bits**
>
> *Glycogen-storage disease (GSD) may be treated by taking small meals of carbohydrate, in USA one child per 25000, births have GSD.*

Storage Diseases (Diseases due to faulty lysosomes)

Several congenital diseases (by birth but not hereditary) have been found to occur due to accumulation of substances within cell. Such as glycogen or various glycolipids. These are caused by mutation in the genes of lysosomal enzymes. About 20 such diseases are known e.g., two of these are given below:

Glycogenesis type II disease (G-Storage disease)

It is caused due to the absence of D-glycosidase. In this disease liver and muscle cells are appeared to be filled with glycogen within membrane bound organelle.

Tay-Sachs disease:

Tay-sach disease is a rare disorder passed from parent to child. It is caused by the absence of an enzyme (Beta hexosaminidase) that helps in the breakdown of fatty substances. These substances in brain called gangliosides, built up to toxic level mainly in babies and young children and affect the function of the neurons.

Symptoms

Child loses muscle control eventually this leads to mental retardation, blindness, paralysis and even death.

1.3.5 Mitochondria (Gk. mitos : thread, chondrion: granules)

Mitochondria (Singular mitochondrion, **Power house of the cell**) look like small thread or granule either spherical or elongated. It is self replicating organelle.

Altman (1890) established them as cell organelle and called them bioblast. The term mitochondria was given by C. Benda (1898).

Size:- The diameter of mitochondria is 0.2-1 µm while length is one µm to 4.1 µm. Their numbers are few to many thousand per cell, depending upon physiological activity of the cell.

Chondriome:- All the mitochondria present in a cell are collectively called chondriome. Usually animal cell have more mitochondria than plants.

Structure:- It is double membrane structure. The outer membrane is smooth while the inner membrane is folded. If outer membrane of mitochondria is removed then it is called as **mitoplast.** The folds of inner membrane are known as **cristae** which increase surface area for chemical reactions. These cristae contain (bear) pin head particles called **oxysomes** or elementary particles or F1 particles. Inside the inner membrane a fluid is present called matrix. The matrix contains enzymes for cellular aerobic respiration, proteins, 70s ribosomes, RNA and double stranded circular DNA. (It is 1% of total DNA of cell.) This DNA can code the synthesis of some type of proteins.

Tit bits

mitochondria is also called

- *Power house of the cell or ATP mill in cell.*
- *Cell within cell.*
- *Cell furnace or storage batteries.*
- *Most busy and active organelle in cell.*
- *Semi autonomous cell organelle.*

Tit bits

F1 particles or oxysomes are knob like structures located on cristae of mitochondria and they are helpful in cellular respiration. They contain ATP synthetase which is responsible for the synthesis of ATP.

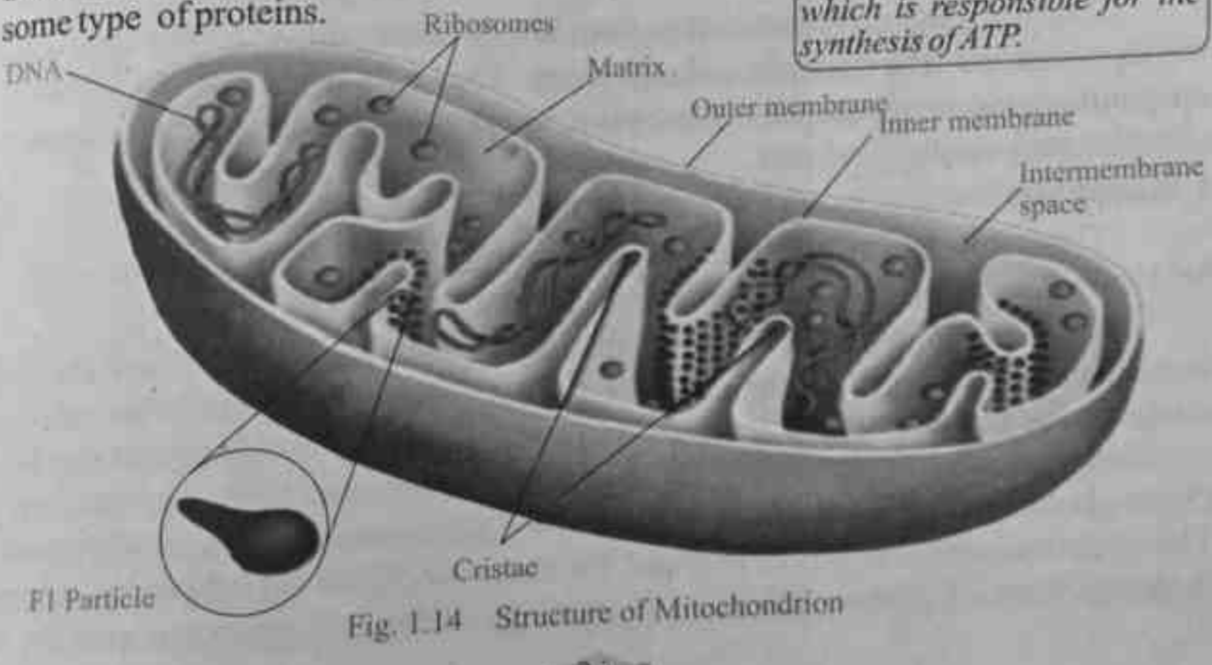


Fig. 1.14 Structure of Mitochondrion

Function of Mitochondria:

They provide site of aerobic respiration. Most of the oxidative metabolism and ATP production occurs in mitochondria. Therefore mitochondria are called power houses of the cell.

$$C_6H_{12}O_6 + 6O_2 + Pi + ADP \longrightarrow 6CO_2 + 6H_2O + ATP$$

Mitochondria also help in vitellogenesis (Yolk formation) in oocyte.

> **Tit bits**
>
> *It is believed that mitochondria have endosymbiotic origin from purple sulphur bacteria or prokaryotic cell. The ribosome of mitochondria and DNA are similar to prokaryotic cell.*

1.3.6 Plastids

The plastid (Gk. Plastos: formed, molded) is a major double membrane organelle found in plant cells. Plastids are the sites of manufacture and storage of important chemical compounds used by the cell. They often contain pigments used in photosynthesis and many types of pigments that can change or determine the cell colour for different purposes. Plastids are classified into chloroplasts, chromoplasts and leucoplasts. All types of plastids are formed from a precursor molecule proplastids.

Chromoplasts:

These are pigmented plastids located in colourful (other than green) parts of plants like petals fruit covering. These plastids also help in cross pollination. These also contain chlorophyll but in very less amount.

> **Tit bits**
>
> *Most plants inherit plastids from one parent e.g., angiosperms inherit plastid from female gamete while many gymnosperms inherit plastid from male pollen.*

Leucoplasts:

These are colourless plastids present in colourless parts of plants like roots, woody stems etc. They are triangular in shape. They help in storage of food. e.g., **amyloplast** which stores starch, **Elaioplast** which stores lipids and **proteinoplast** which stores protein.

Chloroplast:

These are green plastids, present in green parts of plants like leaves, herbaceous stems, unripened fruits coverings etc.

They are double membrane structures. The outer membrane is smooth and more permeable while the inner membrane is less permeable. The inner membrane contains disc like structure called thylakoid and group of thylakoid stacked together is called **granum** (plural Grana). There are many grana in a chloroplast and many chloroplasts in a cell (up to 40). The fluid which surrounds grana is called **stroma.** The stroma contains enzymes required for the synthesis of carbohydrates during dark reactions of photosynthesis. The most abundant and important enzyme is

Rubisco (about 16% of chloroplast), stroma also contains small amount of DNA, RNA and 70s ribosome. Presence of these substances indicate that it is **semiautonomous** organelle of cell like mitochondria.

The grana are connected to each other by long thylakoid membrane called **lamellae.** The chloroplast is the site for photosynthesis. The light reaction takes place in grana which contains large number of photosynthetic pigment in an organized manner, while the dark reactions occur in stroma. It is believed that chloroplast originated from cyanobacteria through endosymbiotic process.

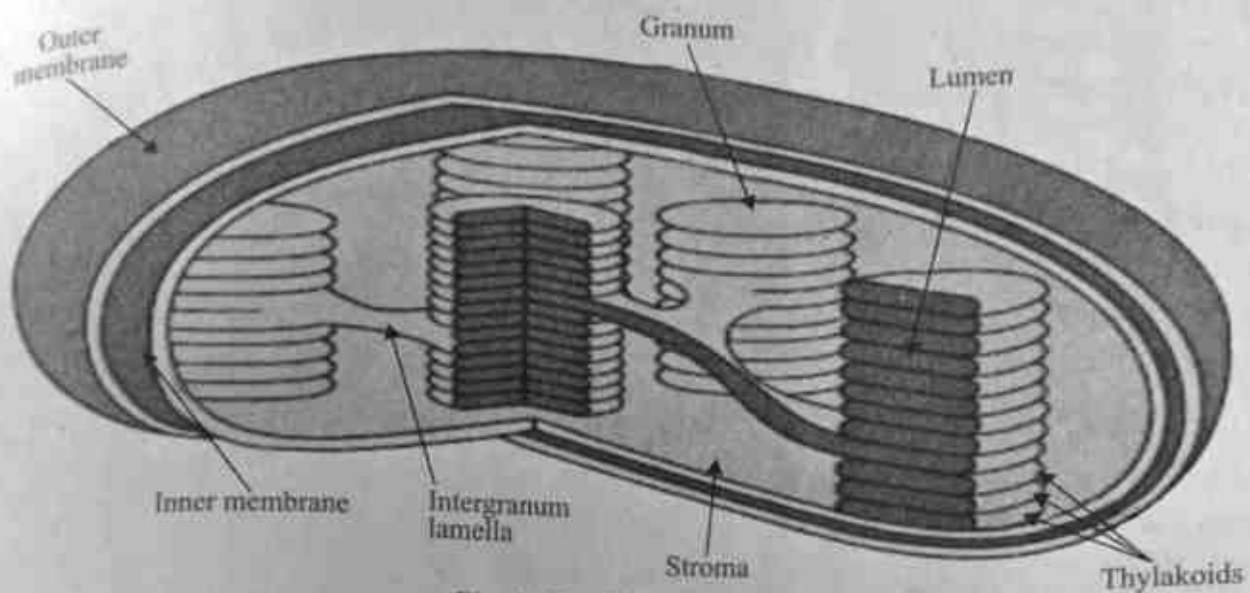


Fig. 1.15 Chloroplast

1.3.7 Cytoskeleton

The cytoskeleton (Gk: Kytos, cell ; Skeleton, dried body) are unbranched cylindrical structures which are made up of proteins and involved in internal structure, movement, contraction, relaxation , and maintain cell shape.

There are three types of cytoskeleton elements based on size and chemical composition. i.e., microtubules, microfilaments and intermediate filaments.

Microtubules:

These are small hollow cylinders, made of self assembling **tubulin protein**, 25nm in diameter. In plants microtubules often found associated with cell wall. Perhaps these are involved in the transport of cell wall materials from Golgi bodies to outside of the cell. During cell division, these microtubules form spindle fibers. Several cell organelles are also derived from special assemblage of microtubules e.g.,cilia, flagella, basal bodies and centrioles.

Microfilaments:

Microfilaments are considerably more slender, made up of contractile protein called **actin** and linked to the inner face of the plasma membrane. These are about 7.0 nm in diameter and occur in bundles or mesh like network. Actin filament contains two chains of actin molecules twisted to each other. Besides the actin protein tropomyosin and troponin proteins also present.

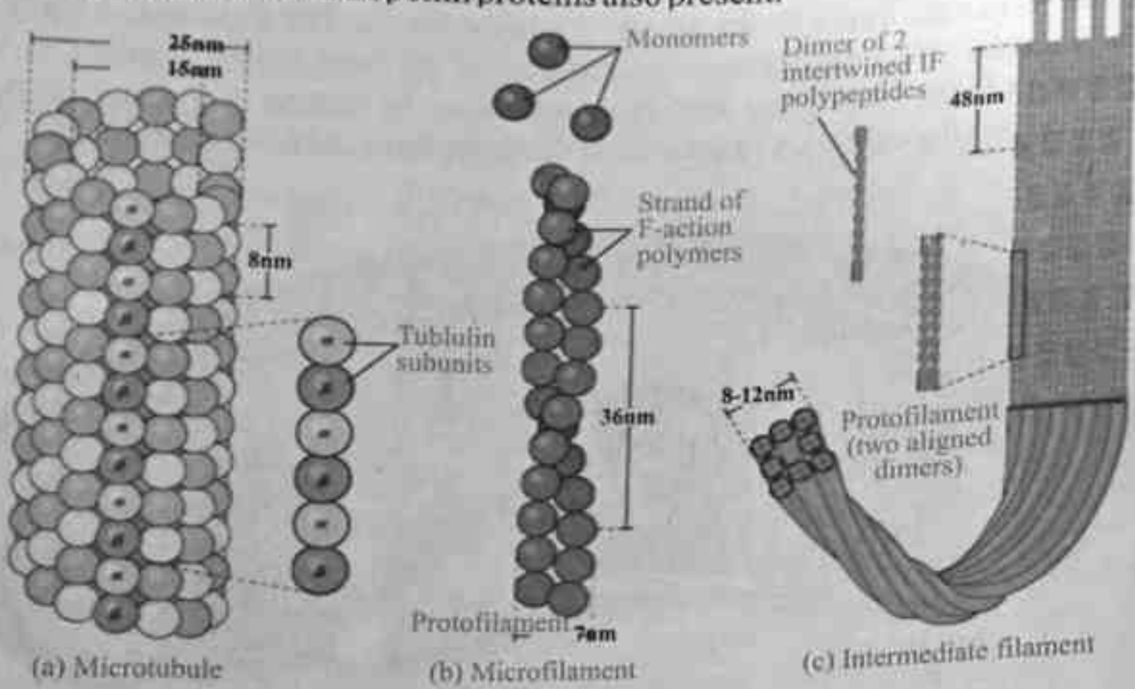


Fig. 1.16 Cytoskeleton

These perform functions of muscle contraction, change in cell shape including division of cytoplasm during cell division.

Intermediate filament:

These filaments are called intermediate because these are intermediate in size between microfilament and microtubule (about 8-12nm) in diameter. These are composed of **vimentin** protein. The intermediate filaments assemble and disassemble and, therefore, play important role in maintaining shape of cell, attachment of muscle cell, support of nerve cell processes i.e. axon.

1.3.8 Peroxisomes

It is a tiny single membrane bound cell organelle, which contain large amount of oxidative enzymes (such as peroxidase, catalase, de-amino acid oxidase, etc.).

These are spherical shaped organelle about 0.6 to 0.7μm in diameter. Their number varies between 70 to 100 per cell. It was first isolated by **De duve and co worker in 1965** in liver cells and other tissues which are rich with oxidative enzymes. It is also found in protozoans, yeasts and many higher plants.

Function

The name peroxisome was applied because this organelle is specifically involved in the formation and decomposition of hydrogen peroxide (H_2O_2) in the cell.

$$H_2O_2 \longleftrightarrow H_2O + \tfrac{1}{2} O_2$$

1.3.9 Glyoxisomes

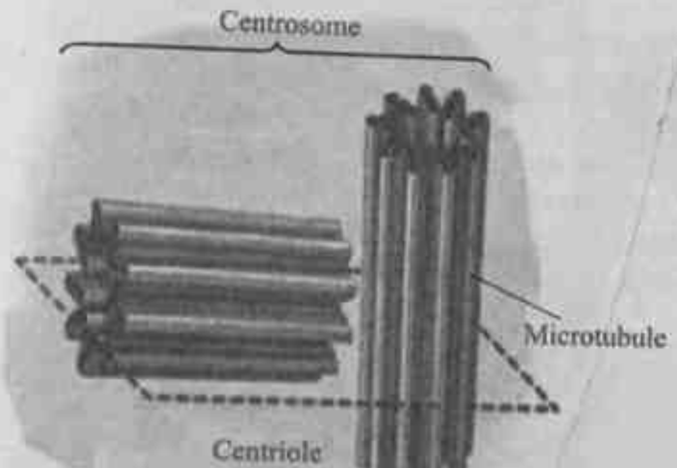
These are cell organelles, mostly found in lipid rich seeds and seedling cells of plants. These contain enzymes like glycolic acid oxidase and catalase. Some other enzymes are also present which are involved in the conversion of lipids into carbohydrate by a process called glyoxylate cycle.

1.3.10 Centrioles

Centrioles are non-membranous organelles, two in number, located near the outer surface of nucleus. The diameter of centriole is 10nm. They are found in animal cells of some microorganisms and lower plants while absent in higher plants. Centrioles were **discovered by Beneden in 1883 and Boveri in 1895.**

Structure:

The cytoplasm which surrounds centrioles is called "centrosphere". Centrioles and centrosphere are collectively called centrosome. In cross section each centriole consists of a cylindrical array of nine microtubules. However, each of the nine microtubules is further composed of triplet tubules. Both centrioles are placed at right angle to each other.



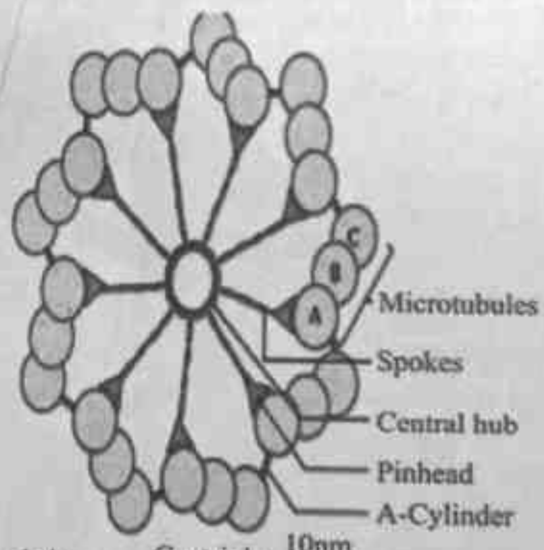


Fig. 1.17 Centriole

Function

They help in cell division. They are self replicating units and replicate just before the cell division. Each pair migrate towards opposite side of the nucleus. The spindle fibers are formed between

> **Tit bits**
>
> *Prokaryotic cells also have cytoskeleton which have same function but their structure is simple.*

these two pairs of centrioles. They play an important role in the location of furrowing during cell division and arrangement of microtubules.

1.3.11 Cilia and Flagella

Cilia (L. cilium, eye lash) and Flagella (L. flagella means whip) are hair like outgrowths of cell membrane and elongated appendages. They are present on the surface of some cells. They help in the movement of the cell. Some stationary cells also contain cilia (such as epithelial lining in respiratory system). The stationary cilia help in the movement of materials over the surface of the cell.

Flagella are five to twenty times longer than cilia. However, both cilia and flagella have same internal structure. They are membrane bounded **cylinders**. This membrane encloses a **matrix.** The matrix contains axonemes or axial filaments. The axonemes consist of nine pairs (doublets) of microtubules, which are arranged in a circle around two central tubules. This arrangement is called 9+2 pattern of microtubules. Microtubules slide over each other during movement of cilia and flagella. Each microtubules has two structures, the **dynein arms** which project towards the neighbouring doublets and

Do you know?

Basal bodies of cilia and flagella are types of centrioles.

Tit bits

Sperm centrioles are important for 2 functions. To form the sperm flagellum and sperm movement and in the development of embryo after fertilization.

Fig. 1.18 Ultra Structure of Cilia and Flagella

spokes which extend towards the centre. Dynein have ability of hydrolysis of ATP and release energy for ciliary or flagellary movements. The flagella and cilia originate from the basal body (also called Kinetosome) which is modified form of centriole. Basal body controls the growth of cilia and flagella. Microtubules in the basal body form 9 + 0 (9 triplets) pattern. Basal body exhibits cartwheel structure.

Mechanism of movement:

Movement of these structures is due to the sliding of double fibrils into groups one after the other. (suggested by **Bradford,** 1955).

Effective stroke:

During effective stroke five out of nine double fibrils contract as a result cilium bends.

Recovery stroke:

During recovery stroke four out of nine double fibrils contract and make the cilium straight.

1.3.12 Nucleus (Greek. karyon=central commander)

Nucleus is a double membrane bounded cell organelle of eukaryotic cell. It was discovered by Robert Brown in 1831 in orchid cell. Nucleus controls all cellular metabolism and contains genetic information of the cell. Nucleus is considered as **controller** or **heart** or **brain** of the cell.

It is self replicating organelle, arises from division of pre-existing nucleus. Generally each cell contains one nucleus but sometime may be two to many, **dikaryote in *Paramecium*** and many in ***Opalina***. It is absent in some eukaryotic cells, such as in mature phloem sieve tube elements in plants and mature RBCs of most mammals.

In animal cells, it generally occupies the **central space** while in case of plant cells, it is pushed towards **periphery** due to the presence of a large central vacuole. It may be spherical, oval, elongated or irregular in **shape.** It is only visible when the cell is in non dividing stage. In dividing cells it disappears and chromatin material is replaced by chromosomes.

Structure: The nucleus of non dividing cell (inter-phase) consists of nuclear membrane, nucleoplasm, chromatin net and nucleolus.

Each nucleus is covered by two **parallel membranes** with a space between (10-50 nm) called the perinuclear space. It is composed of protein and lipid bilayer, like plasma membrane. The outer nuclear membrane is at places continuous with endoplasmic reticulum while inner nuclear membrane encloses the nuclear contents. The ribosomes are also attached to outer surface of nuclear membrane.

At certain points nuclear membrane is provided by **nuclear pores,** around the margins of these nuclear pores both membranes are fused with one another. These pores are also guarded by permeases in the form of a pore complex which regulate RNA, ionic exchange (i.e., **nucleocytoplasmic traffic**) between nucleoplasm and cytoplasm. Nuclear membrane is also known as nuclear envelope.

Nucleoplasm: Nucleoplasm is ground substance of nucleus, which is also known as nuclear matrix or karyoplasm.

Chemical composition of nucleoplasm: It is a transparent complex colloidal form of solution or fluid contains water, protein and enzymes like ATPase, DNA and RNA polymerases, endonucleases. It also contains nucleotides and mineral ions (Ca^{++}, Mg^{++}) etc.

Nucleolus: Nucleoplasm also contains one or more nucleoli, which is non-membrane bound and spherical structure so that the content of nucleus is continuous with the rest of the nucleoplasm. Nucleolus usually attached to chromatin at specific site called nuclear organizer region (NOR). It is visible only during interphase while disappear during cell division.

It contains 85% proteins, 10% RNAs and 5% DNA.

The main function of nucleolus is to form sub units of ribosomes which move to cytoplasm by nuclear pore thus known as ribosome factory of the cell.

Chromatin net is network of nucleoprotein fibres, embedded in nucleoplasm. Chromatin fibres contain genetic information and condensed to form chromosomes during cell division.

Chemically chromatin consists of largely protein both histone (basic protein) and non histone (acidic protein), DNA and little amount of RNA.

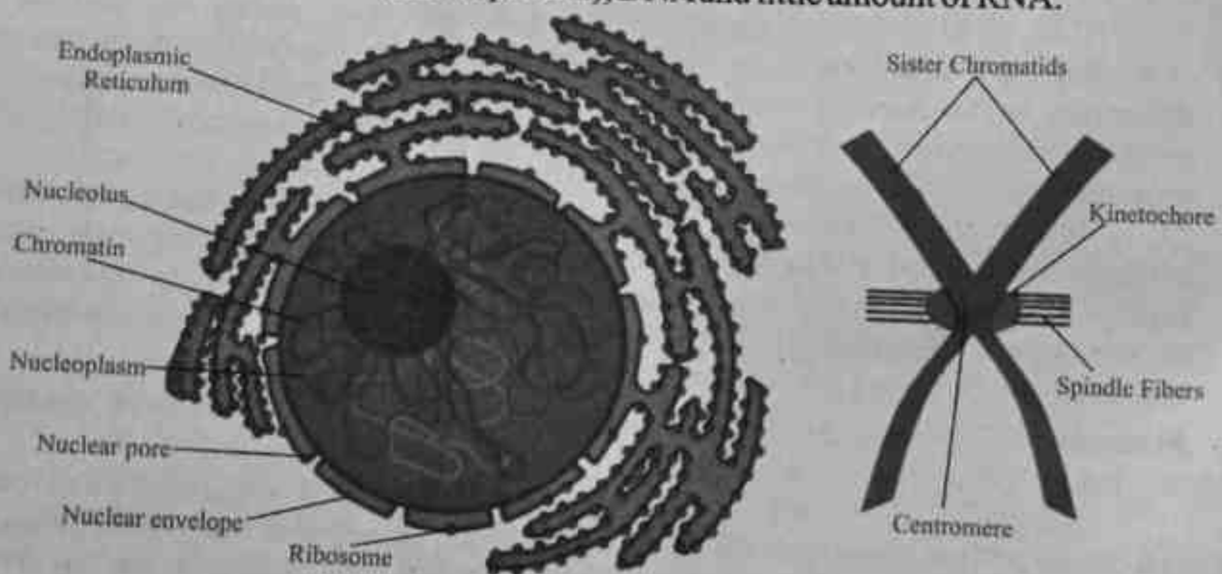


Fig. 1.19 Nucleus and Chromosome

Chromosomes (Greek - chromas : color, Soma: body)

Chromosome is highly condensed form of the chromatin, seen only during cell division. It often deeply absorbs basic dyes during staining thus darkly stained structure.

Chromosomes can be best studied at metaphase stage because size of chromosomes is the shortest during metaphase.

Karyotype

The number of chromosomes is definite for each species, for example in human, each body cell contains 46 chromosomes, Mucor (Fungs) 02, Pea 14, Maize 20, Frog 26, Chimpanzee 48, Fruit Fly 08, *Ascaris* (round worm) 02 etc. Each chromosome can be identified by its size and shape.

Structure of Chromosome

At metaphase stage, each chromosome consists of two identical (sister) cylindrical structures called chromatids. Both sister chromatids are connected together by a common centromere. Around the centromere is a disc of protein called kinetochore where spindle fibers get attached during cell division. Each chromatid is consist of a single long thread of DNA associated with histone and non-histone proteins, RNA is also present in it . Chromosomes are covered by thin proteinaceous sheath called pellicle. They are the vehicle of hereditary material (genes) from parent cell to daughter cell.

> **Do you know?**
>
> *Which human cells do not possess nucleus and which cells are multinucleated?*

1.4 Bacteria as a Model Prokaryotic Cell

Bacteria despite their simplicity, contain a well developed cell structure which is responsible for some of their unique biological structure. The cell wall is composed of **peptidoglycan** (murein) while in eukaryotes it is either composed of **cellulose or chitin.** Beneath the cell wall is cell membrane which lacks sterol such as cholesterol. Their plasma membrane contains respiratory enzymes. In many bacteria slimy capsule is present which is secreted by cell. Flagella are present in most bacteria which are chemically composed of **flagellin** protein. Many of gram -ve bacteria possess hollow proteinaceous filament known as pili. These pili are anchored in the membrane and project through the cell wall. They help in conjugation and attachment on the surface of tissues of the host. They are very thin, only visible under electron microscope and composed of **Pilin protein.** The cell membrane of some bacteria are folded into a structure called mesosome which help in respiration, photosynthesis and formation of new cross walls during cell division. The ribosomes of bacteria are small (70s) but numerous in number. Bacteria have **plasmids** which are small circular rings of DNA and contain genes for drug resistance, heavy metals and insects resistance. Some bacteria also have **transposons.** They are semi parasitic sequences of DNA that can replicate and spread through the host genome. They readily move from one site to another either within or between the DNAs, of bacteria, plasmid or bacteriophage.

Bacteria are haploid organisms, their single chromosome is present in the cytoplasm. That is not covered by nuclear membrane.

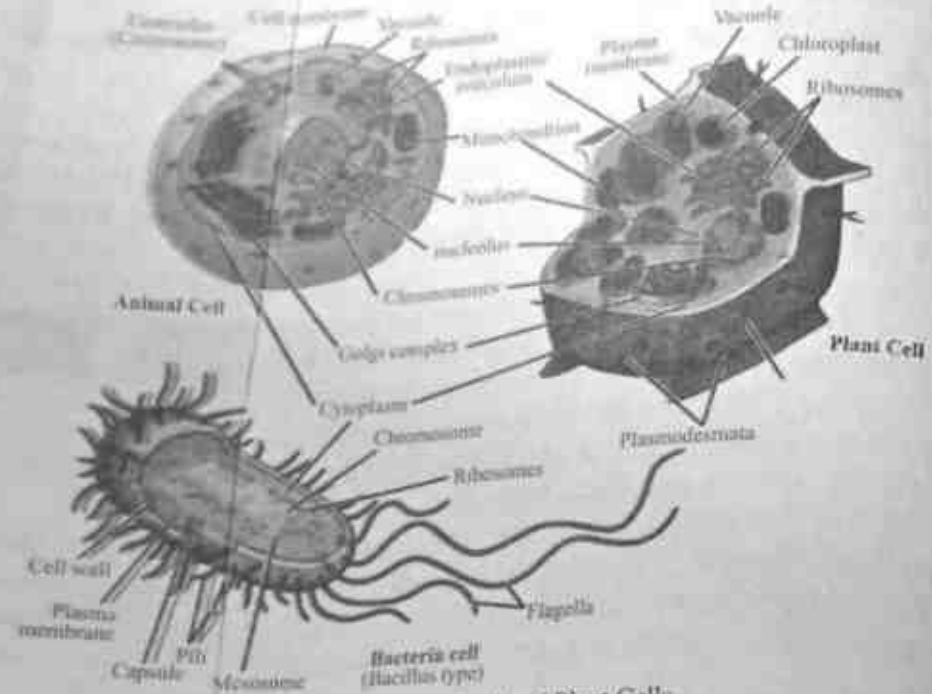


Fig. 1.20 Bacterial, Animal and Plant Cells

Table 1.4 Comparison between prokaryotic and eukaryotic cell

Prokaryotic cell *(pro: before, karyon: nucleus)*	***Eukaryctic Cell*** *(eu: true, karyon: nucleus)*
• *These cells have no prominent nucleus i.e., nuclear material is not bounded by nuclear membrane and nucleolus is also absent.*	• *These cells have distinct nucleus i.e., nuclear material is enclosed by nuclear membrane and nucleolus is also present.*
• *Found only in bacteria and cyanobacteria.*	• *Found in protists, fungi, plants and animals.*
• *Most membranous organelles are absent and double membrane organelles are not present.*	• *Most membranous organelles are present which are either covered by single or double lipo- proteinaceous membrane*
• *Mesosomes are present*	• *Mesosomes are absent*
• *70s Ribosomes.*	• *80s Ribosomes*
• *Single circular chromosome which is composed of only DNA*	• *2 or more linear chromosomes are present which are mostly composed of DNA, Protein and little RNA.*
• *Cell wall contains Polysaccharide with amino acid (peptidoglycan)*	• *Cell wall is present either composed of cellulose (plants, algae) or chitin (fungi) and absent in animal cells*
• *Cell divides by binary fission i.e., no mitosis or meiosis.*	• *Cells divide by mitosis while germ line cells divide by meiosis.*

Activity

Improve your knowledge by searching wikipedia and internet sources and make a list of different techniques used in study of structure of cell. Name the cell organelles that contain DNA. Trace the relationship between ribosome, endoplasmic reticulum, Golgi bodies and lysosomes.

Summary of Structures and functions of cellular components

Component	Structure / Description	Function
Centriole	Located within microtubule organizing center. Contains nine triplet microtubules.	Produces basal body of cilia and flagella; help in mitotic spindle formation.
Chloroplast	It possesses chlorophyll in Thylakoids and is involved in photosynthesis.	Traps, transforms, and uses light energy to convert carbon dioxide and water into glucose and oxygen.
Chromosome	Made up of nucleic acid (DNA) and protein and some RNA.	Controls cellular activities and carries genes.
Cilia, flagella	Both are thread like structures.	Cilia and flagella move small particles through fixed cells and their main role is chemotaxis.
Cytoplasm	Semi fluid enclosed within plasma membrane contains fluid cytosole; organelles and other structures.	Dissolves substances and contain suspended organelles and vesicles.
Cytoskeleton	Interconnecting microfilaments and microtubules; flexible cellular framework.	Help in cell movement; provide support; site for binding of specific enzymes.
Endoplasmic reticulum ER	Extensive membrane system extending throughout the cytoplasm from the plasma membrane to the nuclear envelope.	Storage and internal transport; rough ER is a site for attachment of ribosomes; smooth ER makes lipids and detoxification.
Golgi Apparatus	Stacks of disk and tubular shaped cisternae.	Secretion and packaging cellular substances.
Lysosome	Membrane bound sac like.	Digests polymer into monomer i.e. digestion.

Component	Structure / Description	Function
Microfilament	Rod like structure containing protein actin.	Gives structural support and assists in cell movement.
Microtubule	Hollow, cylindrical structure.	Help in movement of cilia flagella, and chromosomes; transport system.
Microtubule organizing center	Cloud of cytoplasmic material that contains centrioles	Dense site in the cytoplasm that gives rise to large numbers of microtubules with different functions in the cytoskeleton
Mitochondrion	Organelle with double, folded membranes, contains DNA, enzymes and coenzyme.	Convert energy into a form the cell can use (power house).
Nucleolus	Rounded mass within nucleus; contains RNA and protein.	Preassembly point for ribosomal subunits.
Nucleus	Spherical structure surrounded by a nuclear envelope; contains nucleolus, DNA and nucleoplasm.	Contains DNA that control cell's genetic program and metabolic activities.
Plasma membrane	The outer bilayer boundary of the cell; composed of protein, cholesterol, and phospholipids.	Protection; regulation of material movement; cell-to-cell recognition and gives shape.
Ribosome	Contains rRNA and protein; some are free, and some are attached to ER.	Site of protein synthesis.
Vacuole	Single membrane-bounded, sac in the cytoplasm.	Storage site of food and other compounds; also pumps water out of a cell (contractile vacuole while in plant non-contractile)
Vesicle	Small, membrane-bounded sac; contains enzymes or secretory products.	Site of intracellular digestion, storage, or transport.

Summary

- Cell fractionation technique is used to separate cell organelles for detailed study.
- Staining is a technique used in microscopy to enhance contrast in microscopic image.
- The use of microscope to assist in dissection is called microscopic dissection.
- Tissue culture is the growth of tissue or cells separate from the organism.
- Chromatography is a technique which is used to separate different chemical compounds from a mixture.
- Electrophoresis is a procedure used to separate fragment of a charge bearing molecules according to their size, shape and molecular weight.
- The spectrophotometer is an instrument that measures the amount of light passed through a sample.
- The measurement of an object by means of an eye piece graticule is called micrometery.
- Cell wall is present in plants, fungi, algae, and in prokaryotic cell.
- Plasma membrane is composed of 60-80% protein and 20-40% lipids.
- Glycoproteins and glycolipids act as cell surface markers.
- The liquid portion of cytoplasm is called cytosol.
- The ribosome is known as the protein factory of cell.
- In muscle cell smooth endoplasmic reticulum is called sarcoplasmic reticulum.
- Golgi bodies are concerned with cell secretion.
- Lysosome contains about forty different types of digestive enzymes.
- Peroxisomes and glyoxisomes are collectively called microbodies.
- The membrane that encloses the vacuole is called tonoplast.
- Mitochondria are the sites of cellular respiration, the metabolic process that use oxygen to generate energy hence called power houses of cell.
- The disc like structures in chloroplast is known as thylakoid which are site of light reactions of photosynthesis.
- Centriole is non membranous cell organelle found in animal cells.
- The cytoskeleton consists of micro filaments.
- Cilia and flagella have similar structure and function but cilia are much smaller in size than flagella.
- Pili or fimbriae are the structure in bacteria which help in conjugation and attachment with host.

EXERCISE

Section I: Objective Questions

Multiple Choice Questions

A. Select the correct answer.

1. Who observed nucleus in the cells of orchids under the microscope?
   (a) A.F.A. King (b) Robert Brown
   (c) Galileo (d) Henri Dutrochet
2. Robert Brown observed nucleus in 1831 in the cells of
   (a) Pea (b) Monkey
   (c) Orchids (d) Euglena
3. What is called the basic structural as well as functional unit of all living organisms?
   (a) Cell (b) Nucleus
   (c) Gland (d) Tissue
4. All cells arise from
   (a) Dead matter (b) Plants
   (c) Saprophytes (d) Pre-existing cells.
5. The function of an organism is the result of sum of activities and interaction of the
   (a) Neurons (b) Tissues
   (c) Muscles (d) Cells
6. Which type of cells can contract and relax?
   (a) Muscle Cells (b) Excretory Cells
   (c) Nervous Cells (d) Phloem Cells
7. Which type of cells transmit nerve impulses?
   (a) Muscle Cells (b) Nerve Cells
   (c) Nephron Cells (d) Xylem Cells
8. Which type of cells secrete hormones?
   (a) Tissues Cells (b) Muscles Cells
   (c) Respiratory Cells (d) Gland cells
9. Which of the following blood cells carry oxygen?
   (a) W.B.Cs (b) Platelets
   (c) R.B.Cs (d) Thrombocytes
10. In plants, which type of cells carry out photosynthesis?
    (a) Chlorenchymatous (b) Sclerenchymatous
    (c) Meristem cell (d) Collenchymatous

11. The modern technology enables us to isolate various components of cells including its organelles by a process known as
(a) Isolation
(b) Fractionation
(c) Centrifugation
(d) Fermentation

12. It is the outermost layer of the animal cell. It is thin, delicate, elastic and capable of limited self repair". This statement is true for which cell structure?
(a) Cell Wall
(b) Cell Membrane
(c) Nuclear Membrane
(d) Ribosome

13. Cell membrane allows some of the soluble particles to pass through but prevents others. This property is most appropriate to membrane which is
(a) Permeable
(b) Impermeable
(c) Selectively Permeable
(d) Semipermeable

14. In many animal cells the cell membrane helps to take in materials by infolding in the form of vacuoles. This type of intake is termed as
(a) Endocytosis
(b) Phagocytosis
(c) Pinocytosis
(d) Glycolysis

15. Which is called the ingestion of solid material through the cell membrane?
(a) Endocytosis
(b) Phagocytosis
(c) Pinocytosis
(d) Glycolysis

B. Fill the blank spaces with suitable words.

1. Borax carmine is an example of .... staining.
2. The term tissue culture was used by American pathologist ....
3. The discovery of cell was directly related with the invention of the ....
4. The cell is the unit of function and structure of ....
5. Magnification power of microscope depends on ....
6. Group of ribosomes attached to mRNA is known as ....
7. Ribosomes are synthesized in ....
8. The factory for protein synthesis is the ....
9. Secretory and packaging organelle of cell is called ....
10. Glyoxisomes are the most abundantly found in ....
11. Microfilaments are composed of contractile ....
12. Mitochondrial infoldings are called ....
13. The inner surface of cristae in mitochondrial matrix has small knob like structure known as ....
14. Grana is the site for ....
15. Chromatids are held together at ....

Section II: Short Questions.

1. Differentiate between Cilia and Flagella.
2. What is differential staining?
3. What is paper chromatography?
4. Define Spectrophotometry.
5. Why mitochondria is called power house of cell?
6. How mitochondria are similar with bacteria?
7. Draw labeled diagram of chloroplast .
8. Which organelle is called the factory of protein synthesis and why?
9. Write down any three differences between prokaryotic cell and eukaryotic cell.
10. Write the functions of lysosome.

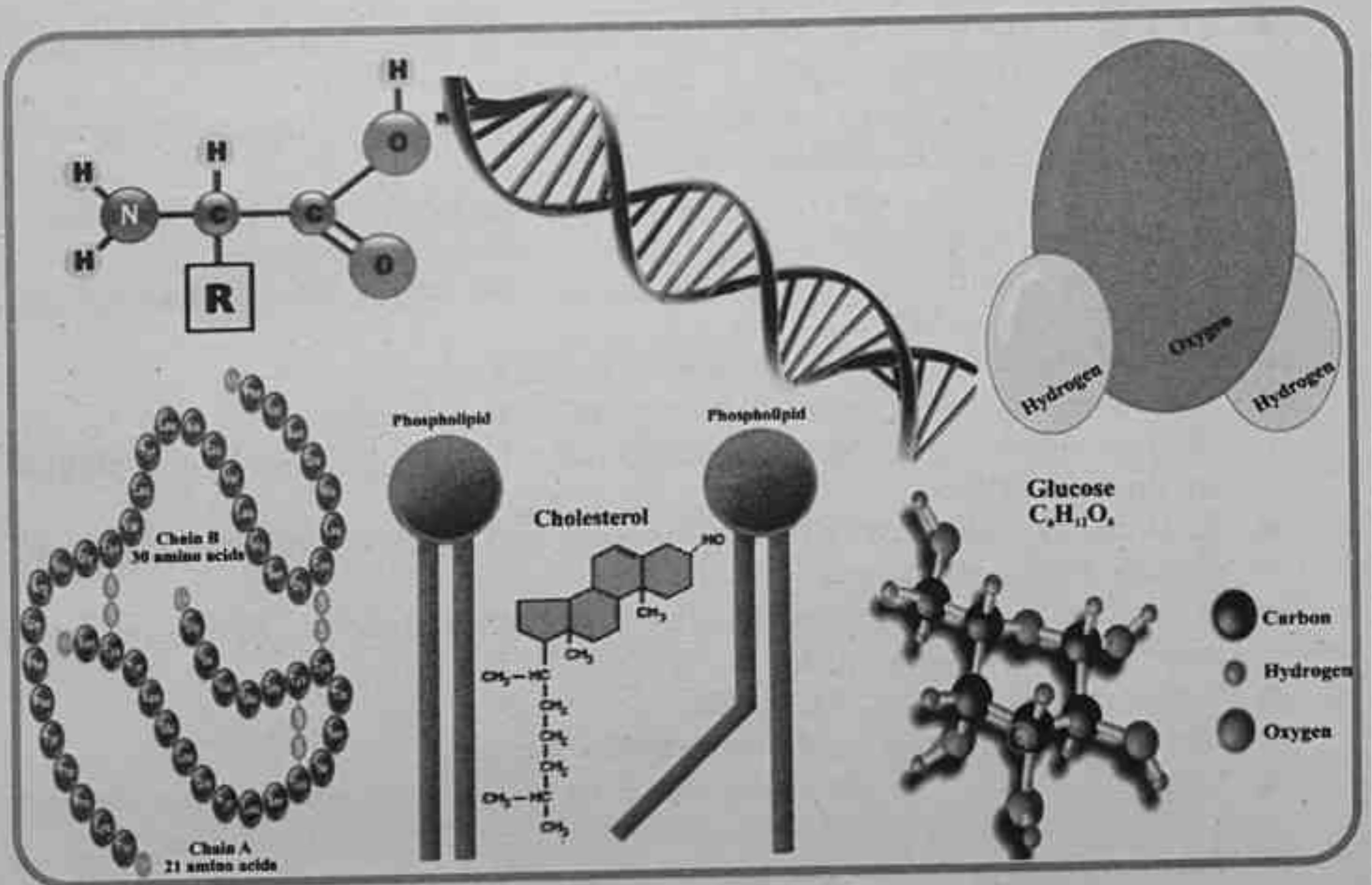
Section III: Extensive Questions.

1. Describe the process of Electrophoresis.
2. Write a detailed note on chromatography.
3. Explain the structure of plant cell wall.
4. Explain the fluid mosaic model of plasma membrane. Write down some important functions of plasma membrane.
5. Explain the structure of ribosome and Golgi complex.
6. Describe the structure of mitochondria and its role in cellular respiration.
7. Define cytoskeleton and describe its components in detail.
8. Explain the mechanism of movement of cilia and flagella.
9. Illustrate the structure of nucleus.
10. Describe the role of chloroplast in photosynthesis.

UNIT 2
BIOLOGICAL MOLECULES

Major Concepts

2.1 Biological Molecules in Protoplasm.
2.2 Importance of Water for Life
2.3 Carbohydrates, their Structure, Role and Classification.
2.4 Proteins, their Structure, Classification and Role
2.5 Lipids, their Structure, Classification and Role.
2.6 Nucleic Acid, its Types, Structures, Functions.
2.7 Conjugated Molecules.



Students Learning Outcomes

On completion of this unit students will be able to:

- Introduce biochemistry and describe the approximate chemical composition of protoplasm.
- Distinguish carbohydrates, proteins, lipids and nucleic acids as the four fundamental kinds of biological molecules.
- Describe and draw sketches of the dehydration synthesis and hydrolysis reactions for the making and breaking of macromolecule polymers.
- Explain how the properties of water (high polarity, hydrogen bonding, high specific heat, high heat of vaporization, cohesion, hydrophobic exclusion, ionization and lower density of ice) make it the cradle of life.
- Define carbohydrates and classify them.
- Distinguish the properties and roles of monosaccharides, write their empirical formula and classify them.
- Compare the isomers and stereoisomers of glucose.
- Distinguish the properties and roles of disaccharides and describe glycosidic bond in the transport of disaccharides.
- Distinguish the properties and roles of polysaccharides and relate them with the molecular structures of starch, glycogen, cellulose and chitin.
- Justify that the laboratory manufactured sweeteners are left handed sugars and can not be metabolized by right handed enzymes.
- Define proteins and amino acids and draw the structural formula of amino acids.
- Outline the synthesis and breakage of peptide linkages.
- Justify the significance of the sequence of amino acids through the example of sickle cell haemoglobin.
- Classify proteins as globular and fibrous proteins.
- List examples and roles of structural and functional proteins.
- Define lipids and describe the properties and roles of acylglycerols, phospholipids, terpenes and waxes.
- Illustrate the molecular structure (making and breaking) of an acylglycerol, a phospholipid and a terpene.
- Evaluate steroids and prostaglandins as important groups of lipids and describe their roles in living organisms.
- Define nucleic acids and nucleotides.
- Describe the molecular level structure of nucleotides.
- Distinguish among the nitrogenous bases found in the nucleotides of nucleic acids.
- Outline the examples of a mononucleotide (ATP) and a dinucleotide (NAD).
- Illustrate the formation of phosphodiester bond.
- Explain the double helical structure of DNA as proposed by Watson and Crick.
- Define gene is a sequence of nucleotides as part of DNA, which codes for the

- Explain the general structure of RNA.
- Distinguish in terms of structures and roles, the three types of RNA.
- Define conjugated molecules and describe the roles of common conjugated molecules i.e. glycolipids, glycoproteins, lipoproteins and nucleoproteins.

Introduction

Biological molecules are present in living organisms such as proteins, carbohydrates, lipids, nucleic acids. The study of biological molecules, their processing and significance for living organisms is called to as **Biochemistry.** The knowledge of Biochemistry is important in many ways for example, to understand the working of biological systems, development in agriculture, pharmaceutical industries, food industries and more importantly for the expansion of field of genetics and biotechnology.

2.1 Biological Molecules in Protoplasm

All the matter of universe contains more than 100 elements although living organisms are composed of 25 elements, yet only 16 of these are essential for life. Six most common elements in all living organisms are hydrogen, carbon, oxygen, nitrogen, sulphur and phosphorous.

They account for about 99% of total mass of living organisms.

Do you know?

Protoplasm is the living content of the cell that is surrounded by a plasma membrane. It is a general term for cytoplasm and nucleoplasm.

Biological importance of hydrogen oxygen, nitrogen and carbon is largely due to their valencies having one, two, three and four respectively and their ability to form more stable covalent bond than any other element with same valencies.

Table 2.1 Approximate Chemical Composition of a Mammalian Cell

Water	70%
Protein	18%
Carbohydrate	4%
Lipids	3%
DNA	0.25%
RNA	1.1%
Other organic substances	
Enzymes, Hormones etc.	2%
Inorganic ions	1%

Table 2.2 Approximate Percentage of Bioelements in human body

Oxygen	65%
Carbon	18.5%
Hydrogen	9.5%
Nitrogen	3.3%
Calcium	1.5%
Phosphorus	1%
Potassium	0.4%
Sulphur	0.3%
Sodium	0.2%
Chlorine	0.2%
Magnesium	0.1%
Trace elements (14 types) less than	0.01%

Do you know?

The six most abundant elements in human body are oxygen, carbon, hydrogen, nitrogen, oxygen, calcium and phosphorus.

In biochemistry, **trace elements** are dietary elements that are needed in a very minute quantity for proper growth, development and functioning of the organism. Examples of trace elements are:

Copper, Boron, Chromium, Iodine, Zinc, Iron, Manganese, Cobalt, Fluorine, Silicon, Vanadium, Molybdenum, Tin and Selenium.

Macro-organic molecules:

There are four types of macro organic molecules in living things. These are proteins, carbohydrates, lipids and nucleic acids.

Do you know?

Macromolecules are made from many repeating units i.e., polymers and have higher molecular weight, while Micro molecules are individual units of polymers and have low molecular weight.

Protein are the most abundant organic compounds in protoplasm. Basic units of proteins are amino acids. Proteins are present in different forms like enzymes, hormones, antibodies etc. These are building materials of life.

Carbohydrates are composed of C, H, O and provide fuel for the metabolic activities of the cell, also store reserve food in cell.

Lipids are heterogenous groups of hydrophobic compounds, which act as reserved food stored and building material for cellular organelles.

Nucleic acids (DNA and RNA) are most essential organic compounds, for living organisms, their basic unit is nucleotide. DNA acts as hereditary material, while RNAs synthesize proteins under the instruction of DNA.

Main Metabolic Reactions in a Cell:

Condensation:

Specific small molecules when join together they form large molecule or polymers. This process is called condensation, in which water is produced, while energy is used. During condensation, when two monomers join, an **OH⁻** is removed from one monomer and **H⁺** is removed from the other. The condensation is also called dehydration synthesis.

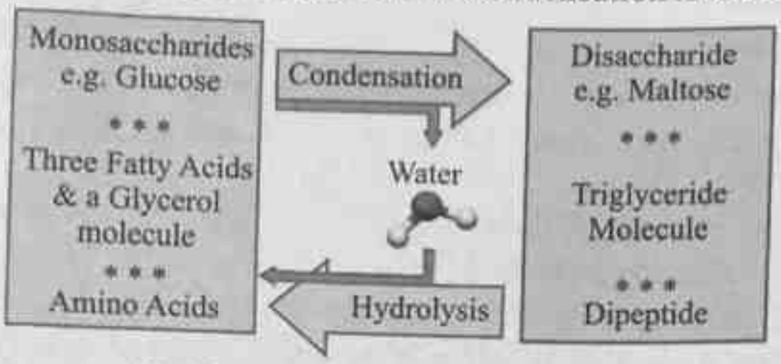


Fig. 2.1 Condensation and Hydrolysis

Hydrolysis:

Usually means the breakdown of polymer into monomers. In this process water is used, one monomer gets H^+ and other OH^- ion with the help of enzymes. When a bond is broken, energy is released. This process is also known as hydration.

2.2 Biological Importance of Water

Water is the most abundant component of protoplasm, with out it, life can not exist. It is important for different reasons; Such as vital chemical constituent of living cells and secondly it provides an environment for those organisms that live in water. The bodies of living organisms contain about 70-90% of water. Water has following important properties.

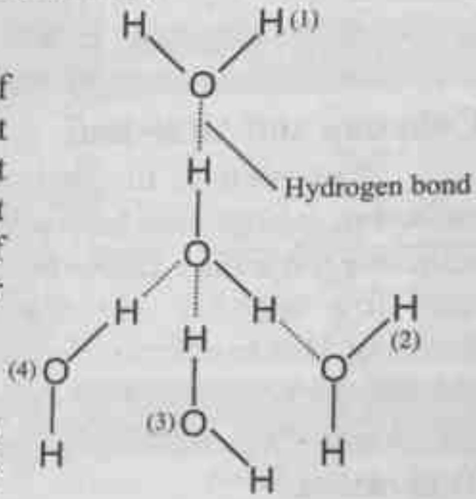


Fig. 2.2 Hydrogen bond

High Polarity:

Water is a polar molecule because its hydrogen contains slightly positive charge and oxygen contains slightly negative charge. A polar covalent bond is formed between hydrogen and oxygen atoms of water. Due to this polar covalent bond water is called polar molecule and thus it is universal solvent for polar substances, ionic compounds or electrolytes. The non-polar molecules having charged groups on their molecules can also be dissolved in water like sugar.

Do you know?

Bone contains only 20% water while brain 85% and blood 88%. The body of jellyfish contains 99% of water.

Hydrogen Bonding:

Hydrogen bond is electrostatic attraction between two polar groups that occurs when an hydrogen atom covalently bond to a highly electronegative atom such as oxygen, nitrogen and fluorine.

Due to hydrogen bonding water has a specific boiling and freezing point. (Boil at 100°C and freezes at 0°C). The boiling and freezing point of water is important to sustain life on earth.

High Specific Heat:

The heat capacity of water is the amount of heat required to raise the temperature of one gram of water by one degree centigrade (15°C to 16°C), i.e., one calorie or 4.18 joules.

The high heat capacity of water means that a large increase in heat energy results in a relatively small rise in temperature. This is because most of the energy is used in breaking hydrogen bonds which restrict the movement of molecules. Due to this property of water, hot water cools slowly while cool water gets hot slowly. As a result the temperature of earth and living bodies does not change quickly and environment remains stable.

High Heat of Vapourization:

High heat of vapourization is a measure of the heat energy required to vapourize a liquid. A relatively large amount of energy is needed to vapourize water. This is due to hydrogen bonding. High heat of vapourization is useful for animals and plants to get rid of excess body heat during sweating, panting and transpiration etc.

Cohesion and Adhesion:

Cohesion is the intermolecular attraction between similar molecules while **adhesion** is attraction between dissimilar molecules. Water exhibit both cohesive and adhesive properties. Due to the cohesion water molecules stick together, remain in liquid and flow together. The cohesion is due to hydrogen bonding. Due to adhesive force water stick with the wall of the container (such as in xylem wall). This property is because of the polar nature of water.

Ionization:

It is the process by which an atom or a molecule acquires a negative or positive charge by gaining or losing electrons to form ions. On ionization water releases equal number of **H** and **OH** ions. The state of equilibrium is maintained at 25°C.

Hydrophobic Exclusion:

It is the reduction of the contact area between water and hydrophobic substances when placed in water. This property of water plays an important role in maintaining the integrity of lipid bilayer of all plasma membranes.

Tit bits

The heat of vapourization of water is 574 kcal/kg and evaporation of only 2ml out of one liter of water, lowers the temperature of remaining water by 1°C.

Tit bits

The part of compound that reacts with an other compound is called functional Group e.g., Hydroxyl Group, Keto Group, Aldehyde Group and Corboxyl Groups.

Density and Freezing Properties:

The density of water decreases below 4°C, therefore, ice is lighter than water, and tends to float. It is the only substance whose solid form is less denser than its liquid, because it has maximum hydrogen bonds. Ice insulate the water below it thus increases the chances of survival of organisms during winter.

2.3 Carbohydrates

These are organic compound, containing the elements of Carbon, Hydrogen and Oxygen in the ratio of 1:2:1. Their general formula is $\mathbf{C_x(H_2O)_y}$, where **x** and **y** are variable numbers. Carbohydrates are also known as hydrated carbon because the number of hydrogen and oxygen atom is same as in water.

Chemically they are polyhydroxy aldehyde or ketone or complex substances.

Their chemistry is determined by aldehyde and ketone group e.g. aldehyde are very easily oxidized and hence are powerful reducing agents. Carbohydrates are commonly called sugars or saccharides.

Tit bits

Water is effective lubricant, prevent friction e.g. Tears protect the surface of eyes, from rubbing of eye lids, act as cushion around many organs (cerebro spinal fluid around central nervous system and amniotic fluid around foetus prevent from trauma).

Do you know?

The source of carbohydrates are green living things (e.g. Plants cyanobacteria, algae and many bacteria).

Classification:

There are three main classes of carbohydrates, that is monosaccharide, Oligosaccharide and polysaccharide.

Monosaccharide: (Gk. Mono: one, Saccharide: sweets or sugar)

They are simplest form of carbohydrates which cannot be hydrolyzed into simple units. The monosaccharides are small organic compounds made up of one sugar molecule, containing 3 to 7 carbon atoms.

They are very sweet in taste and easily soluble in water. All carbon atoms in a monosaccharide except one have a hydroxyl group while the remaining carbon either contain aldehyde or ketone. The sugar with aldehyde group is called aldo sugar and with ketone group is called keto sugar. Specific formula for monosaccharide is $C_n(H_2O)_n$ where, n is the number of carbon atoms in monosaccharides.

What are Vitamins?

Any of various organic substances that are essential for normal growth and nutrition. They are needed in minute quantities in the diet, act especially as coenzymes and precursors of coenzymes in the metabolic process but do not provide energy or serve as building unit. These are present in natural food stuffs or some times produced within body.

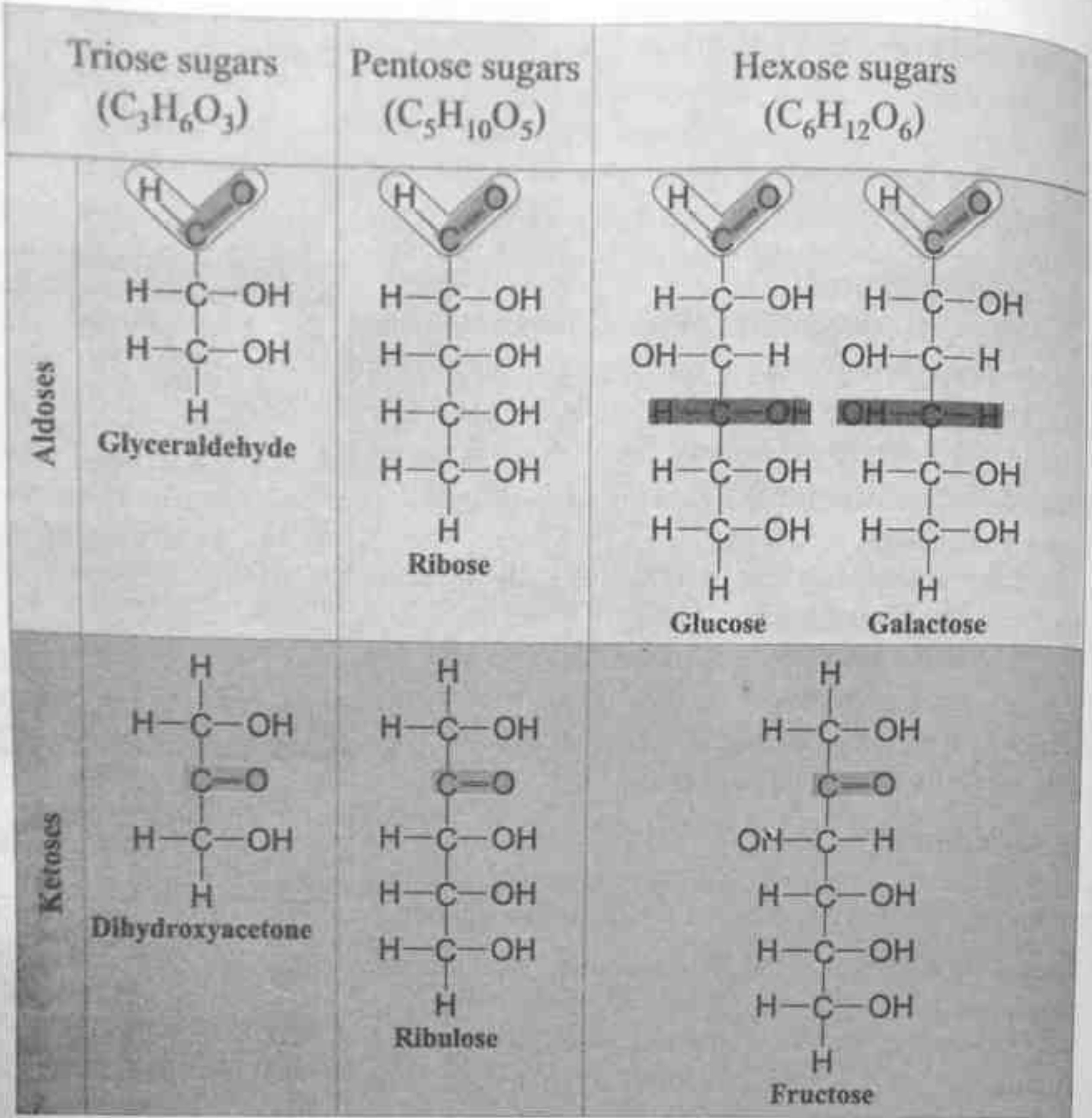


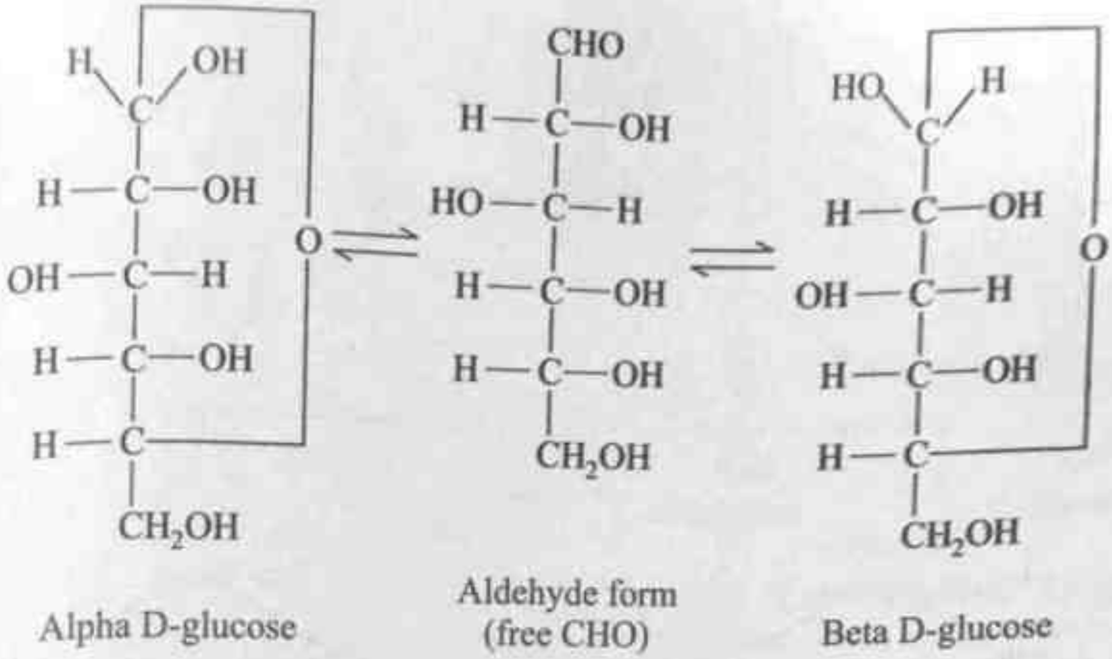
Fig. 2.3 Monosaccharides

Molecular and structural formula:

The molecular formula for a hexose is written as $\mathbf{C_6H_{12}O_6}$. It is useful to show the arrangement of atoms in a molecule by a diagram which is known as structural formula.

Ring structure:

Pentoses and hexoses usually form rings in water. In pentoses and hexoses the chain of carbon atom is long enough to close up on itself and form a stable ring structure e.g. glucose. When glucose forms a ring, carbon atom No.1 joins to the oxygen on carbon atom No.5. The ring, therefore, contains oxygen and the last carbon of glucose is not part of ring.



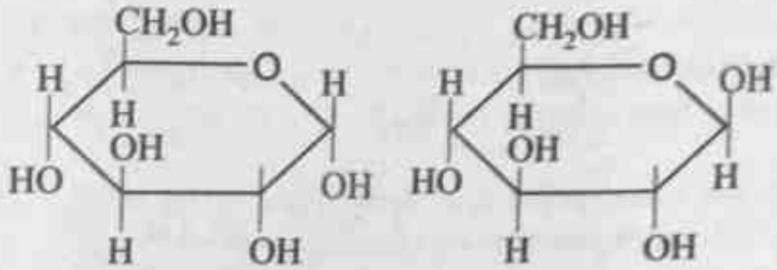


Fig. 2.4 Linear and ring forms

The hydroxyl group, (OH) on carbon atom number one may be above or below the plane of ring. If it is below the ring is known as alpha glucose (α -glucose) and if it is above then known as β-glucose (Beta glucose). The two different forms of same chemical is known as isomer.

Trioses:

Their formula is $C_3H_6O_3$ for example glyceraldehyde, dihydroxy acetone. These are intermediate substances in cellular respiration and photosynthesis.

Pentoses:

Their formula is $C_5H_{10}O_5$ e.g. ribose, deoxyribose and ribulose. Ribose is the component of RNA, ATP, NAD, FAD, NADP etc. Deoxyribose is the component of DNA while ribulose is the component of RUBP which is the CO_2 acceptor in photosynthesis.

Hexoses:

Their formula is $C_6H_{12}O_6$ e.g., glucose, fructose, galactose. Glucose is the most common respiratory substrate and also most common monosaccharide.

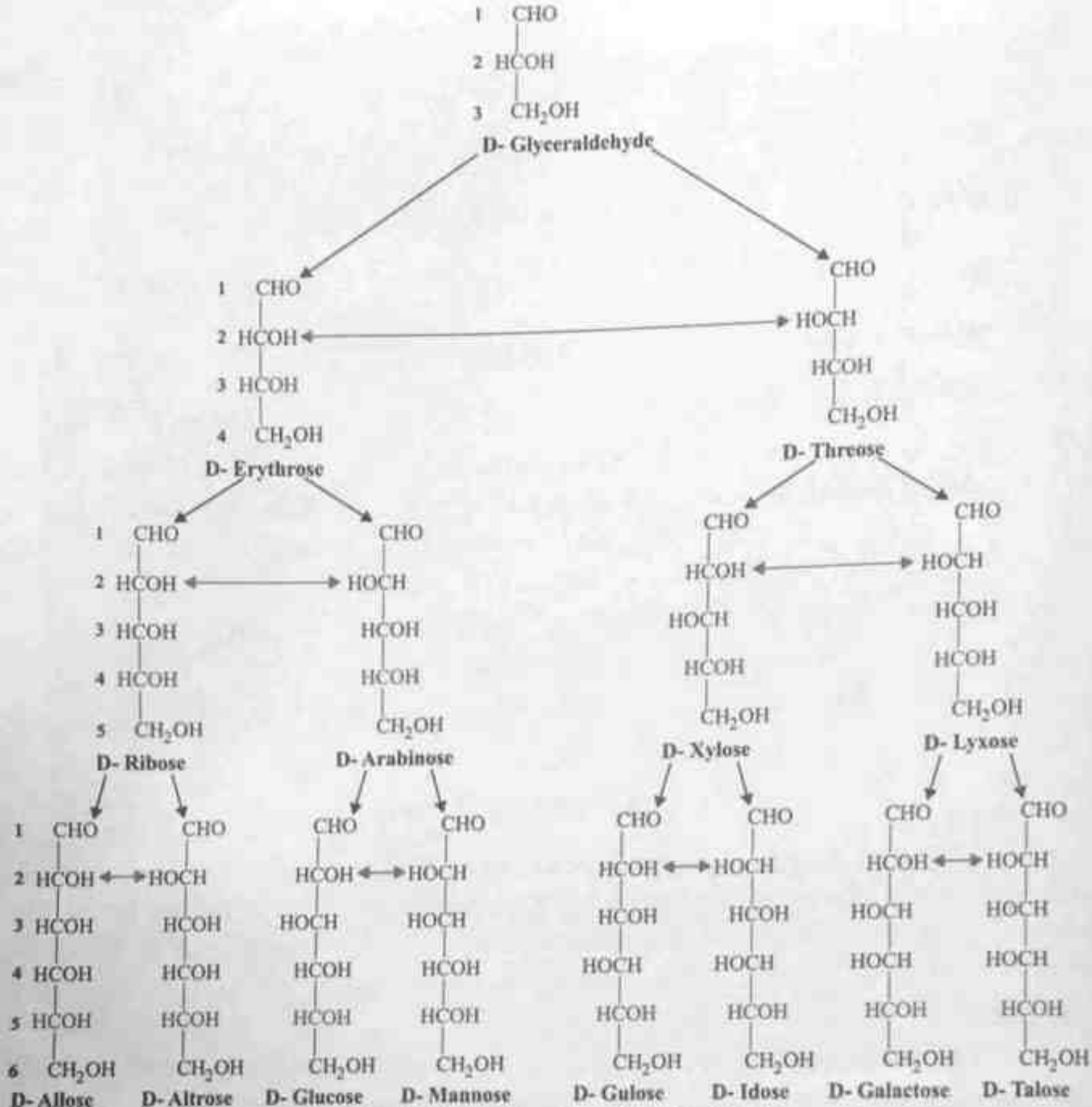


Fig. 2.5(a) Stereochemistry of the D-aldoses

Comparison between Structural Isomers and Stereoisomers:

Isomers (Gk. Iso: equal, meros: part) are molecules with the same molecular formula but different chemical structure. It means that isomers contain same number of atoms of each element but have different arrangements.

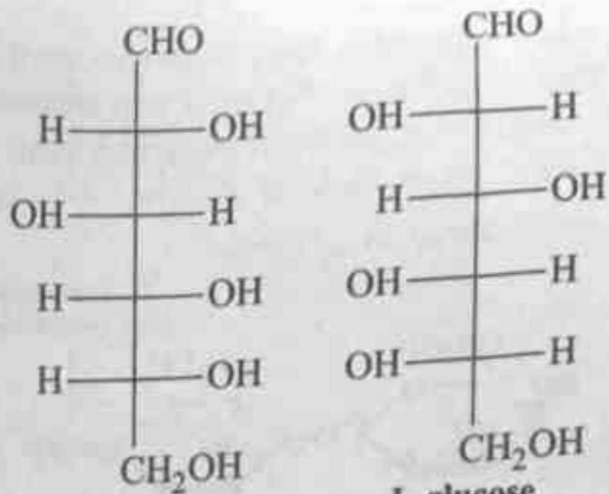
- Isomers do not generally share similar properties,

> **Activity**
>
> *Can you justify that laboratory manufacturing sweetners are the left handed sugar and cannot be metabolized by the right handed enzyme.*

unless they also have same functional group. There are two main forms of isomerism, the structural isomerism and stereoisomerism.

In **structural isomers** (also called constitutional isomers) the atoms and functional groups are joined together in different ways, glucose and fructose are structural isomers.

In **stereo-isomerism** the bond structure is the same but the geometrical positioning of atom and functional groups in space differs e.g., **D-glucose** and **L-glucose.**



D-glucose **L-glucose**

Fig. 2.5(b)

The Laboratory Manufactured Sweeteners are "Left - handed" Sugars:

Two forms of chemical compounds may exist, that are mirror image of each other. A suitable analogy is pair of gloves, they can be either left handed or right handed. Sugar are also left handed and right handed molecules.

Our digestive enzymes can only digest the right handed sugar molecules but generally do not digest the left handed and allow them to pass through body without digestion.

The LH sugar have same physical properties as D-glucose, therefore, may be used instead of D-glucose e.g., for baking and also making ice cream. The left-handed sugar are not commonly used because they are expensive, not commonly available and their over use cause serious disturbance for diarrhea patients. The laboratory manufactured sugar such as tagatose, sucralose etc. are examples of LH sugar. These sugar molecules can not be digested because mostly the enzymes for their digestion are not synthesized in the body and our cells do not have receptors for them. LH sugar are not converted into fats.

Oligosaccharides:

They are made up of 2 to 10 monosaccharides. Some examples of oligosaccharides are Disaccharides, Trisaccharides, Tetrasaccharides. The most common oligosaccharides are disaccharides.

Disaccharide:

It is made up of two monosaccharide (usually hexoses) combine by means of chemical reaction known as condensation.

Disaccharides are less sweet in taste and less soluble in water as compared to monosaccharides.

Disaccharides on hydrolysis give two

Tit bits

Malting is the process of converting of barley or other cereal grains into malt for use in brewing, distilling. This process takes place in malt house or malting floor.

monosaccharides, some common examples are maltose, lactose, sucrose and cellobiose. The bond formed between two monosaccharide is called glycosidic bond and it is normally formed between carbon atom 1 and 4 of neighbouring unit while in sucrose between carbon 1 of glucose and carbon 2 of fructose. The general formula of disaccharide is $C_{12}H_{22}O_{11}$.

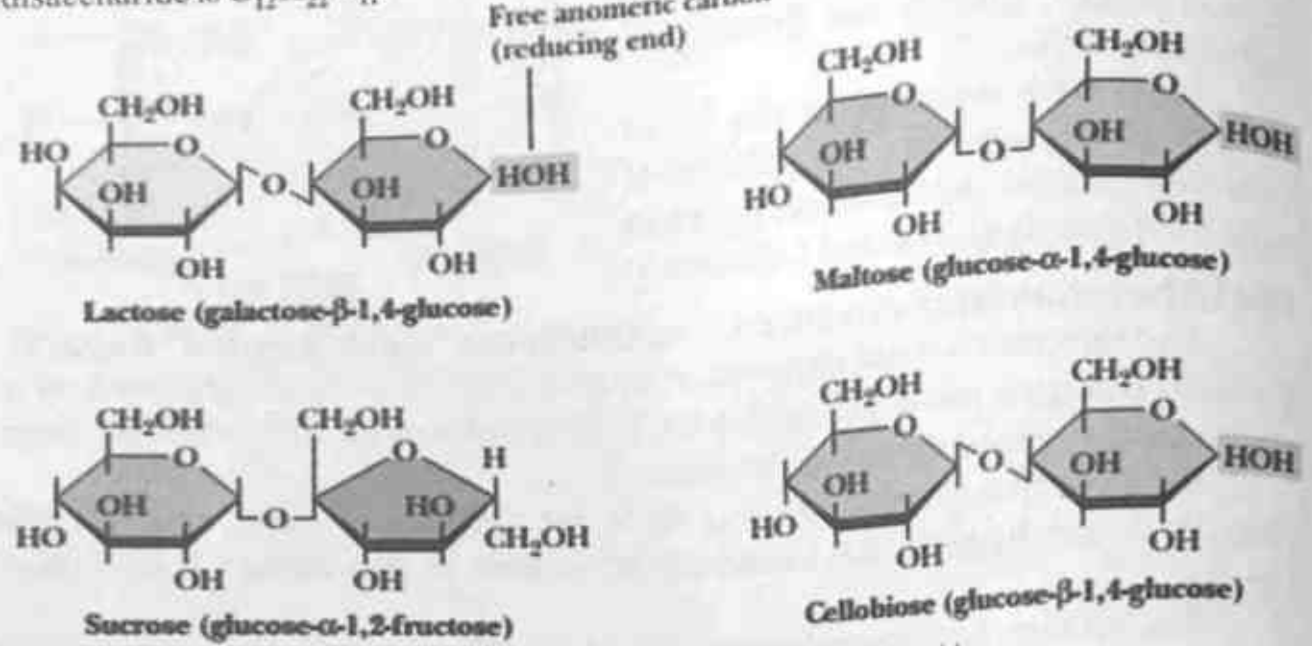


Fig 2.6 Structures of several common disaccharides.

The Role of Disaccharides:

Maltose is a disaccharide found in fruits and also found in our digestive tract as a result of breakdown product during digestion of starch by enzyme called amylase. It is also used in brewing industries to synthesize alcohol.

Lactose is milk sugar and it is an important energy source for young mammals. The **sucrose** or cane sugar is the most abundant disaccharide in nature and is hydrolyzed into glucose and fructose. It is obtained commercially from sugar cane or sugar beet, the sugar we normally buy in shops. All monosaccharides and some disaccharides including maltose and lactose are reducing sugars because these sugars can carry out a type of chemical reaction known as reduction. Sucrose is the most common non reducing sugar.

> **Tit bits**
>
> *Starch gives blue color when treated with iodine and gives many molecules of glucose on hydrolysis.*

> **Tit bits**
>
> *Glycogen gives a red color when treated with iodine while cellulose does not show any reaction with iodine thus does not give color.*

Polysaccharides:

Polysaccharides exhibit following properties. They are made up of several monosaccharide, linked by glycosidic linkage may be branched or unbranched. They are tasteless and insoluble or some time sparingly soluble in water. They are most abundant in nature. Their general formula is $C_x(H_2O)_y$.

Types of polysaccharide:

Important polysaccharides are starch, glycogen, cellulose, dextrin, agar, chitin, pectin. All the above polysaccharides function chiefly as food, energy storage and structural material.

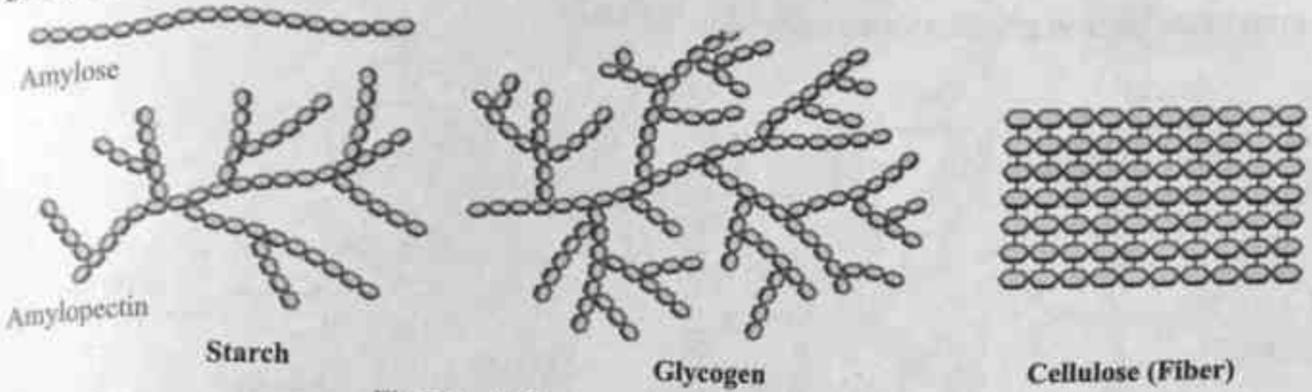


Fig.2.7 Different types of polysaccharides

Starch:

Starch is the polymer of glucose. It is major fuel store in plant and main source of food for animals. There are two types of starches, the simplest form is **amylose,** which has straight chain structure and joined by 1-4 **glycosidic** linkage. The other form is **amylopectin** which is more complexed and branched polymer with 1-6 linkage at branched point. Amylose is soluble in warm water but insoluble in cold water due to its simple structure while amylopectin is neither soluble in warm nor in cold water.

Cellulose:

It is a polymer of glucose and the most abundant carbohydrate in nature, unlike starch and glycogen it has structural role and main constituent of cell wall of plants and

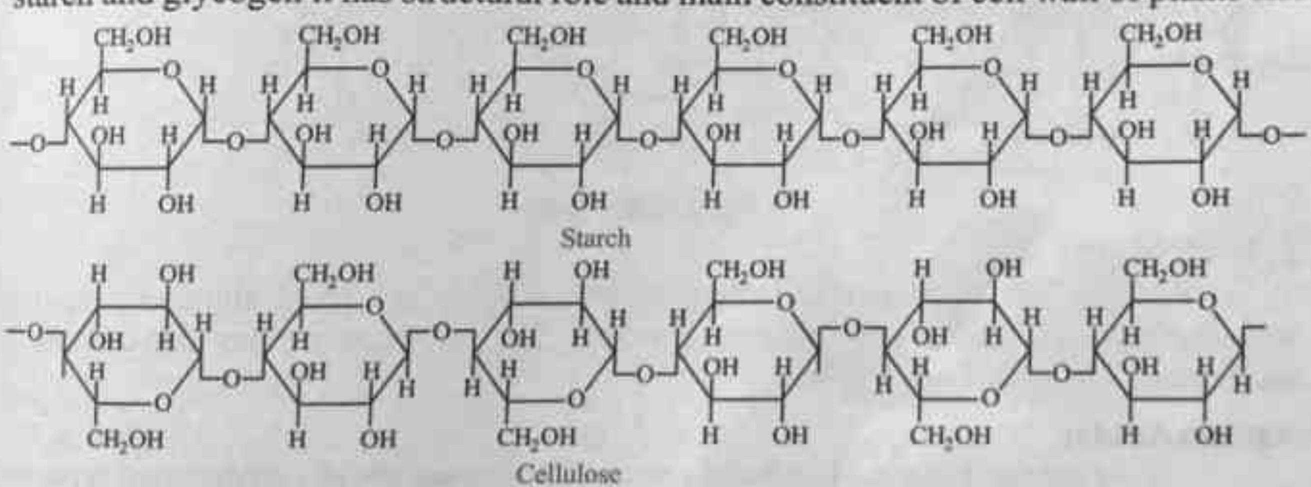


Fig. 2.8 Cellulose and Starch

algae. Cellulose is highly insoluble in water and we can not digest it because we do not have cellulase enzyme. However, herbivores can digest it because their digestive tract contain micro-organisms like bacteria, yeast, protozoans which secrete cellulase enzyme.

Glycogen:

It is a polymer of glucose and also called as animal starch. It is stored in liver and muscles. It is also found in fungi. It is insoluble in water due to complex structure and converted back to glucose monomer when needed.

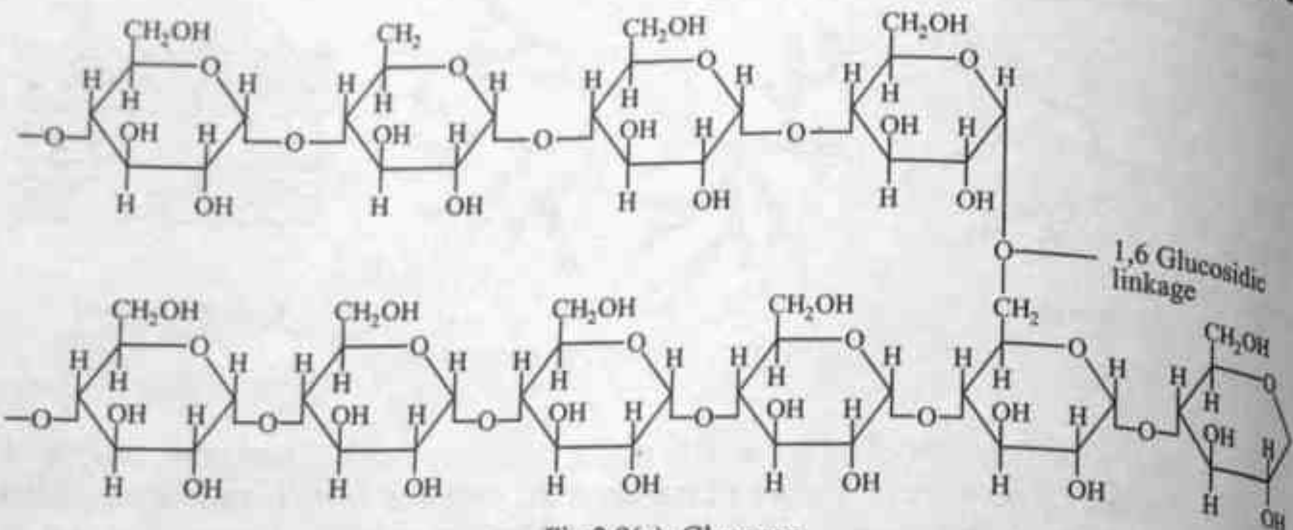


Fig.2.9(a): Glycogen

Chitin:

It is the structural nitrogenous polysaccharide and closely related to cellulose, found in cell wall of fungi and exoskeleton of arthropods.

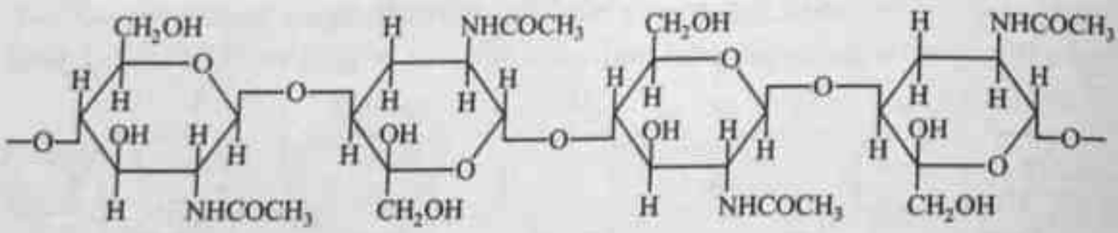


Fig. 2.9(b): Chitin

2.4 Proteins

Proteins are polymers of amino acids and they are most abundant organic substances in the cell. All proteins must contain C,H,O and N, some may also contain, P and S while few have Fe, I, Mg^{+} etc.

Amino Acids:

These are the building blocks of proteins. There are about 170 different types of amino acids discovered in cells and tissues, out of these 25 are involved in protein synthesis. Most proteins, however, are made up of 20 types of amino acids. Each amino acid consists of an alpha carbon. On one side of this alpha carbon NH_2 (amino group) is present while on other side COOH (Carboxylic acid group) is present.

On the third side Hydrogen is present while fourth side radical group is attached which is different in all amino acids.

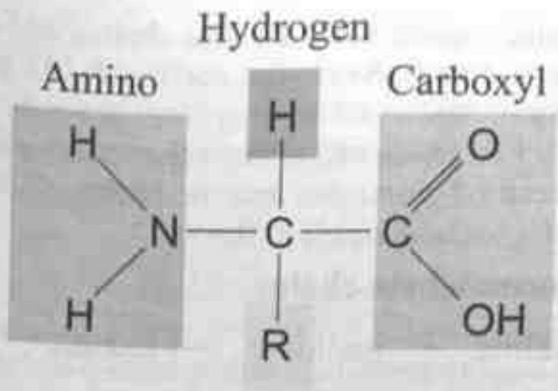
Many amino acids are non essential because body of the organisms can synthesize them, thus are mostly not required as dietary food. Few amino acids are essential because they are required in diet.

2.4.1 Peptide linkage

Amino acids are linked together to from polypeptide chain. The linkage between amino acids are called peptide or amide linkage. One or more polypeptide chains unite to form a protein molecule. The peptide linkage is formed by the condensation reaction between the amino group of one amino acid and the carboxyl group of another amino acid. Water is released during this reaction.

2.4.2 Significance of sequence of Amino acids

Each protein molecule is composed of unique and specific arrangement of 20 different types of amino acids. The sequence is determined by the order of nucleotides in the DNA. The arrangement of amino acids in a protein molecule is highly specific for its proper functioning. If any amino acid is not in its normal place, the protein fails to carry on its normal function. Best example is the sickle cell anemia disease of human beings. The



R-group (variant)

Fig. 2.10 An Amino Acid

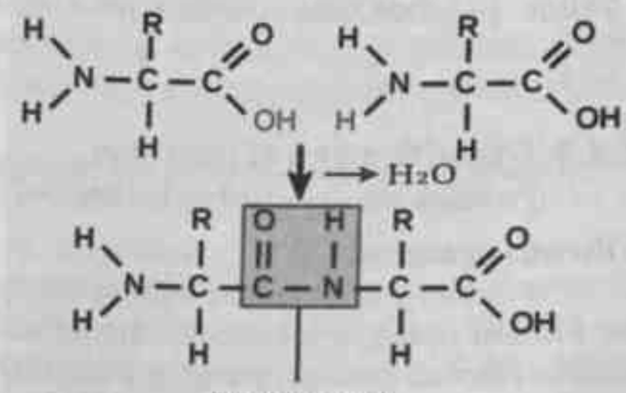


Fig. 2.11 A Dipeptide

Do you know?

Word protein has been derived from Greek word "proteios" which means prime or first.

Sickle cell   Normal Red Blood Cell

Fig. 2.12 Sickle cell anemia

normal human RBC are disc shaped and the haemoglobin consists of four polypeptide chains, two alpha chains, each with 141 amino acids and two beta chains each with 146 amino acids.

In sickle cell anemia the amino acid no. 6 of beta chain of haemoglobin is valine instead of glutamate and the haemoglobin fails to carry any or sufficient oxygen and RBCs become sickle in shape.

Normal beta chain:

Valine	–	histidine	–	leucine	–	threonine	–	proline	–	glutamate
1		2		3		4		5		6
										G Replaced by V ↓

Sickle cell anemia:

Valine	–	histidine	–	leucine	–	threonine	–	proline	–	valine
1		2		3		4		5		6

2.4.3 Classification of proteins

Proteins are classified on the basis of their shape into two types.

Fibrous proteins:

Fibrous proteins consist of molecules having one or more polypeptide chains in the form of fibrils, insoluble in watery medium. They are non-crystalline and elastic in nature. Fibrous proteins perform structural role in cells and organisms. Examples are keratin (in nails and hairs) fibrin (of blood clot), myosin (in muscle cells), silk fibers (from silkworm and spider webs) and collagen (connective tissues of skin, bones, ligament, tendon etc).

Globular proteins:

Globular proteins are spherical or ellipsoid in shape. This shape is due to multiple folding of polypeptide chains. They are soluble in watery medium, such as salt solution, solution of acids or bases or alcohol and can be crystallized. They can be disorganized with changes in the physical and physiological environment. Examples are enzymes, antibodies, many hormones, haemoglobin and myoglobin etc.

2.4.5 Role of Proteins

The proteins are very important organic molecules of living organisms. They are involved in all types of function of body. Each protein has a specific function.

Structural Role:

Proteins as structural components:

They build many structures of the cell. All known structures, exclusively or predominantly composed of proteins. Bones, nails, hair, flesh and even blood of higher animals also contain huge quantity of proteins.

Proteins provide mechanical support:

Many structural proteins determine the shape of the organ or of a cell and provide mechanical strength that protect soft and delicate organs or cell organelles e.g., bones, collagen fibers and cytoskeletons.

Functional role:

Enzymes are proteins, work as biocatalysts, all cellular reactions are catalyzed by enzymes which decrease the energy of activation i.e., energy barrier.

Many proteins help in transportation, such as **haemoglobin** transports oxygen and CO_2 gases.

Myoglobin is another protein complex that stores oxygen in the red muscles. Protein molecules also store energy in muscles of the body which supply energy to the body when outside source of food is inadequate such as **phosphocreatine.**

Proteins also provide immune responses or defense e.g., organisms defend themselves from the harmful effects of pathogens by producing, defense proteins called **antibodies** with in their body.

Blood clotting proteins such as **fibrinogen** and **prothrombin**, prevent the loss of blood from the body after an injury.

Proteins also regulate metabolic processes e.g., **hormones.**

Contractility is one of the most outstanding property of proteins. Contractile muscle proteins **(actin and myosin)**. Tubulin of microtubule **(cilia, flagella** and centrioles) help in the movement of chromosomes during anaphase of cell division are caused by proteins **(spindle fibers).**

2.5 Lipids

The lipids are a heterogeneous group of organic compounds which are insoluble in water but soluble in organic solvents like alcohol, ether, chloroform, acetone, and benzene etc. Lipids have greasy or oily consistency and include the compounds like fats, oils, waxes, cholesterol and related compounds.

Like carbohydrates, lipids are also composed of C, H and O. However, the percentage of oxygen in lipids is less than the carbohydrates which makes lipids lighter and make it much less soluble in water than most carbohydrates.

Due to hydrophobic property lipids form the structures like membranes, act as storage compounds and possess double energy as compared to carbohydrates due to high proportion of C-H bonds.

2.5.1 Classification and role of lipids

As lipids are heterogeneous substances and made up of different building blocks. So lipids are classified on the basis of solubility and the products obtained upon hydrolysis. There are following main groups of lipids.

- Acylglycerol
- Phospholipids

- Terpenes
- Waxes

Acylglycerol: (Neutral fats):

They are esters of fatty acids and glycerol. They are most abundant form of lipids in living things. An **ester** is a compound produced as a result of chemical reaction of any alcohol with any acid and release of a water molecule. In case of acylglycerol alcohol is glycerol. Glycerol is three carbon compound having OH group attached with each carbon atom.

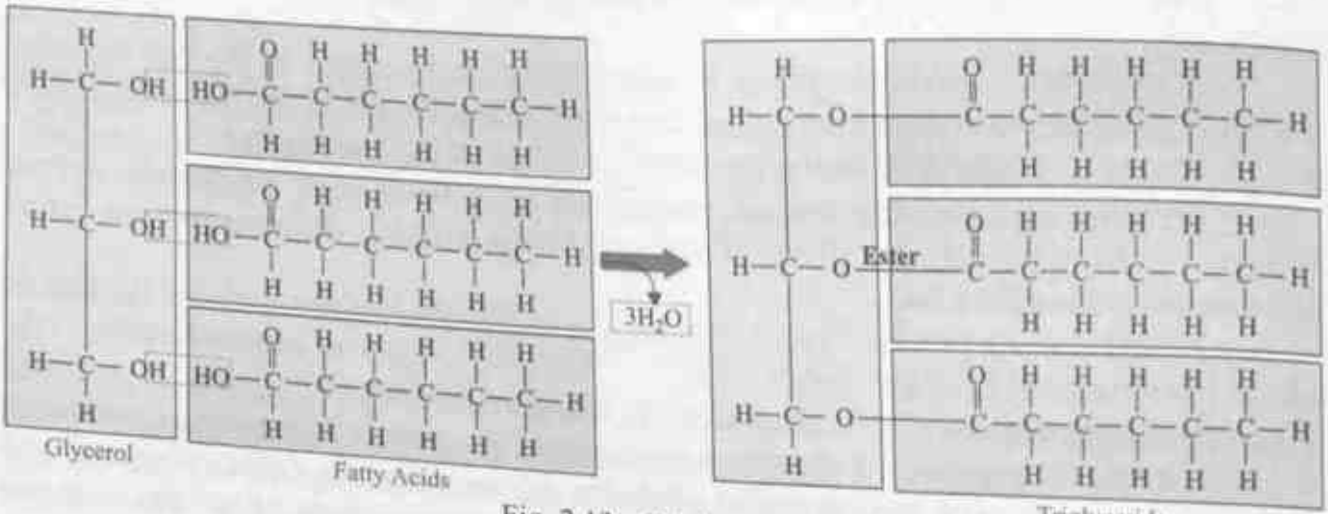


Fig. 2.13 Triglyceride

A fatty acid is a long straight chain of carbon atoms in even number (2-30) to which a carboxyl group is attached at the end. The acylglycerol may be in the form of monoglycerol, diglycerol or triglycerol depending on the number of fatty acids attached with glycerol. Triglycerol is most common among them.

There are about 30 types of fatty acids. These types of fatty acids vary in number of carbon atoms and bonds between carbon atoms (e.g., acetic acid 2 Carbons, stearic acid 18 Carbons).

A fatty acid may be **saturated** if it contains no double bond between carbon atoms or **unsaturated** if it contains 1—6 double bonds e.g. oleic acid.

The saturated fatty acids are solid at room temperature, contain more energy due to high number of C—H bonds and mostly obtained from animals. On the other hand unsaturated fatty acids are liquid at room temperature, contain less energy due to less number of C—H bonds and usually obtained from plants.

Tit bits

One gram of carbohydrate gives 4.1 Kcal, one gram of protein gives 4.6 Kcal while one gram of lipid gives 9 Kcal of energy.

Do you know?

Acylglycerol are called neutral fats because both acid and base are present in them.

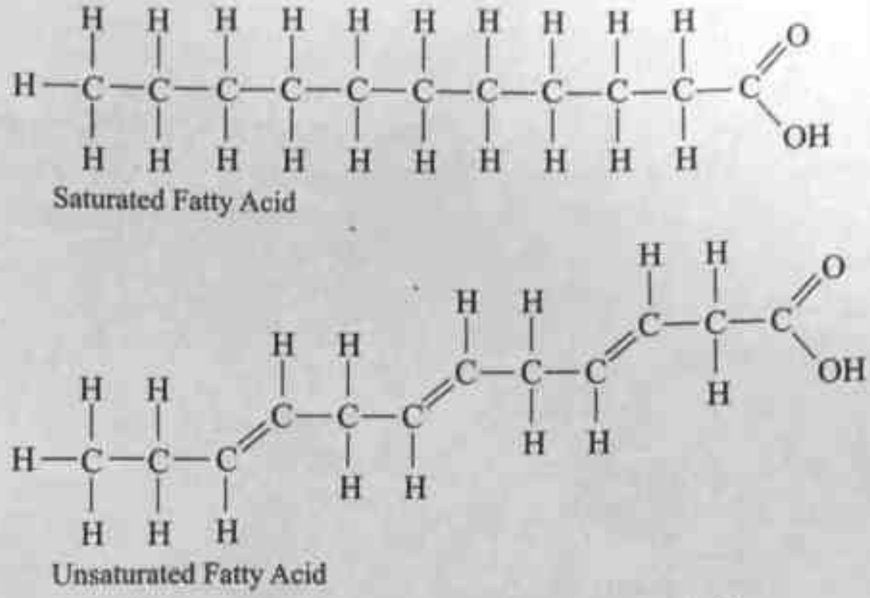


Fig. 2.14 Saturated and Unsaturated Fatty Acids

Prostaglandins (PG):

The name prostaglandins is derived from prostate gland because it was first isolated from seminal fluid in 1935. It was believed to be part of prostatic secretions.

They are group of physiologically active lipid compounds having diverse hormone like effects in animals. Prostaglandins have been found in almost every tissue in human and other animals. They are derived enzymatically from fatty acids. Every prostaglandin contains 20 carbon atoms, including a 5 carbon ring.

In 1971 it was determined that aspirin like drugs could inhibit the synthesis of prostaglandin. The prostaglandins have a wide variety of effects such as cause dilation and contraction in smooth muscle cells, cause aggregation and disaggregation of platelets, regulate inflammation, regulate hormones, control cell growth, sensitize spinal neuron for pain, act on thermoregulatory center of hypothalamus to regulate fever etc.

Phospholipids:

Phospholipids are a class of lipids that are major components of all cell membranes. They can form lipid bilayers because of their **amphiphilic** characteristics. It`s molecule consists of 2 hydrophobic fatty acid tails and a hydrophilic head, consisting of phosphate group. The two components are joined together by a glycerol molecule. The phosphate group can be modified into nitrogenous organic compound such as choline, serine, ethanolamine etc.

> **Do you know?**
>
> ***Effects of too much fats in diet.***
>
> *Makes a person obese and also cause cardio vascular disorder like B.P. heart attack etc.*

In biological systems the phospholipids often occur with other molecules for example proteins, glycolipids, sterols and a bilayer such as "cell membrane". Lipid bilayers occur when hydrophobic tails line up against one another, forming a membrane of hydrophilic heads on both sides facing water.

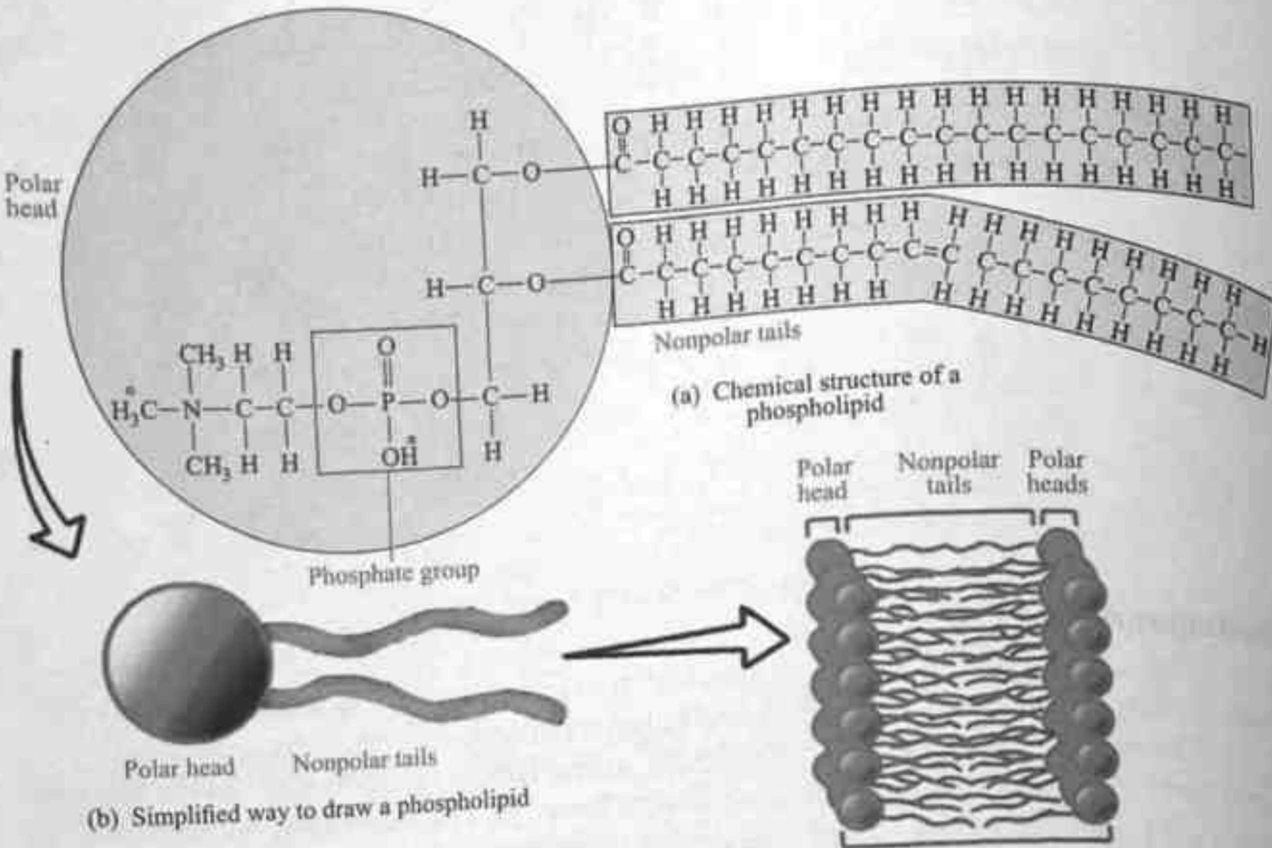


Fig. 2.15 Phosopholipid

Terpenes:

Terpenes are a large and diverse class of organic compounds, produced by a variety of plants and some insects. The building block of terpene is isoprene unit. This

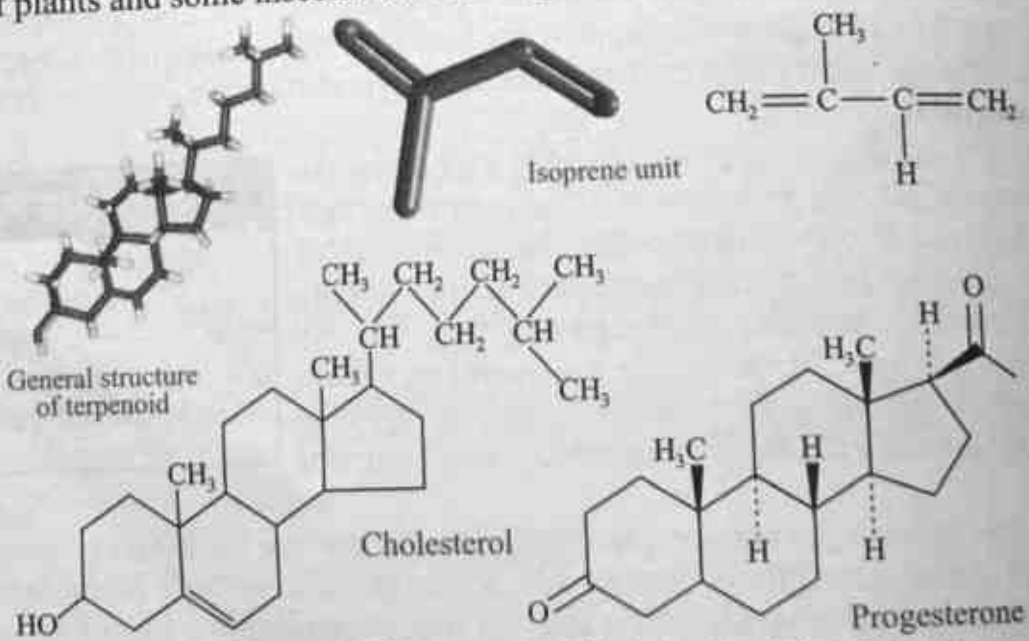


Fig. 2.16 Structure of Isoprene unit, Cholesterol and Progesterone

unit is condensed in different way to form many compounds. Two isoprene units join together to form a monoterpene $C_{10}H_{16}$ e.g., menthol and four isoprene units form a diterpene $C_{20}H_{32}$ e.g. vitamin A. Six isoprene units form triterpene $C_{30}H_{48}$ e.g., Ambrein, while rubber is a polyterpene.

Steroids:

Steroids are organic molecules and are included in lipids due to their similarities with other lipids. They are non fatty acid lipids. Their core structure is composed of 17 carbon atoms bounded in 4 interlocked rings. The first three rings are six sided while the fourth one is five sided. There are different types of steroids which vary by their functional groups attached to their four ring core.

Hundreds of steroids are found in plants, animals and fungi. All steroids are manufactured in cell.

Steroids play very important functions in the body. For example cholesterol is the structural component of cell membrane and brain tissue. Sex hormones like estrogen, progesterone in female and testosterone in male are steroids in nature. Vitamin D which regulates calcium metabolism and bile salts which emulsify fats are steroids.

> **Test your knowledge?**
> *Why the use of artificial steroids are banned in sports?*

> **Do you know?**
> *Synthetic prostaglandins are used to induce parturition, to prevent and treat peptic ulcer, to prevent egg binding, treatment of pulmonary hypertension etc.*

> **Do you know?**
> *Most common type of phospholipid is phosphatidylcholine also known as lecithin.*

Waxes:

They are organic compounds consist of long alkyl chain. They may also include various functional groups, fatty acids, alcohol, ketones and aldehydes.

Waxes are synthesized by many plants and animals. The most common animal wax is bee`s wax while in plants epicuticular waxes. They provide protection, act as water barrier, prevent abrassive damage etc. Cutin on leaves and fruits, suberin in plant roots are also examples of waxes.

> **Synthetic waxes**
> *Waxes are used in making:*
> - *Plastics*
> - *Candles*
> - *Coatings*

2.6 Nucleic Acids

Nucleic acids are the most important and essential group of complex organic substances in living things. They are polymers of nucleotides. The principal nucleic acids, DNA and RNA are the carrier of hereditary information and control synthesis of proteins.

Nucleic acid was first isolated in 1869 by a Swiss physician, Fredrick Miescher from the nucleus of pus cells and sperms of salmon fish. He named it as nuclein (because first recorded in nucleus), later their acidic nature was observed (due to the presence of phosphoric acid) and were named nucleic acids.

Jones in 1920 proved the fact that there are two types of nucleic acids, i.e. deoxyribonucleic acid (DNA) and ribonucleic acid (RNA).

2.6.1 Chemical constituents of nucleic acid

As already described that nucleic acids are the polymeric organic molecules which are polymerized by the condensation of monomeric units called nucleotides. Nucleic acids despite their structural and functional diversity exhibit a constant chemical composition.

Structure of nucleotides:

The partial hydrolysis of nucleic acids yield compounds known as nucleotides or nucleosides while complete hydrolysis yields a mixture of bases, pentose sugars and phosphate ions.

DNA is made up of deoxyribonucloetides while RNA is composed of ribonucleotides.

Bases:

Base is a nitrogen containing heterocyclic organic molecule. There are two main types of bases in nucleic acids. i.e. pyrimidine and purine.

Pyrimidine Bases:

These consist of nitrogen containing six corner benzene ring like structure, monocyclic. (molecular formula is **(N_2C_4)**. Three major types of bases are derived from the parent pyrimidine bases i.e. thymine, cytosine and uracil.

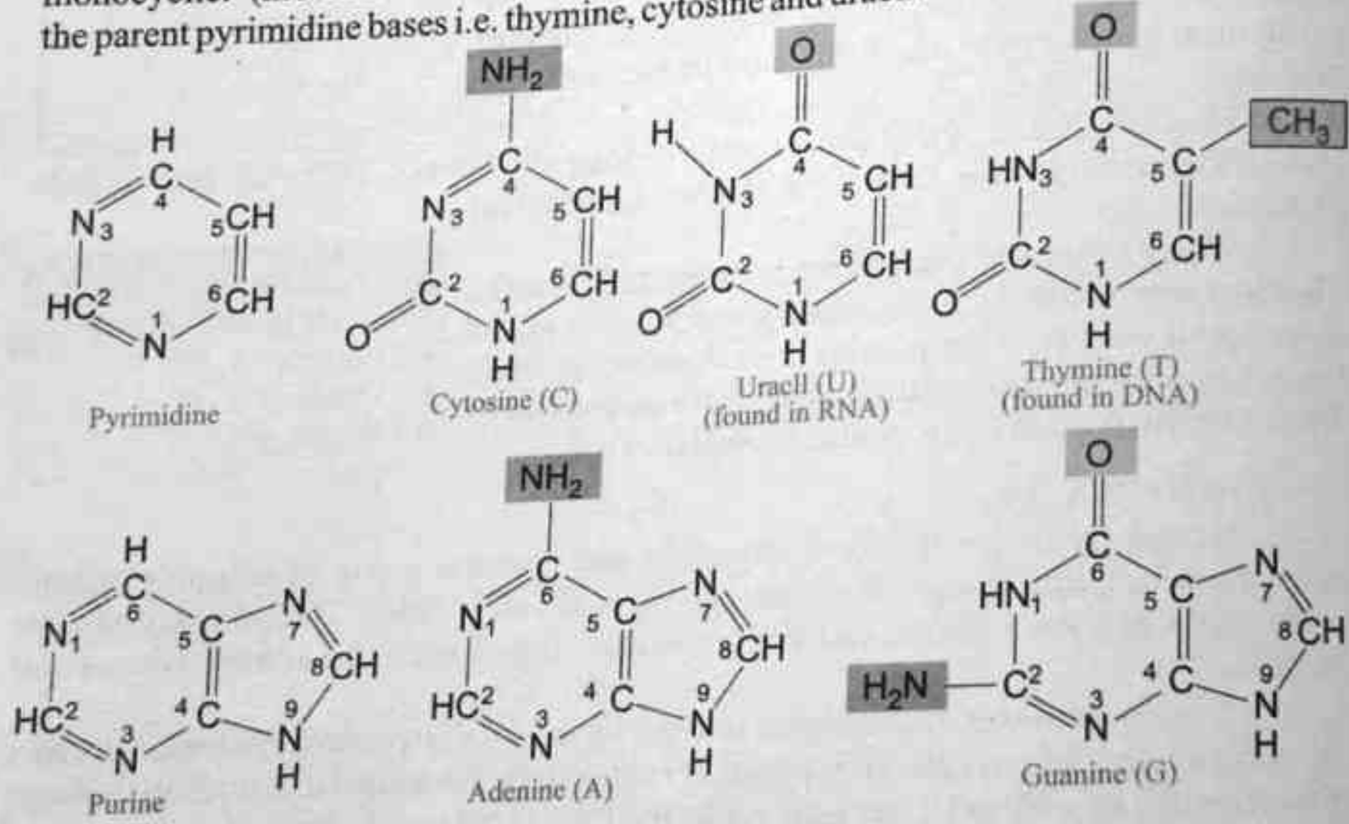


Fig. 2.17 Types of Nitrogenous Bases

Purine bases: These are second type of nitrogen containing heterocyclic organic molecules consist of two cycles. It is nine member bicyclic molecule **(N_4C_5)**. They are of two types, i.e., adenine and guanine.

Pentose sugars:

There are two types of 5 carbon containing pentose sugars which are yielded during complete hydrolysis of nucleic acids i.e. deoxyribose **($C_5H_{10}O_4$)** from DNA and ribose **($C_5H_{10}O_5$)** from RNA.

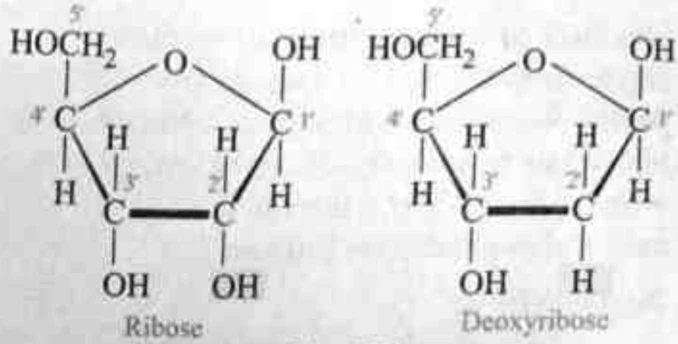


Fig. 2.18

Deoxyribose has almost the same structure like ribose, the only difference is having one atom of oxygen less at carbon no. 2.

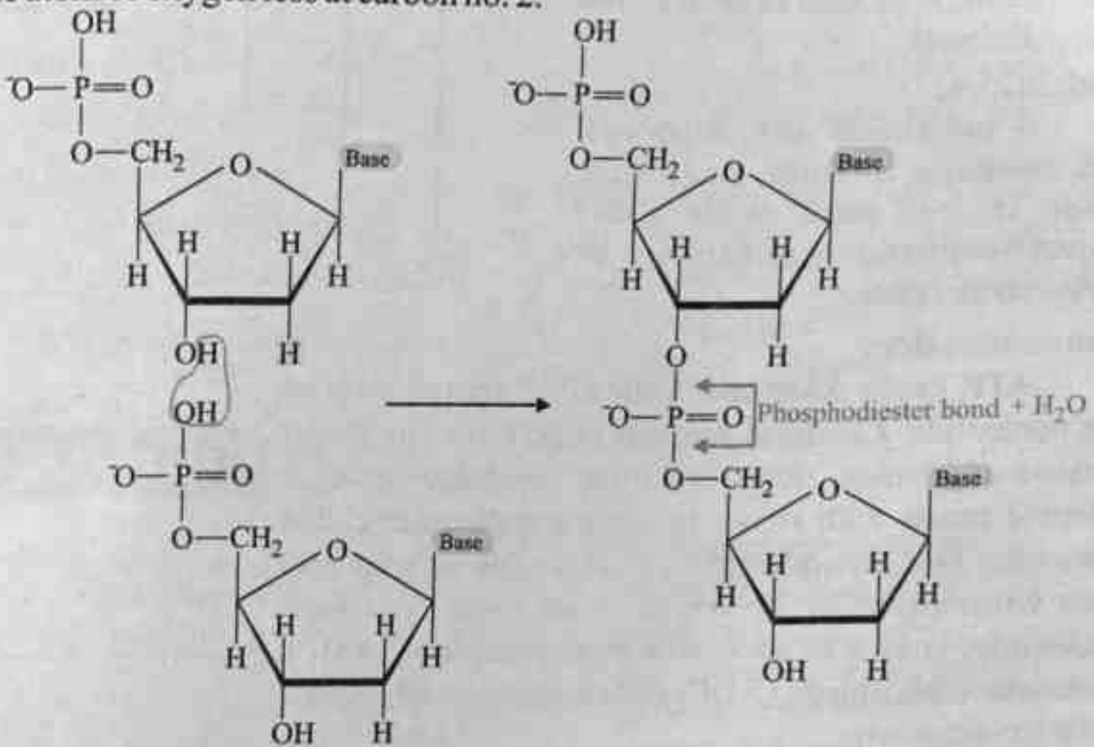


Fig. 2.19 Phosphodiester Bond

Phosphoric Acid:

Phosphoric Acid **(H_3PO_4)** has the ability to develop ester linkage with hydroxyl group (OH) of pentose sugar.

Phosphodiester linkage:

In a typical nucleotide the nitrogenous base is always attached to carbon one of pentose sugar while phosphoric acid (in a chain) is

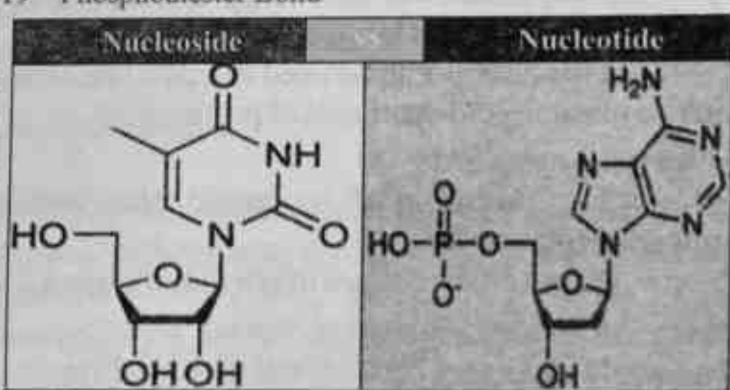


Fig. 2.20 Nucleoside and Nucleotide

attached to carbon three of pentose sugar in front and to carbon five of pentose sugar behind it. Since phosphate forms a double ester linkage with pentose sugar. Thus the linkage is called phosphodiester linkage.

Nucleosides:

Nucleoside is formed when a nitrogen containing base is linked with a pentose sugar. The bond that combines the base with sugar is called glucosidic bond.

Nucleotides:

A nucleoside and phosphoric acid combine to form nucleotide, which in free state exists either monophosphate, diphosphate or triphosphate esters.

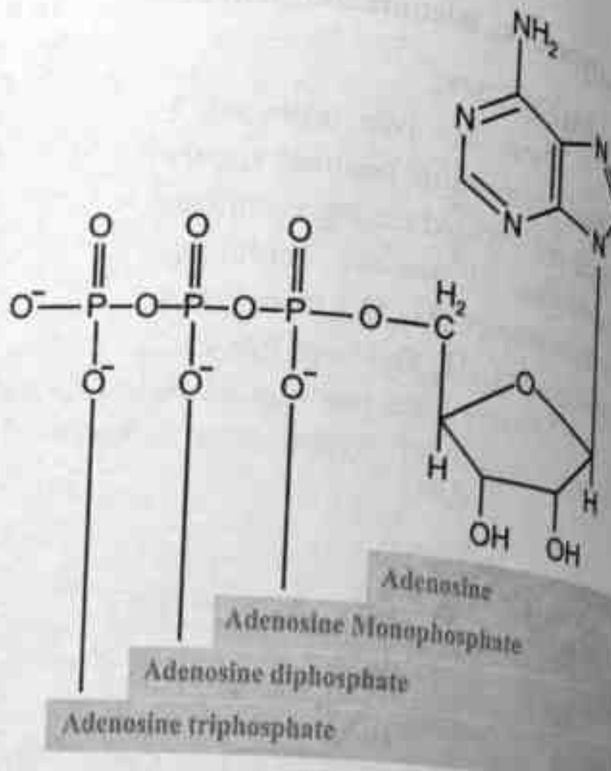


Fig. 2.21 Structure of ATP

Mononucleotide:

ATP, cyclic AMP and cyclic GMP are made up of one nucleotide. Chemical analysis of ATP reveals that it consists of adenine, ribose and three phosphate groups. Adenine reacts with ribose to form a nucleoside called adenosine. One, two or three molecules of phosphoric acid react with adenosine by condensation reaction to form nucleotide, known as adenosine monophosphate (AMP), adenosine diphosphate (ADP) and adenosine triphosphate (ATP) respectively.

Do you know?

Nucleotides are also component of ATP, cAMP, NAD, FAD and certain coenzymes.

ATP is known as energy currency of the cell, being organic phosphates on hydrolysis it releases large quantity of energy.

This energy can be used to make muscles contract, drive active transport, transmit nerve impulse and synthesis of proteins etc.

Phosphorylation:

The addition of inorganic phosphate with an organic molecule is called phosphorylation.

There are two types of phosphorylation.

1. **Photophosphorylation**

If energy for phosphosrylation comes from sunlight is called photophosphorylation e.g., formation of ATP during photosynthesis.

2. **Oxidative phosphorylation**

If energy for phosphorylation comes from breakdown of organic molecule in cell is called as oxidative phosphorylation. e.g., formation of ATP during cellular respiration.

Dinucleotide (Nicotinamide adenine dinucleotide NAD)

Most enzymes need additional chemical components to become functional called cofactors. Cofactors may be inorganic or organic but other than proteins are known as coenzymes e.g., nicotinamide adenine dinucleotide (NAD) and many vitamins.

Structure of NAD:

NAD consists of two nucleotides, one consists of nicotinamide base, sugar and phosphate group, Other consists of adenine base, sugar and phosphate group. Both nucleotides are linked by their phosphate group forming a dinucleotide. NAD is derived from nicotinic acid or niacin (vitamin B). In metabolism, NAD is involved in redox reactions, carrying electron from one reaction to other. This co-enzyme is, therefore, found in two forms in cells. NAD^+ is an oxidizing agent. It accepts two energetic electrons and a proton from other molecules and become reduced (NADH), which can be used as reducing agent to donate electorns. These electron transfer reactions are the main function of NAD.

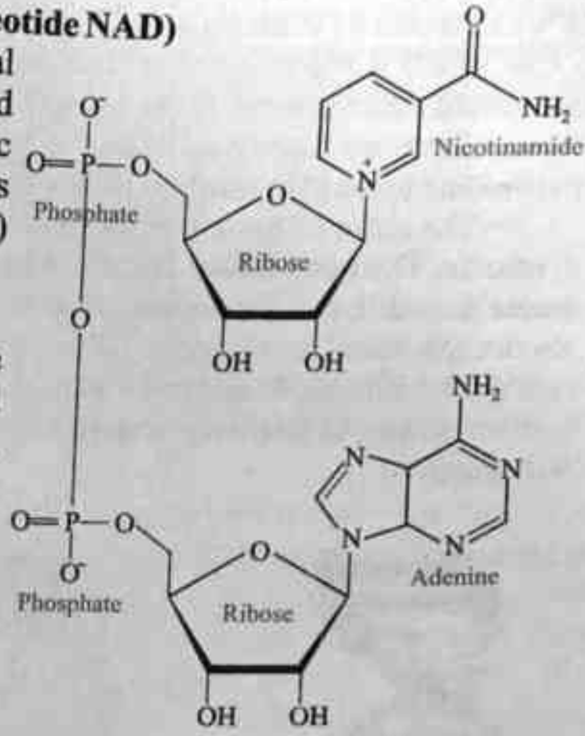


Fig. 2.22 Nicotinamide Adenine Dinucleotide (NAD)

Do you know?

cAMP, is a chemical messenger, carry message of proteinous hormones through the cell.

Another example of dinucleotide is flavin adenine dinucleotide (FAD) which is also a co-enzyme sometime used instead of NAD. It accepts two electrons (reduced) and two protons to become $FADH_2$.

Polynucleotides:

DNA andRNA are examples of polynucleotides.

Deoxyribonucleic acid (DNA):

Deoxyribonucleic acid is a polymer of deoxyribonucleotides found mostly in nucleus, few traces in mitochondrion and chloroplast. It contains instructions, an organism needs to develop, live and reproduce.

Discovery: Nucleic acid was first observed by a Swiss biochemist named Friedrich Meischer in 1869. But for long time researchers did not find its exact structure and function. It was until 1953 that James Watson, Francis Crick, Maurice Wilkins and

Rosalind Franklin figured out the structure of DNA (double helix).

Watson, Crick and Wilkins were awarded nobel prize of medicine in 1962 for giving comprehensive information for the structure and importance of DNA.

DNA structure (Watson and Crick Model of DNA):

DNA is made up of molecules called deoxyribonucleotides. Each nucleotide consists of a deoxyribose sugar, phosphate group and a nitrogen containing base.

There are four types of bases, two purine bases (Adenine and guanine) and two pyrimidine bases (Thymine and cytosine).

The order of these nitrogenous bases determines DNA's instructions for protein synthesis. The nucleotides are attached together to form two long strands that twist to create a double helix structure, running in opposite direction antiparallel and winding about each other like a circular ladder. The phosphate and sugar molecules make the sides (upright) while the bases make rungs. The bases on one strand pair with the bases on another strand in a specific manner. Adenine always pairs with thymine and cytosine with guanine.

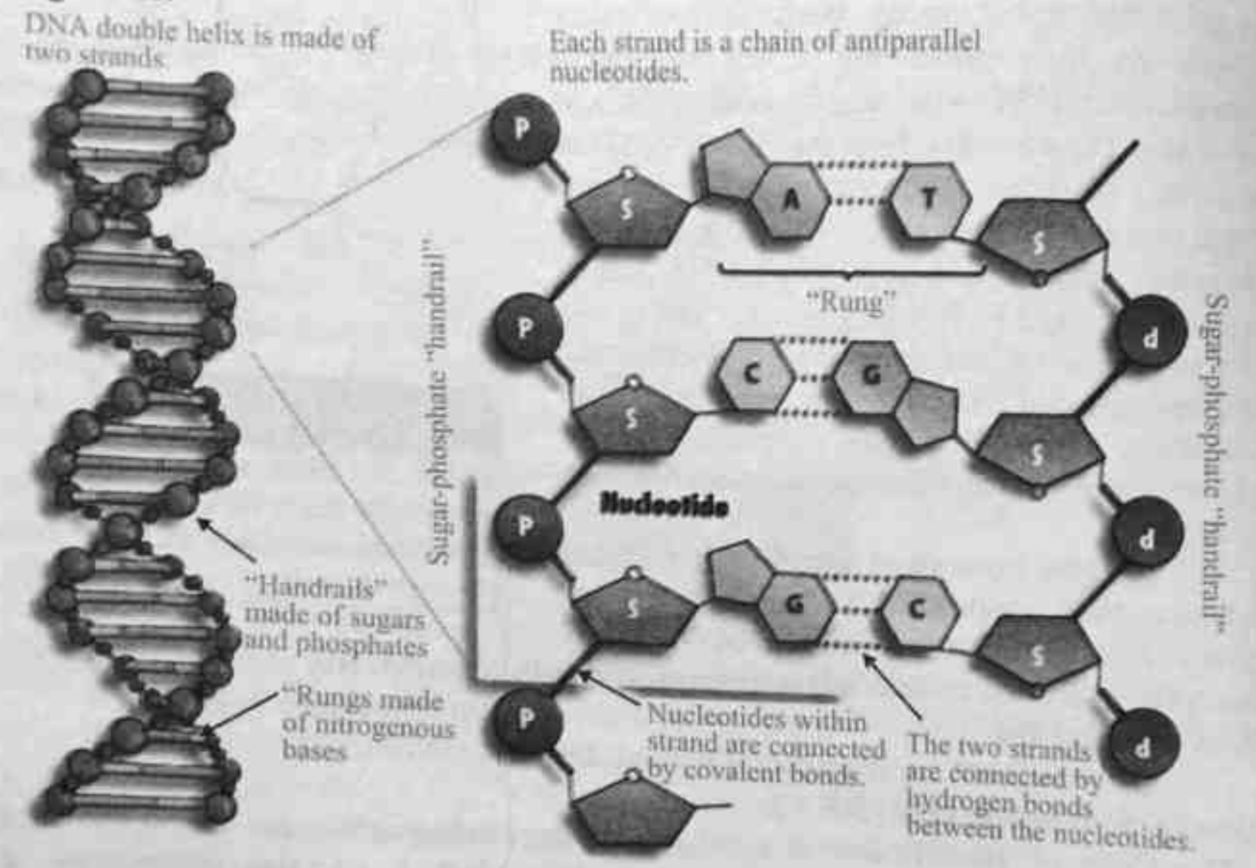


Fig. 2.23 Structure of DNA

The diameter of the two helix is 2nm and makes a full spiral turn at every 3.4nm.

The amount of DNA is fixed for a particular species as it depends upon the number of chromosomes. The amount of DNA in germ cells (sperm and egg) is half to that of somatic cells.

Structure of Ribonucleic Acid (RNA):

RNA is a long unbranched polymeric molecule formed by interlinkage of four monomeric units known as ribonucleotides of adenine, guanine, cytosine and uracil bases.

RNA molecules are single stranded, except Reo virus. However, some RNA molecules have regions in which hydrogen bonds between $A = U$ and $G \equiv C$ bases are formed between different regions of the same molecule thus coiled itself look like double stranded hair-pin loops. RNA is mostly present in cytoplasm but synthesized within the nucleus by using only one strand of DNA as template (3'—5') direction. Thus it is true copy of the genetic information contained in DNA. RNA helps DNA in protein synthesis. In some animal and all plant viruses, RNA functions as hereditary material. The amount of RNA varies from cell to cell.

Do you know?

About 97% of transcriptional output is non protein coding in eukaryotes. So they are called non coding RNA (ncRNA).

What is a Gene?

A gene is a region of DNA which is made up of specific sequence of nucleotides, which codes a specific polypeptide chain. A nucleotide sequence of gene in DNA specifies, the amino acid sequence of proteins through the genetic code. A set of three nucleotides known as codon each correspond to a specific amino acid e.g., if a polypeptide chain has 100 amino acids then the number of nucleotide in a gene will be 300.

Types of RNA:

There are three main types of RNA which are synthesized from different parts of DNA in a process called transcription and then are moved out in the cytoplasm to perform specific functions.

Main three types are mRNA, tRNA and rRNA.

Messenger RNA:

The mRNA is a type of RNA that carries information from DNA to the ribosomes, the site of protein synthesis in a cell. The coding sequence of mRNA determines the amino acid sequence in protein that is to be produced. There are many types of mRNA because for the translation of every polypeptide chain a specific mRNA is required. (mRNA is about 3—5% of total RNA of cell).

Transfer RNA:

The tRNA is a small RNA chain of about 80 nucleotides that transfers a specific amino acid to the growing polypeptide chain at ribosomal site of protein synthesis. There are at least 20 types of tRNA in each cell because for each amino acid a separate transfer RNA is required. About 60 types of tRNA have been identified so far. Transfer RNA are about 15% of total RNA of cell.

Ribosomal RNA:

The rRNA is the catalytic component of ribosome. It is synthesized by the genes present on DNA of several chromosomes found within the region of nucleus called nuclear organizer. The base sequence of rRNA of all organisms is similar thus there is only one type of rRNA. It is most abundant about 80% of total RNAs of the cell.

2.7 Conjugated Molecules

Conjugated molecules are types of molecules that are formed by the combination of two different classes of molecules e.g., when carbohydrate molecule combines covalently with protein, a more complex molecule is formed called glycoprotein. Some other examples of conjugated molecules are as under.

Lipoproteins: The lipoprotein forms when lipid combines with protein. These types of molecules are frequently found in cell membranes and other types of membranes in the cell like mitochondria, endoplasmic reticulum, nuclear membrane etc.

Nucleoproteins: It is formed by the combination of nucleic acid with protein e.g., Ribosome and chromosomes of eukaryotes are basically nucleoproteins in composition.

Glycolipids: These are lipids with a carbohydrate attached with glucosidic bond. Such molecules are part of cell membrane.

Table 2.3 Differences between DNA and RNA.

DNA	RNA
1. It is mainly located in the nucleus. A small quantity occurs in mitochondria and chloroplast.	1. It is mainly located in the cytoplasm. A small quantity is found in the nucleus.
2. Its quantity is constant in each cell of a species.	2. Its quantity varies in different cells.
3. It contains deoxyribose sugar. Bases are A, G, C and T.	3. It contains ribose sugar. Bases are A, G, C and U.
4. It consists of 2 polynucleotide chains held together by hydrogen bonds, and coiled into a double helix.	4. It consists of a single polynucleotide chain. It may fold on itself due to hydrogen bonds and coiled into a pseudohelix.
5. It is of 2 types: linear intranuclear and circular extranuclear.(such as in bacteria).	5. It is of 3 types: mRNA, tRNA, rRNA. Each type has many subtypes.
6. It is the genetic material in all organisms.	6. It is the genetic material only in certain viruses.
7. It transfers its information to mRNA (Transcription).	7. mRNA transfers its information to polypeptide (Translation).

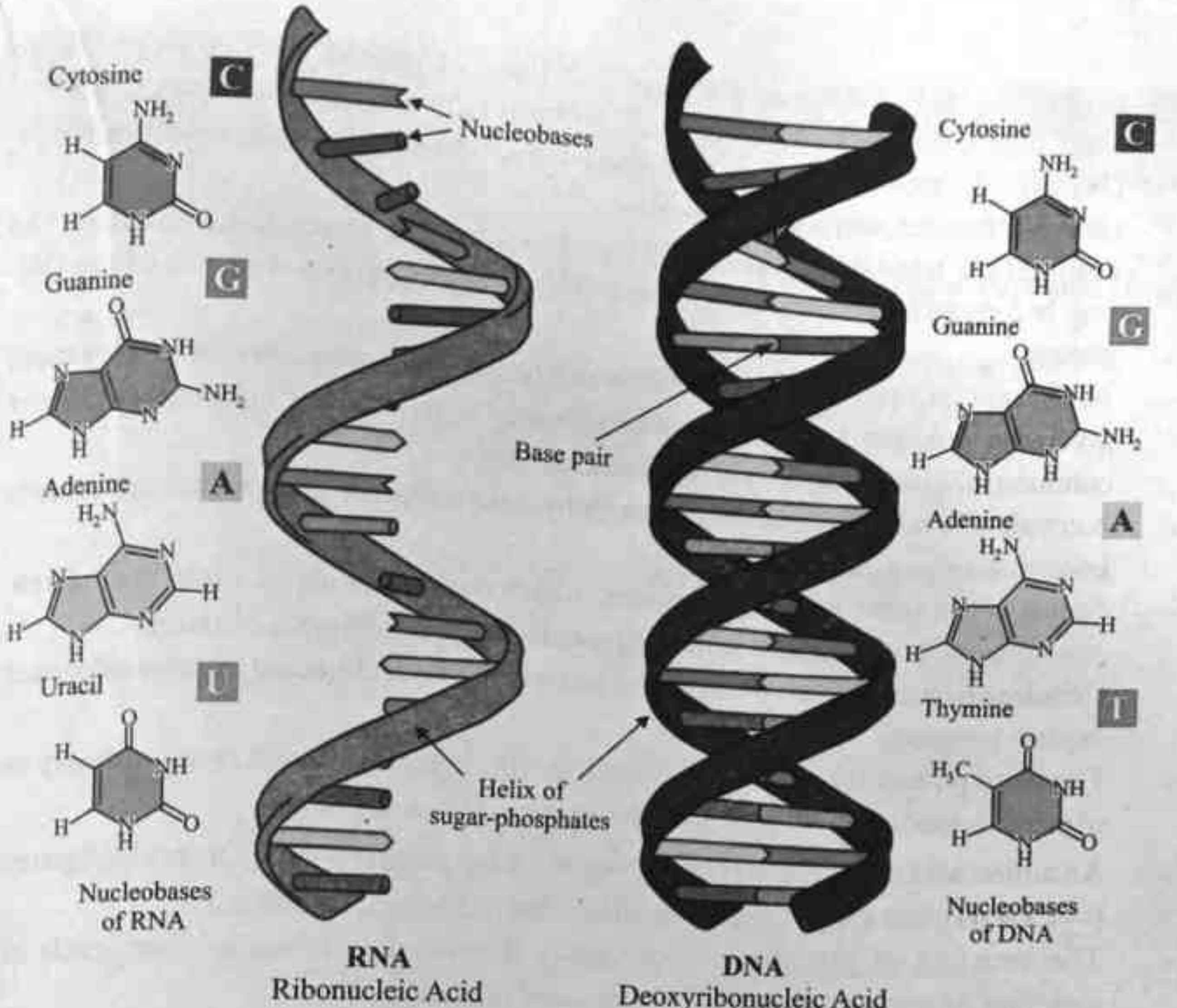


Fig. 2.24 Difference between DNA and RNA

Critical Thinking

Why reducing sugar gets red when tested with Benedict's solution? The Benedict's solution contains copper II salt (blue) that can be converted to copper I oxide (red). We say it has been reduced. Some sugars are able to cause this change, and thus called reducing sugars. Benedict's test can, therefore, be used to test for the presence of reducing sugars such as glucose, fructose and maltose.

SUMMARY

- Hydrogen, oxygen, carbon, and nitrogen constitute more than 97% of the atoms in the human body.
- Water is an important compound for the life and its proper functioning is due to its polarity, low density in ice form, high heat of vaporization, high heat capacity, cohesive and adhesive properties.

- Chemically, the carbohydrates may be defined as optically active polyhydroxy aldehydes or ketones or the compounds which produce such units on hydrolysis.
- Carbohydrates are classified into three subtypes: monosaccharides, oligosaccharides, and polysaccharides.
- Many of the large sugar units (> C5) tend to form ring structures in solution. The ring is formed by the reaction of the aldehyde or keto group with one of the OH-groups.
- The joining of two to ten monosaccharides forms an oligosaccharide. One or more glycoside linkages hold the monosaccharides together. The simplest, and most common, oligosaccharides are the disaccharides.
- A covalent bond formed between a carbohydrate molecule and another molecule is known as a glycosidic bond.
- Amylose is a water soluble component which constitutes about 15-20% of starch. Amylopectin is insoluble in water and constitutes about 80-85% of starch.
- Cellulose occurs exclusively in plants and it is the most abundant organic substance in plant kingdom.
- The word protein is derived from Greek word, "proteios" which means primary or of prime importance. All proteins are polymers of α-amino acids.
- An amino acid is a molecule containing an amino group **($—NH_2$)**, a carboxyl group **(—COOH)**, and a hydrogen atom, all bonded to a central carbon atom.
- The structure of proteins is traditionally discussed in terms of four levels of structure, as primary, secondary, tertiary, and quaternary.
- Fatty acids are long-chain hydrocarbon molecules containing a carboxylic acid moiety at one end. They are called as the building blocks of lipids.
- The unpleasant odour and taste developed by most natural fats upon ageing is referred to as rancidity.
- Waxes are a type of long chain nonpolar lipids. Natural waxes are typically esters of fatty acids and long chain alcohols.
- Paraffin wax is a type of synthetic wax derived from petroleum and refined by vacuum distillation.
- Nucleic acids are long polymers of repeating subunits called nucleotides.
- Evidence that DNA is a helical molecule was provided by an X-ray diffraction photograph of DNA fiber taken by Rosalind Franklin.
- There are four types of conjugated molecules; glycolipids, glycoproteins, nucleoproteins, and lipoproteins.

EXERCISE

Section I: Objective Questions

Multiple Choice Questions

A. Choose the best correct answer.

1. The six elements that make up 99% of all elements found in human beings are
   (a) C, H, O Na, Mg and P (b) C, N, O, S Zn, and P
   (c) H, O, C, Ca, P and N (d) C, H, O,Ca, Cu and S.
2. What are the most diverse molecules in the cell?
   (a) Lipids (b) Mineral salts
   (c) Proteins (d) Carbohydrates.
3. One of the following groups contains all polysaccharides?
   (a) Sucrose, glucose and fructose (b) Maltose, lactose and fructose
   (c) Glycogen, sucrose and maltose (d) Glycogen, cellulose and starch
4. Lactose is composed of
   (a) Glucose + galactose (b) Fructose + galactose
   (c) Glucose + fructose (d) Glucose + glucose.
5. An ATP molecule is consisting of
   (a) Mono nucleotide (b) Nucleoside
   (c) Polynucleotide (d) Vitamin
6. Lipids are insoluble in water because lipid molecules are
   (a) Hydrophilic (b) Hydrophobic
   (c) Neutral (d) Polar
7. In double helix of DNA, the two DNA strands are
   (a) Coiled around a common axis (b) Coiled around each other
   (c) Coiled differently (d) coiled over protein sheath.
8. In DNA the nitrogenous base that takes place of uracil is:
   (a) Thymine (b) Adenine
   (c) Guanine (d) Cytosine
9. Proteins are synthesized from
   (a) Glucose (b) Fatty acids
   (c) Amino acids (d) A-ketoglutaric acid.

B. Fill in the Blanks.

1. The branch of biology which deals with the chemical compounds and chemical processes is called _____.

2. Animal fats are ______ at room temperature.
3. Peptide bond is present between ________.
4. Any compound composed of an alcohol and an organic acid is called ______.
5. The basic unit of nucleic acid is ______.
6. The saturated fatty acids have ________ bond between carbon atoms.
7. Glycogen is also known as animal ________.
8. When two different types of organic molecules join together, make a complex molecule called _____.
9. The addition of inorganic phosphate with an organic molecules is called _____.
10. The bond between water molecules is known as ______.

Section II: Write Short Answers

1. What are monosaccharides?
2. What are reducing sugars?
3. Write two main functions of carbohydrates in plants.
4. What do you understand by the term glycosidic linkage?
5. What is glycogen? How is it different from starch?
6. What are the hydrolysis products of (i) sucrose (ii) lactose?
7. What is the basic structural difference between starch and cellulose?
8. Differentiate between globular and fibrous proteins.
9. What are nucleic acids? Mention their two important functions.
10. What is the difference between a nucleoside and a nucleotide?
11. The two strands in DNA are not identical but are complementary. Give reason.
12. Write the important structural and functional differences between DNA and RNA.
13. What are the different types of RNA found in the cell?

Section III: Extensive Questions

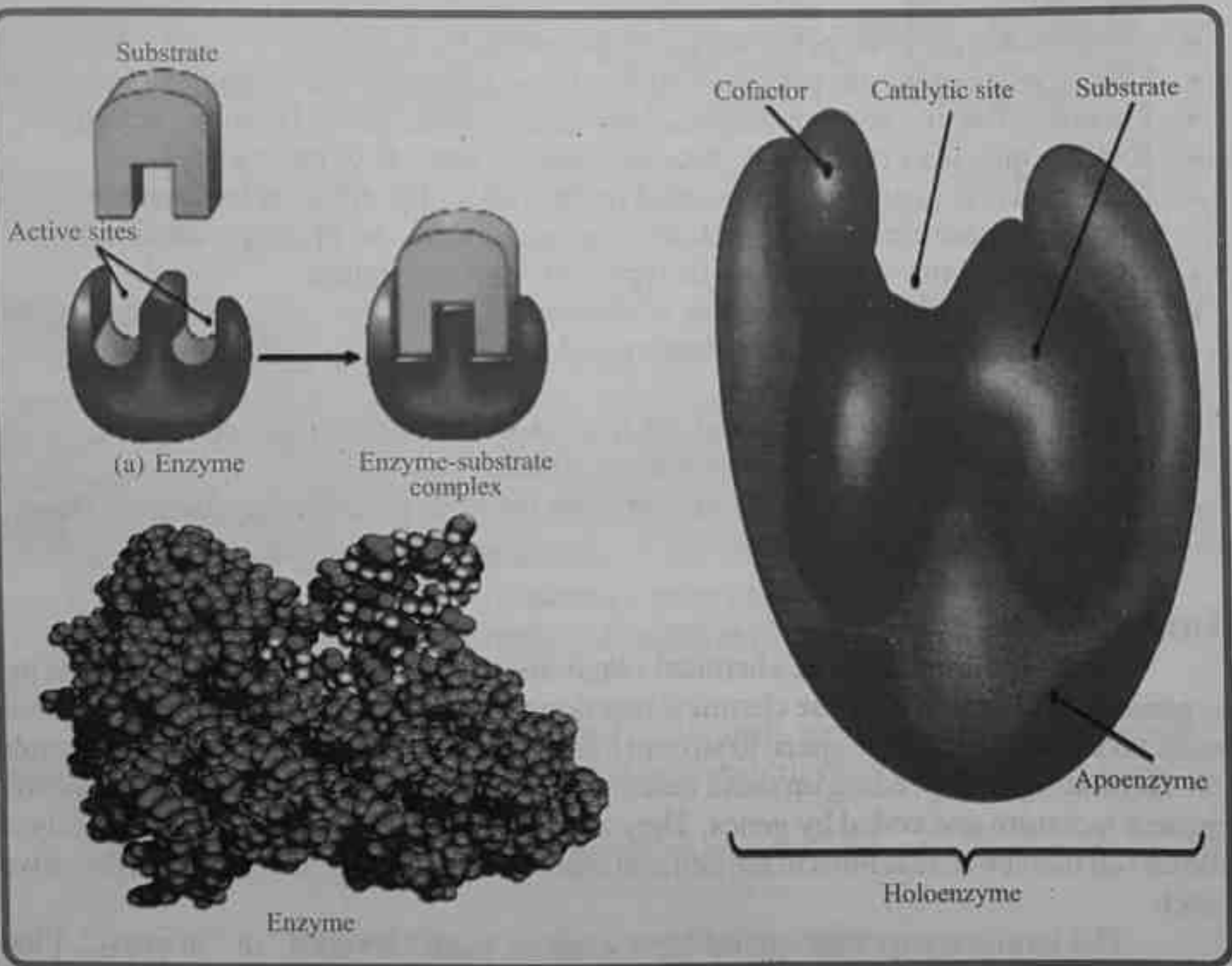
1. How are amino acids linked to form proteins?
2. What are the three components of a nucleotide? How are nucleotides linked to form nucleic acids?
3. Which of the purines and pyrimidines are capable of forming base-pairs with each other? Also draw their structure.
4. What are the two kinds of subunits that makeup a natural fat molecule, and how are they arranged in the molecule?
5. Describe the differences between a saturated and an unsaturated fat.

UNIT 3

ENZYMES

Major Concepts

3.1 Structure of Enzymes
3.2 Mechanism of Enzyme Action
3.3 Factors Affecting the Rate of Enzymatic Action
3.4 Enzyme Inhibition
3.5 Classification of Enzymes



Students Learning Outcomes

On completion of this unit students will be able to:

- Describe the structure of enzyme.
- Explain the role and component parts of the active site of an enzyme.
- Differentiate among three types of co-factors i.e. inorganic ions, prosthetic group and co-enzymes by giving examples.
- Explain the mechanism of enzyme action through Induced Fit Model, comparing it with Lock and Key Model.
- Explain how an enzyme catalyzes specific reactions.
- Define energy of activation and explain through graph how an enzyme speeds up a reaction by lowering the energy of activation.
- Describe the effect of temperature on the rate of enzyme action.
- Compare the optimum temperature of enzymes of human and thermophilic bacteria.
- Describe the range of pH at which human enzymes function.
- Compare the optimum pH of different enzymes like trypsin, pepsin, papain.
- Describe how the concentration of enzyme affects the rate of enzyme action.
- Explain the effect of substrate concentration on the rate of enzyme action.
- Construct and interpret graphs based on data about the effect of temperature, enzyme concentration and substrate concentration on the of enzyme action.
- Describe enzymatic inhibition, its types and its significance.
- Name the molecules which act as inhibitors.
- Categorize inhibitors into competitive and non-competitive inhibitors.
- Explain feedback inhibition.
- Classify enzymes on the basis of the reactions catalyzed (oxido-reductases, transferases, hydrolases, isomerases and ligases).
- Classify enzymes on the basis of substrates they use (lipases, diastases, amylase, proteases etc).

Introduction

There are thousands of chemical reactions taking place in the body of a living organism. The sum of all these chemical reactions is called metabolism. These reactions must take place with a high speed to sustain life. A special group of chemicals responsible for facilitating and speeding up these reactions are called enzymes. Enzymes are mostly protein in nature and coded by genes. They are large group of chemicals which catalyze almost all metabolic reactions in the cell and other parts of the organisms e.g., in digestive tract.

The term enzyme was coined from a Greek word "levened" or "in yeast". First enzyme was discovered by **Payen and Persoz** from germinating barley seeds in 1833 and named it **diastase**. The term enzyme was introduced by **Wilhelm kuhne in 1877**.

Enzymes can be defined as "the **thermolabile biocatalyst**" protein in nature, specific in function and coded by DNA.

They work inside or outside of the cell. The substance on which enzyme acts is called **substrate** which is usually very smaller than enzyme. When enzyme combines with substrate it forms an enzyme-substrate complex. After enzyme substrate reaction product is formed and enzyme itself remains unchanged which can be used again for another substrate. Most enzymes are protein in nature, although a few are catalytic RNA molecules called **ribozymes**, that can catalyze specific substarte in a similar way as proteinaceous enzymes.

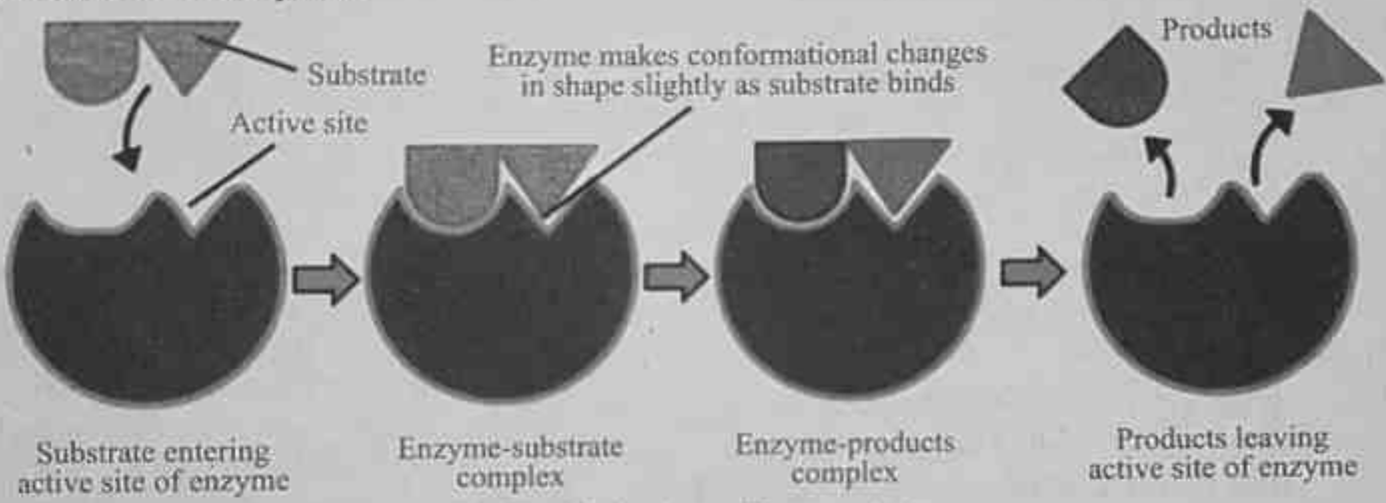


Fig.3.1 Mechanism of Enzyme Action

3.1 Structure of Enzymes

Enzymes are generally globular proteins. The sequence of amino acids specifies the structure of active site which determines the catalytic activity of enzyme. An enzyme may have one or more active sites. Active site of enzyme consists of two parts i.e.,

> **Do you know?**
>
> *Ribozyme is found in ribosomes. It controls polypeptide elongation during protein synthesis such as peptidyl transferase.*

a. **Binding site** where substrate attaches.

b. **Catalytic site** where catalysis of substrate takes place.
   The catalytic site is very small portion comprises of (2 to 12) amino acids.

Chemical Nature of Enzymes:

Most enzymes are proteins, so each has its own specific structure, which is required for its proper functioning. A complete functional enzyme is called holoenzyme.

The **holoenzyme** consists of two parts

a. **Apoenzyme:** It is the proteinaceous part of an enzyme.

b. **Cofactor:** It is non-proteinaceous part of an enzyme.

Apoenzyme + Cofactor = Holoenzyme.

Some enzymes are only composed of protein i.e., no cofactors are attached with them e.g. lipase.

Physical Nature of Enzymes:

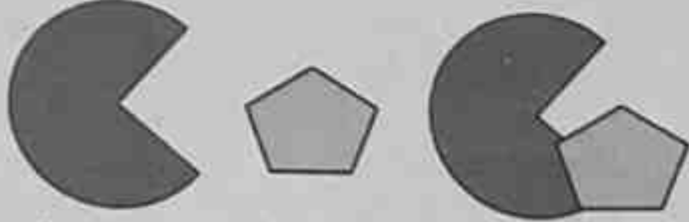


Fig.3.2 Holoenzyme

Enzymes have relatively high molecular weight e.g., the molecular weight of **peroxidase** is 40,000 Daltons or 40 KDa and **catalase** 250 KDa approximately. Enzymes due to proteinaceous nature may denature in high temperature. The enzymes form colloidal suspension in the cytosol, therefore, at low temperature their activity may decrease or stop. High fever is harmful for the body because enzymes may denature in high temperature.

Activity

If an enzyme breaks three lac moles of substrate in a second. What will be its turnover numbers?

Catalytic Characteristics of Enzymes:

Being catalysts, enzymes show following characteristics.

i) They are very **efficient** in function e.g., one enzyme may catlyze 100000 substrate in one second. (The unit is called as one turnover number).

ii) Enzymes need **specific temperature** for their proper functioning. So drinking cold water during meal is medically wrong.

iii) Enzymes need **specific pH** for their proper functioning.

iv) Enzymes are highly **specific** i.e., one enzyme acts only a specific substrate e.g., amylase acts only on amylose.

v) Enzymes remain constant after the reaction so they can be used again and again.

vi) Enzyme may be studied in living cell ***(in vivo)*** or outside living cell i.e., in glassware ***(in vitro).***

vii) Most of enzymes need **co-factor** for their functioning.

viii) Enzymes need **aqueous environment** for their functioning, that's why we feel thirst after taking meal.

Tit bits

Turn over unit

If you turn something over, or if it turn over, it is moved so that the top part is now facing downward or change or reversal of position.

Tit bits

Dalton

A very small unified atomic mass unit (symbol Da) in biology, one hydrogen atom has mass of one Da. The molecular weight of proteins and other macromolecules are usually measured in kilodaltons (KDa).

Three dimensional structure of enzyme:

The enzymes are globular proteins. The specificity of enzymes comes from their unique three dimensional structure. Tertiary structure of a protein or any other macromolecule, play important role in their proper functioning.

The simple protein consists of only one long polypeptide chain e.g., ribonuclease consists of 124 amino acids. The kind of amino acids and the sequence in which they are arranged determines the three dimensional structure of an enzyme.

Enzyme Cofactors:

Some enzymes do not need additional components to show full activity. However, most of the enzymes require non-protein molecule called cofactors to be bound for activity. Cofactor can be either inorganic metal ions or organic compounds like flavin or haeme. These cofactors serve many purposes e.g., **metal ions** help in making enzyme-substrate complex either by moulding active site or shape of substrate. The **organic substances** may be **co-enzyme** which are released from the enzyme active site during the reaction. They are loosely attached with enzyme. **Prosthetic groups** are tightly bound with enzyme hence the permanent part of enzyme. Most vitamins are co-enzymes or components of co-enzymes. That is why vitamins are needed in our daily life.

3.2 Mechanism of Enzyme Action

Enzymes must bind their substrate before they can catalyze any chemical reaction.

To understand the mechanism of enzyme action two models have been proposed.

Lock and Key Model:

This model was developed by a Germen chemist **Emil Fischer** in 1894.

The specific action of enzyme with a single substrate can be explained using a lock and key analogy. In this analogy the lock is the enzyme and the key is the substrate. Only the correctly sized key that is substrate fits into the key hole which is active site of lock that is enzyme. The same enzyme can be used to catalyze hundreds of same substrates. The enzymes work on this mechanism are called non regulatory enzymes e.g., lipase, amylase etc. This model explains the specificity of enzymes but does not say anything about the change in active site.

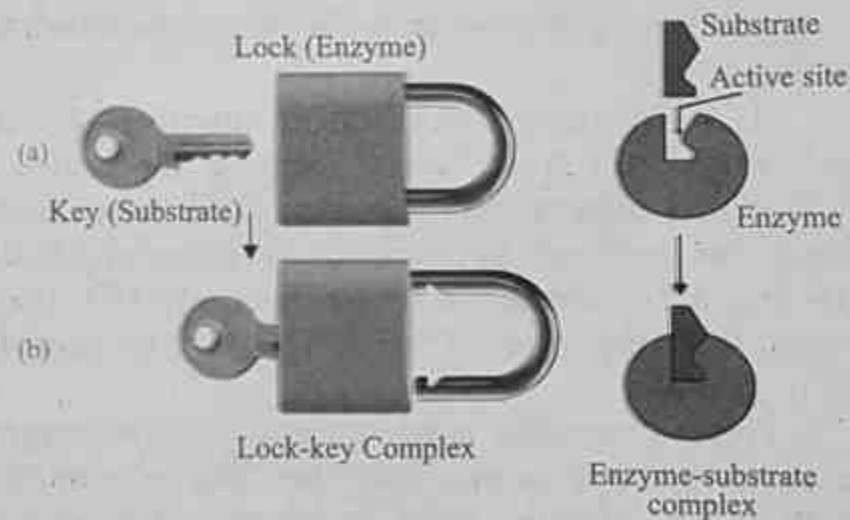


Fig.3.3 Emil Fischer Model

Activity

Study the lock and key enzyme action and induced fit model of enzyme action by animated videos through internet.

Induced-Fit Hypothesis (Model):

In 1958 **Daniel Koshland** suggested a modification to the lock and key model. According to induced-fit model the active site of enzyme is a flexible structure. Enzyme

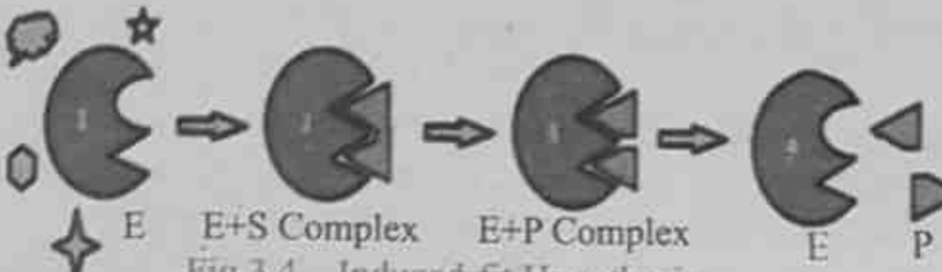


Fig.3.4 Induced-fit Hypothesis

Tit bits

Luciferase is an enzyme in fireflies responsible for light production.

molecules are in an inactive form. To become active, enzymes must undergo slight conformational changes in the structure to accommodate the substrate. A suitable analogy would be that of hand and gloves. The hand corresponds to the substrate and glove as enzyme is shaped by insertion of the hand. Enzymes which follow the induced-fit mechanism are called regulatory or allosteric enzymes e.g hexokinase.

Tit bits

Enzymes are denatured by heat but not by cold thus enzymes stored in below $0^{\circ}C$ are able to function after thawing.

3.3 Factors Affecting The Rate of Enzyme Action

The activity of enzymes is affected by the following factors.

Temperature:

Heat increases molecular motion. As the temperature rises from "zero" reacting molecules of substrate and enzyme will get more and more kinetic energy. This increases the chance of a successful collision and so the rate of reaction increases. For every $10^{\circ}C$ rise in temperature the rate of enzyme activity doubles approximately.

Do you know?

The food like meat, fruits may turn bad because of the enzyme activity. Therefore, it is advised to keep such food in refrigerator.

There is a specific temperature at which an enzyme catalytic activity is fastest and this is known as **optimum** temperature. The optimum temperature for enzymes found in human is $37^{\circ}C$. After this point the rate of enzyme activity will decrease and at $45\text{-}50^{\circ}C$

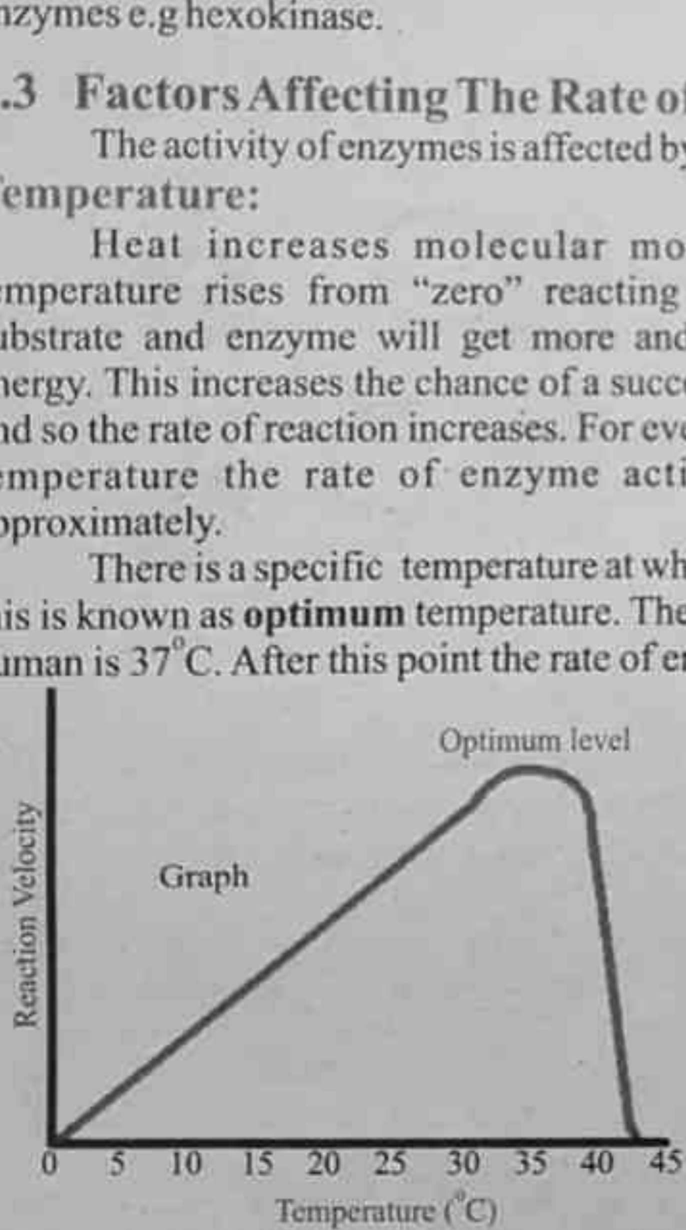


Fig.3.5 Effect of Temperature on enzyme action

Table 3.1 Optimum pH of different enzymes

Enzymes	*Optimum pH*
Pancreatic Lipase	*7.4-7.8*
Pepsin	*2.0*
Trypsin	*7.8 - 8.7*
Maltase	*6.1 - 6.8*
Arginase	*9.7*
Sucrase	*4.5*

the enzyme activity will be stopped, as enzyme binding site will denature at this temperature. Some bacteria live in hot springs so optimum temperature for their enzymes is more than 37°C. Such enzymes have been used in biological washing powders and detergents. That is why cloth washing need lukewarm water, not too hot.

pH:

Every enzyme needs a specific pH for its proper functioning. The pH at which an enzyme works maximum is called its optimum pH. Some enzymes work best in acidic medium e.g., pepsin, some in neutral medium e.g., amylase and other in alkaline medium e.g., lipase.

However, most of enzymes in our body work in the range of pH 6-8. Some enzymes may work on both acidic and alkaline media e.g., papain enzyme in green papaya.

Change in pH alters the ionic charge of acidic and basidic groups as a result ionic bonding is disrupted. This ionic bonding is needed to maintain the specific shape of enzyme. Thus the change in pH may change the shape of enzyme as well as denature active site.

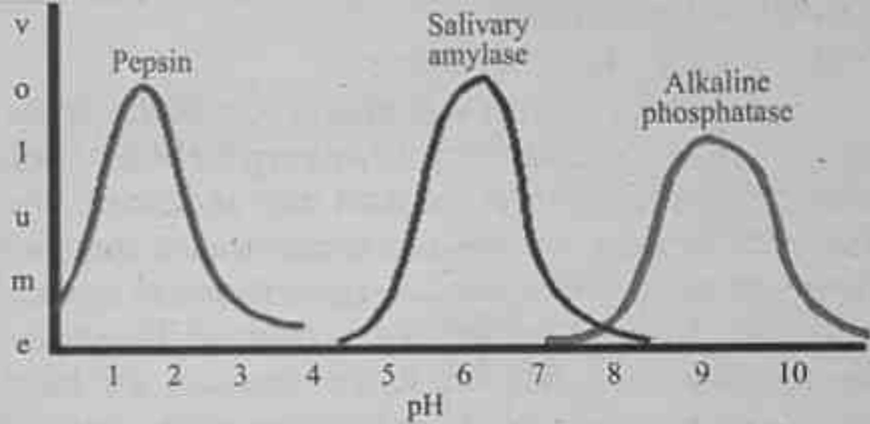


Fig.3.6 Effect of pH on enzyme action

Activity

Find the pH of different food substances by searching internet.

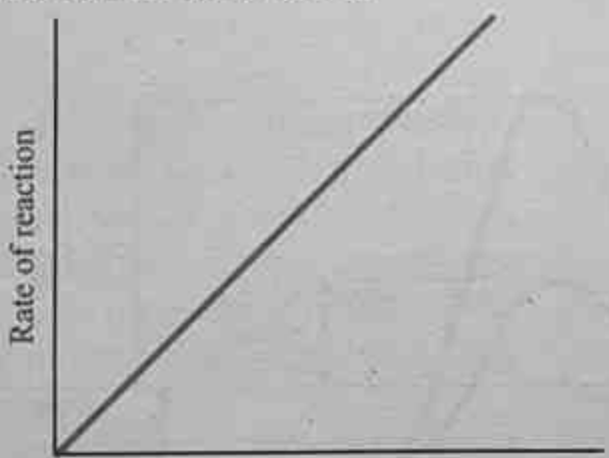


Fig. 3.7 Enzyme Concentration

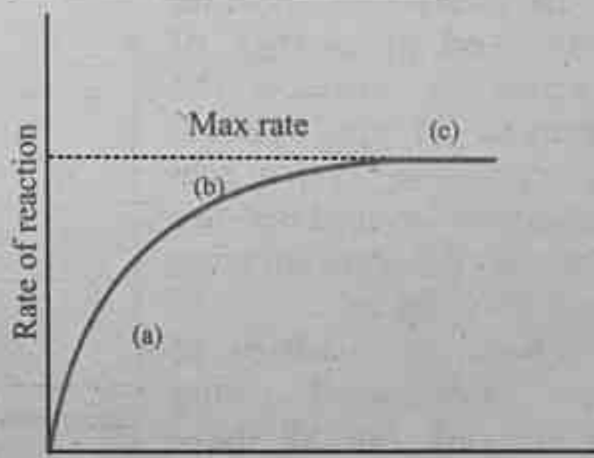


Fig. 3.8 Concentration of Substrate

Tit bits

A restriction enzyme is an enzyme that cleaves DNA into fragments. These enzymes are found in bacteria and provide a defense mechanism against invading viruses. They restrict the entry of foreign DNA in to the host.

Enzyme Concentration:

Enzyme concentration is directly proportional to enzyme activity. If substrate concentration is maintained at high level , and other conditions such as pH and temperature is kept constant then with the increase of enzyme concentration the activity of enzyme will also increase and with the decrease of enzyme concentration the activity of enzyme will also decrease.

Usually in natural conditions the substrate concentration is always high than enzymes. However, when the enzyme concentration become saturated as compared to substrate, then the rate of reaction will not increase further, this maximum rate (Vmax value) is never obtained.

Substrate Concentration:

Like enzymes the substrate concentration is also directly proportional to enzyme activity up to optimum level. If we keep the other conditions such as temperature, pH and enzyme concentration at constant state and change the amount of substrate then we find that with increase in substrate concentration the reaction rate will increase only up to optimum level. This is because more substrate molecules will be colliding with enzyme molecules so more product will be formed. However, at certain concentration substrate become saturated then any further increase will have no effect on the rate of reaction because at this point all the active sites of enzyme will be occupied, maximum rate (V-max).

Energy of Activation(EA):

The minimal amount of energy required to start a chemical reaction is called activation energy. It is denoted by EA and measured in units of kilo joules per mole (KJ/Mol) or kilocalories per mole (Kcal/Mol).

In non-living system, heat is used as energy of activation to increase the movement of molecules. However, in living system heat energy cannot be used because this heat may denature enzymes and proteins of the cell.

There are hundreds of reactions continuously going on in the cell. For all these reactions large amount of activation energy is required. Such a huge amount of energy is not present in living organisms. However, living organisms possess enzymes which lower the activation energy. In the

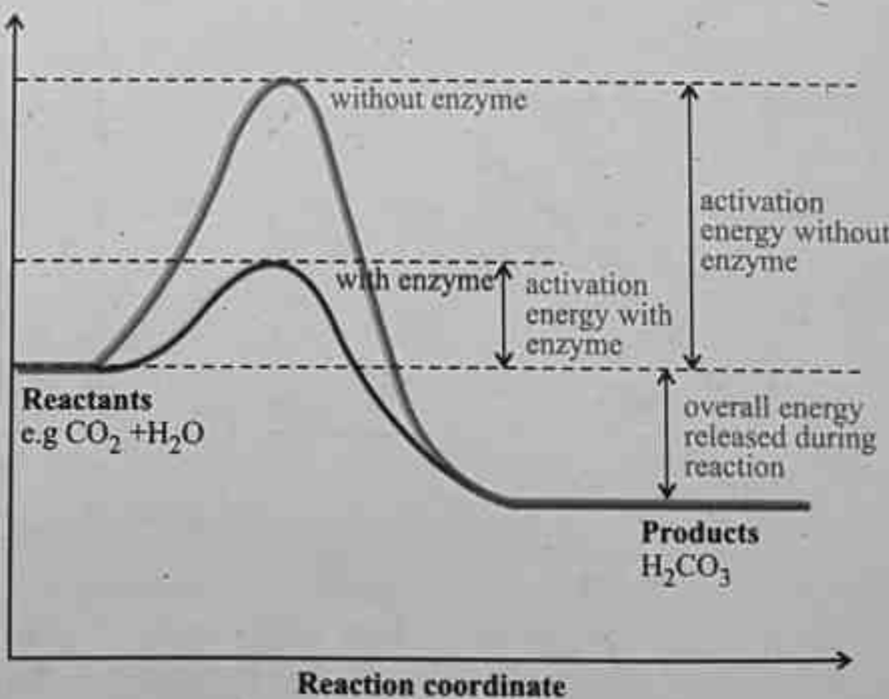


Fig. 3.9 Effect of enzyme on activation energy

presence of enzymes less activation energy is required but in the absence of enzymes more activation energy is required to convert a substrate into product.

3.4 Enzyme Inhibition

The term enzyme inhibition means to stop enzyme from its expression (functioning), usually by enzyme inhibitors or due to change in temperature or pH. Such molecules or substances which stop enzyme activity are called enzyme inhibitors, such as drugs, toxins, products of enzymes etc. Some of the poisons are enzyme inhibitors, that's why a person exposed to poison may die. On the other hand, there are enzyme activators which bind to enzyme to increase enzyme activity.

> **Tit bits**
>
> *Cyanides are powerful poisons of organisms because they can kill them by inhibiting cytochrome oxidase essential for respiration.*

Types of Inhibitors:

Generally there are two main types of enzyme inhibitors that is irreversible and reversible inhibitors.

Irreversible Inhibitors:

These inhibitors stop enzyme activity permanently either by destroying (denaturing) the active site of enzyme or occupying active site by making covalent bond with active site. The irreversible inhibitors often contain reactive functional groups e.g., aldehydes, alkenes. These electrophilic groups make covalent bonds with amino acid side chains.

> **Scientific Knowledge**
>
> *The enzymes which catalyze chemical reaction again and again are called regulatory enzymes.*

The irreversible inhibitors may be natural or artificial e.g., poisons, venom of snakes, drugs etc.

Reversible Inhibitors:

Such inhibitors which attach to enzymes with non-covalent interactions such as hydrogen bond, hydrophobic interactions and ionic bond. These inhibitors generally do not undergo chemical reactions when bonded to enzyme and easily removed from enzymes.

Reversible inhibitors are of two types.

Competitive Inhibitors:

Such inhibitors which have similar shape to the substrate molecule hence compete with substrate to occupy active site. The

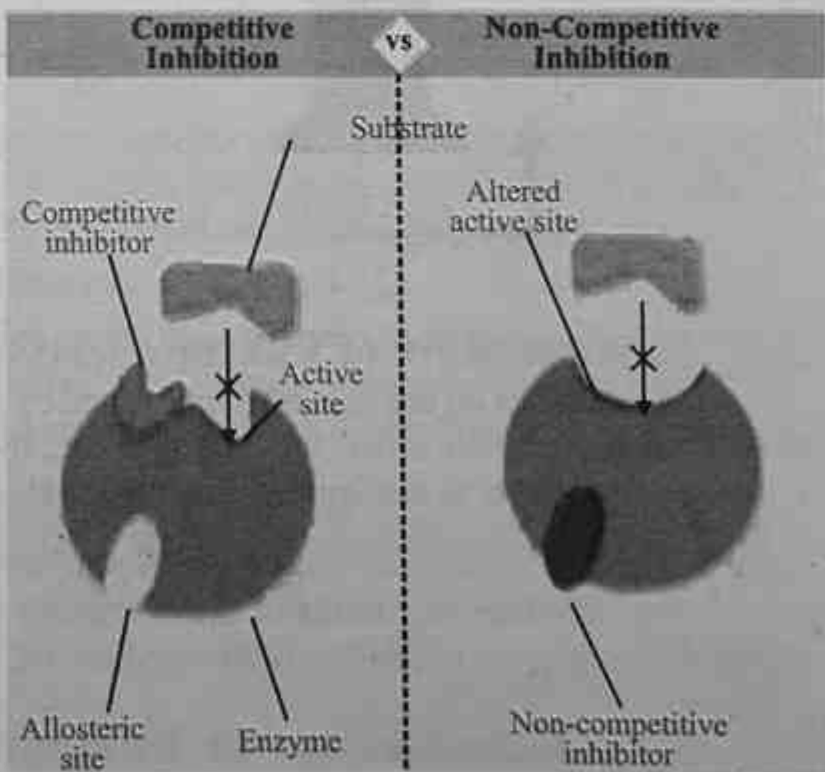


Fig. 3.10 Competitive and Non-competitive inhibitors

process of inhibition depends on the concentration of substrate and inhibitors. With high concentration of inhibitors the chances of inhibition are also high.

Non Competitive Inhibitors:

These inhibitors do not possess structural similarities with the substrate molecule, therefore, attach to allosteric site of enzyme than active site. The attachment of inhibitors changes the shape of active site. Thus substrate cannot bind with active site. Such type of inhibitors are not affected by substrate concentration.

Feed Back Inhibitons:

The production of enzymes, hormones and other products should be in limits to maintain homeostatic conditions. The over production of any product in the body, may prove fatal.

The mechanism through which the production of different products controlled in the body is known as feedback mechanism.

Many enzyme catalyzed reactions are carried out through the biochemical pathways. In these pathways the product of first reaction becomes the substrate for the next reaction. At the end of the pathway a desired product is synthesized. In order to regulate the concentration of that product the biochemical pathway needs to be shut down. This is done through feedback mechanism (automatic system) e.g., the amino acid aspartate changes into threonine through a sequence of five enzymatic reactions. When threonine production become sufficient, it starts accumulating on the allosteric site of enzyme. Thus changes the shape of active site as a result threonine production stops.

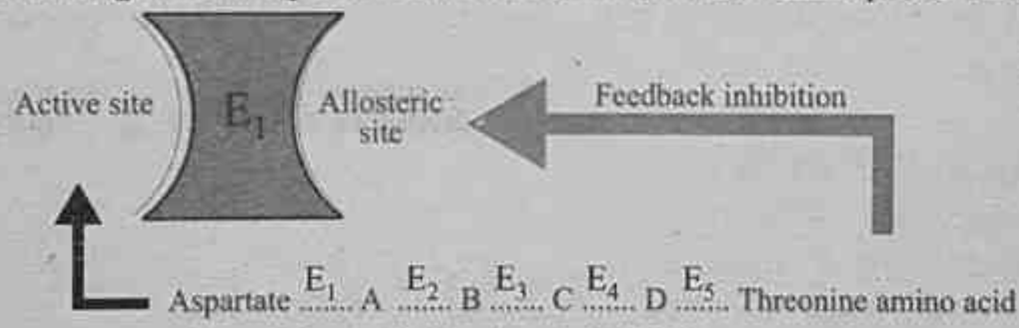


Fig. 3.11 Feedback Inhibition

3.5 Nomenclature of Enzymes (classification of enzymes)

The name of an enzyme is often formed by adding "ase" to the name of substrate. They are named for the action they perform e.g., hydrogenase is an enzyme that removes hydrogen atom from its substrate and cellulase which breaks down cellulose.

1. Classification on the basis of reaction types or functions

The international union of Biochemistry in 1961 has given a nomenclature system for enzymes. According to this system the enzymes are classified into following six groups.

i) Oxidoreductases ii) Transferases iii) Hydrolases
iv) Lyases v) Isomerases vi) Ligases

Oxidoreductases:

These enzymes catalyse different types of oxidation-reduction reactions i.e. removing or adding electrons or hydrogen ions from or to the substrate. The sub classes of these enzymes are oxidases, oxygenases and peroxidases.

Transferases:

These enzymes cause transfer of group from one molecule to another molecule called transferases. Examples of such groups are amino group, carboxyl group, methyl and carbonyl group. Example of transferases enzymes are hexokinases which transfer phosphate group from ATP to glucose.

Hydrolases:

These enzymes break down proteins, fats and carbohydrates by adding water so are called hydrolases e.g., lipase, sucrase, maltase, cellulase, proteinase etc.

Lyases:

These enzymes catalyse the breakdown of specific covalent bond and removal of functional group without hydrolysis e.g., decarboxylase, add or remove carboxyl group, deaminases, add or remove amino group etc.

Isomerases:

Isomers are molecules having similar molecular formula but different structural formula e.g., glucose, fructose and galactose are isomers having same molecular formula $C_6H_{12}O_6$ but have different structures. Isomerase enzymes bring about intramolecular rearrangement within a molecule e.g., phospho-hexose isomerase change glucose 6-phosphate to fructose 6-phosphate.

Ligases:

These enzymes are responsible for formation of bond between two substrates e.g., polymerase joins monomers into polymers, such as joining of mononucleotide into dinucleotide or polynucleotide by DNA polymerase or RNA polymerase.

2. Classification on the basis of name of substrate

Enzymes can also be classified on the basis of name of substrate on which they use e.g., protease breaks protein into amino acids, lipase hydrolyses lipid, amylase breaks down amylose, nuclease acts on nucleic acid, diastase acts on starch etc.

Table 3.2 Comparison between reversible and irreversible enzyme inhibition

Reversible inhibitor	Irreversible inhibitor
1- Binds via non covalent interactions. 2- Do not perform any chemical changes. 3- Can be reversed, as there is no bonding between the inhibitor and substrate.	1- Binds via covalent interactions. 2- Inhibitor binds to the substrate and prevents catalytic activity of enzymes. 3- Irreversibility is due to strong covalent bonding.

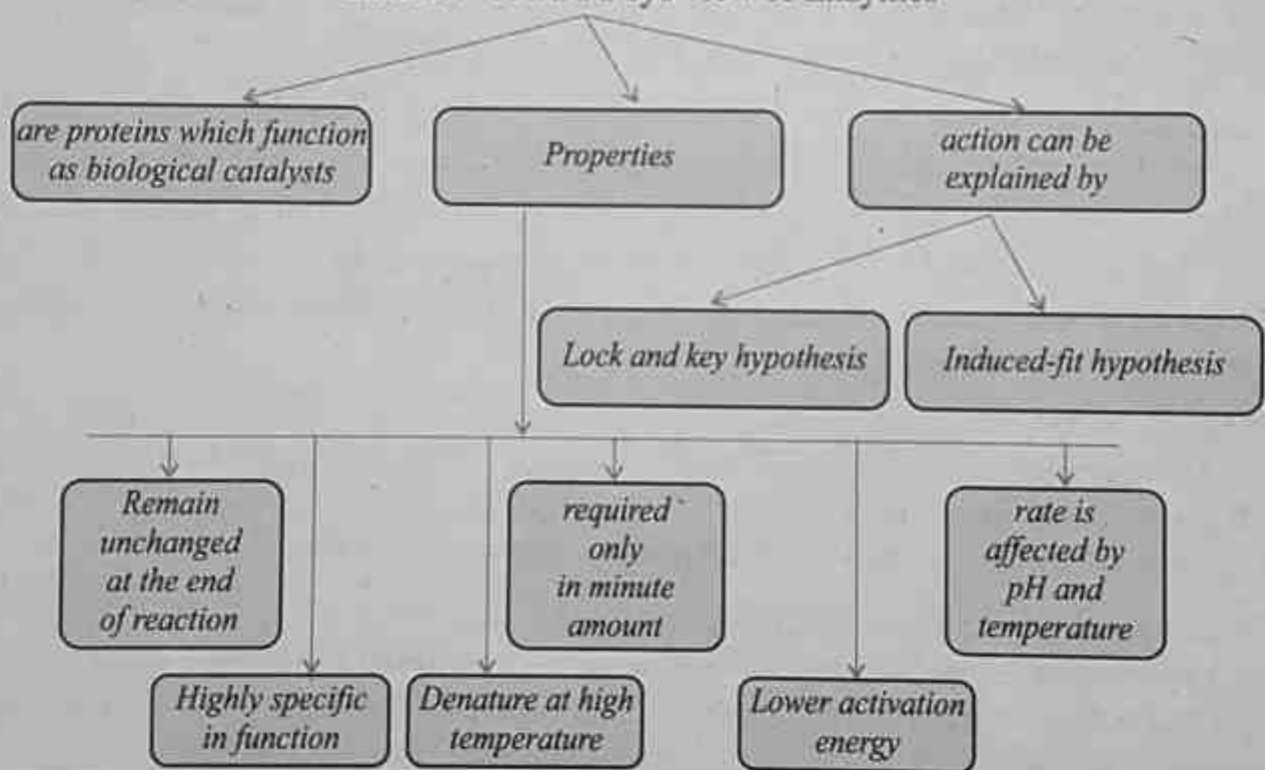
Table: 3.3 Comparison between Competitive and non-competitive enzyme inhibition

Competitive inhibition	Non-competitive inhibition
1- Example: succinate dehydrogenase is inhibited by malonate. 2- Inhibitor binds to active sites. 3- Inhibitor does not change the shape of the active site. 4- Increase in substrate concentration reduces the effect.	1- Example: pyruvate kinase is inhibited by alanine. 2- Inhibitor binds away from the active site i.e., at allosteric site. 3- Inhibitor changes the shape of the active site. 4- Increase in substrate concentration does not affect.

Do you know?

Germinating seeds have enzymes which convert insoluble stored food into simpler soluble substances for example the enzyme amylase digests starch and converts it into maltose.

Table 3.4 A Bird's eye view of Enzymes



Skills: Analyzing

Relate enzyme activity with antibiotics by searching internet and try to find out the reason why antibiotics are not effective against viruses.

Do you know?

Papain enzyme also known as papaya proteinase -1. It is a cystein protease present in papaya and mountain papaya. Active both in acidic and basic medium.

Industrial Enzymes

The commercial use of enzymes is increasing day by day due to the advancements of biological knowledge of enzymes.

The enzymes are used in variety of industries such a pharmaceuticals, chemical productions, Bio fuels, food and beverages industry and consumer products like Laundary detergents, products of cosmetics, meat tenderizers etc.

SUMMARY

- The ability to do work is called energy.
- Work is the transfer of energy.
- The study of energy is called thermodynamics.
- A kilocalorie (kcal) is the amount of heat necessary to raise the temperature of 1 kg of water by 1 centigrade and is equal to 1,000 calories.
- A calorie (c) is the amount of heat it takes to raise the temperature of 1 g (1 cc) of water 1 centigrade that is from 14.5 to 15.5 centigrade.
- An enzyme is a biological catalyst that can accelerate a specific chemical reaction by lowering the activation energy but remains unaltered in the process.
- The minimum amount of free energy to carry out a reaction is called energy of activation.
- The amount of excess energy is called free energy.
- The lowering of the activation of energy a reaction is called catalysis.
- Any substance that performs catalysis is called a catalyst.
- The metal ions which are loosely attached with the enzymes are called metallic cofactors.
- The synthesis of ATP during reactions of glycolysis and Krebs cycle is called substrate level phosphorylation.
- The coupling reaction in which synthesis of ATP molecule takes place during movement of H^+ across an H^+ gradient is called chemiosmosis.
- The molecule which reacts with enzymes but is converted into desired products is called an inhibitor.
- Reversible inhibitors temporarily prevent the formation of enzymes product complex.
- Irreversible inhibitors destroy enzymes by altering active site so that the substrate cannot bind to the active site.
- Competitive inhibitor closely resembles the chemical structure and molecular geometry of the substrate thus compete with substrate for the same active site.
- Non competitive inhibitor molecule binds to an enzyme other than active site.
- Cofactor is the non protein part of an enzyme responsible for attachment of substrate to active site and also participate in the catalytic reaction.
- Enzymes are named by adding "ase" to the end of the name of substrate they act, e.g., proteases, lipases etc.

- Enzymes are named by taking into consideration both the substrate acted upon and the type of reaction catalysed, e.g., DNA-polmerase.
- Enzymes are named according to the types of reaction they catalyse, e.g., oxidases, reductases etc.
- Some enzymes are named as per substance synthesized e.g., rhodonase catalyses synthesis of rhodonate from hydrochloric acid and sodium thiosulphate.
- Lock and key model was first postulated in 1894 by Emil Fischer.
- The induced-fit theory was given by Koshland in 1959.

EXERCISE

Section I: Objective Questions

Multiple Choice Questions

A. Choose the best correct answer.

1. A biochemical reaction would proceed at a very slow speed making life impossible in the absence of
   (a) Enzyme (b) Cofactor
   (c) Coenzyme (d) Substrate
2. An enzyme with its coenzyme or prosthetic group is called as
   (a) Holoenzyme (b) Apoenzyme
   (c) Activator (d) Inhibitor
3. Generally a single enzyme catalyzes only a single substrate or a group of related substrates, therefore, the enzymes are
   (a) Specific (b) Reactive
   (c) Activator (d) Inhibitor
4. The enzymes involved in cellular respiration are found in
   (a) Golgi bodies (b) Mitochondria
   (c) Chloroplast (d) Ribosomes
5. Every enzyme functions most effectively over a narrow range of pH known as
   (a) Maximum (b) Minimum
   (c) Optimum (d) Both a and b
6. Enzymes are sensitive to minor changes in
   (a) pH (b) Substrate concentration
   (c) Temperature (d) All of these
7. The chemical substance with which an enzyme reacts is called its
   (a) Substrate (b) Active site
   (c) Inhibitor (d) Cofactor
8. Enzymes require which medium for its activity.
   (a) Solid (b) Semi-solid
   (c) Aqueous (d) Jelly-like

9. The optimum temperature for enzymes in human body is
   (a) 4°C (b) 37°C
   (c) 41°C (d) 50°C
10. The catalytic activity of an enzyme is restricted to its small portion called
   (a) Active site (b) Passive site
   (c) Intermediate (d) Allosteric site
11. The reversible inhibitors usually constitute
   (a) Strong linkage with enzyme (b) Weak linkage with enzyme
   (c) No linkage with enzyme (d) Medium linkage with enzyme

B. Fill in the blanks.

1. The detachable cofactor of enzyme is called ....
2. Reversible inhibitors may be competitive or ....
3. The minimal amount of energy required to carry out a chemical reaction is called ....
4. Enzymes become denatured due to .... temperature .
5. The optimum pH of pepsin is ....
6. Induced fit hypothesis was proposed by .... in 1958.

Section II: Shorts Questions.

A. Differentiate between following.

1. Hydrolases and Lyases
2. Reversible and irreversible inhibitor.
3. Apoenzyme and coenzyme
4. Active site and allosteric site
5. Competitive and non-competative enzyme inhibition.

B. Short questions.

1. How does temperature affect enzyme activity?
2. How does pH affect enzyme activity?
3. What is meant by energy of activation?
4. How feed back inhibition is important?
5. What is meant by optimum temperature and optimum pH?
6. Write the names of six classes of enzymes on the basis of reaction they perform.

Section III: Extensive Questions.

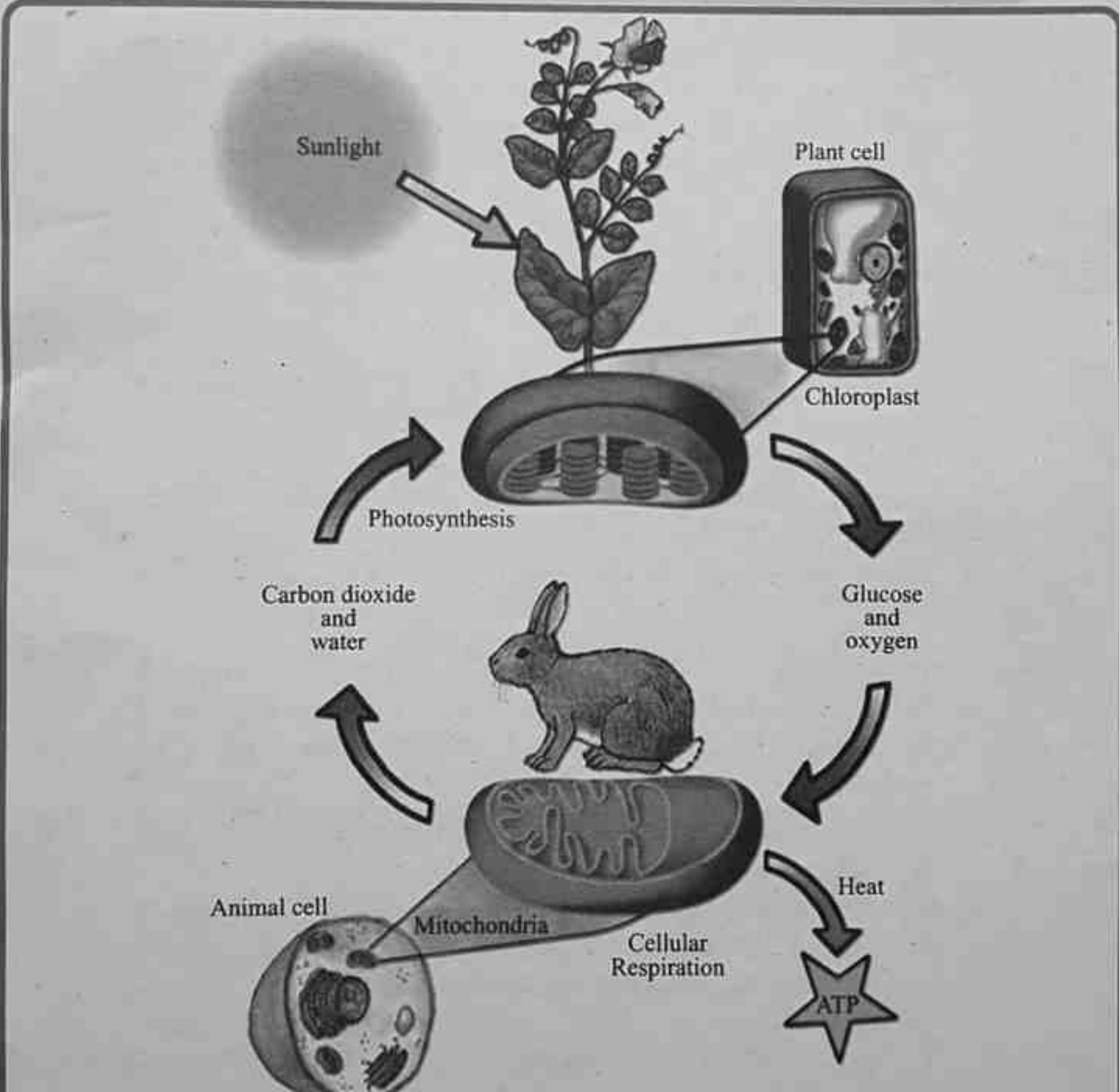
1. Describe the structure of an enzyme.
2. Describe the two models about the mechanism of enzyme action.
3. Explain different factors which affect enzyme activity.
4. Define enzyme inhibition and describe different types of enzyme inhibitors in detail.
5. Write a detailed note on classification of enzyme on the basis of their reaction type.

UNIT 4

BIOENERGETICS

Major Concepts

4.1 Photosynthesis
4.2 Cellular Respiration
4.3 Photorespiration



Students Learning Outcomes

On completion of this unit students will be able to:

- Explain the role of light in photosynthesis.
- Identify the two general types of photosynthetic pigments (carotenoids and Chlorophylls).
- The role of photosynthetic pigments in the absorption and conversion of light energy into chemical energy.
- Differentiate between the absorption spectra of chlorophyll a and b.
- Describe the arrangement of photosynthetic pigments in the form of photosystem I and II.
- State the role of CO_2 as one of the raw materials of photosynthesis.
- Explain the role of water in photosynthesis.
- Describe the events of non-cyclic photophosphorylation and outline the cyclic photophosphorylation.
- Explain the Calvin cycle.
- Explain the process of anaerobic respiration in terms of glycolysis and conversion of pyruvate into lactic acid or ethanol.
- Outline the events of glycolysis.
- Describe the conversion of pyruvate to acetyl-CoA.
- Outline the steps of Krebs cycle.
- Explain the passage of electrons through electron transport chain.
- Describe chemiosmosis and relate it with electron transport chain.
- Explain the substrate-level Phosphorylation during which exergonic reactions are coupled with the synthesis of ATP.
- Comprehend the importance of PGAL in photosynthesis and respiration.
- Outline the cellular respiration of proteins and fats and correlate these with that of glucose.
- Define photorespiration and outline the events occurring through it.
- Rationalize how the disadvantageous process of photorespiration evolved.
- Explain the effect of temperature on the oxidative activity of RuBP carboxylase.
- Outline the process of C4 photosynthesis as an adaptation evolved in some plants to deal with the problem of photorespiration.

Bioenergetics

Bioenergetics is the field of biochemistry and cell biology which deals with the study of the processes by which cells use, store and release energy. The quantitative study of energy relationships in biological system is called **bioenergetics**.

A central component of bioenergetics is energy transformation, the conversion of energy from one form to another. The biological energy transformations obey the laws of thermodynamics. Energy is necessary for growth and reproduction. We cannot exhibit any of characteristics of life without a ready supply of energy. In this chapter we will discuss the most fundamental metabolic processes which are photosynthesis and respiration.

Tit bits

An exergonic reaction is a spontaneous chemical reaction that releases energy. It is catabolic reaction. An endergonic reaction is an anabolic chemical reaction that consumes energy.

4.1 Photosynthesis

Photosynthesis is the biological process that captures light (solar) energy and converts it into chemical energy (i.e. organic molecules, e.g., glucose). It takes place in plants, algae, cyanobacteria and many bacteria.

Photosynthesis is a "redox" process which links non-living world to the living world. It involves the reduction of carbon dioxide into sugars and the oxidation of water into molecular oxygen. The overall reactions of photosynthesis can be summarized as follows:

Reduction

$$6CO_2 + 12H_2O \xrightarrow[\text{Chlorophyll}]{\text{Sunlight}} C_6H_{12}O_6 + 6H_2O + 6O_2$$

Oxidation

4.1.1 Role of Light in Photosynthesis

Light is a form of energy called **Electromagnetic energy or radiation**. Solar radiation is consist of photons. Photons (Gk. "*Phos*"=Light) are separate and distinct packets of energy which come from solar radiation. Photons travel in waves, these waves contain energy. Short waves contain more energy than long wave.

The full range of electromagnetic radiation in the universe is called **electromagnetic spectrum** while visible light (380-750 nm) is only a small part of the spectrum.

Visible light:

Visible light is the part of the spectrum that the human eye can see which is white light. Photons of visible light have just the right amount of energy to promote electrons to higher electron shell in atoms. Leaves absorb only 1% of total light, which falls on them, rest is reflected or transmitted. The synthesis of ATP from ADP or AMP is called phosphorylation which is endergonic process.

$$\mathbf{ADP + Pi + energy \rightleftharpoons ATP}$$

In photosynthetic organisms the energy comes from light thus the process of formation of ATP during photosynthesis is referred to as **photophosphorylation.** Light falls on green tissues thereby water molecules are broken down (photolysis) into $\mathbf{H^+}$ ions, $\mathbf{OH^-}$ radicals and electrons. The $\mathbf{OH^-}$ radicals are collected and reassembled as water and molecular oxygen, both are released into

Do you know?

Some carotenoids may protect chlorophyll and human eye from intense light by absorbing and dissipating excessive light energy.

atmosphere. The Hydrogen ions (protons) are pumped across the thylakoid membrane into the lumen. H^+ ions are used to convert NADP to $NADPH_2$ in photosystem I.

4.1.2 Role of Photosynthetic Pigments

A photosynthetic pigment is a pigment that is present in chloroplasts or photosynthetic bacteria and captures the light energy necessary for photosynthesis. Different pigments absorb light of different wavelengths. The light appear in different colours when passed through a prism.

Carotenoids:

These are a group of yellow, orange, red or brown pigments that absorb blue, violet and green light. They are associated with the chlorophyll inside the chloroplast or occur alone inside the chloroplast. Carotenoids absorb different wavelengths than chlorophyll, so broaden the spectrum of light that provides energy for photosynthesis. The chlorophyll *b* and carotenoids together are called accessory pigments because they absorb light and transfer the energy to chlorophyll *a* which then starts the light reaction.

> **Tit bits**
>
> *Carotenoids in flowers and fruits attract insects, birds and other animals for pollination and seed dispersal respectively. They also protect chlorophyll from oxidation by oxygen produced in photosynthesis.*

Carotenoids $\longrightarrow$ Chlorophyll *b* $\longrightarrow$ Chlorophyll *a*

Chlorophylls:

Chlorophylls are green and main photosynthetic pigments which absorb violet, blue, orange and red wavelengths, while green and yellow are least absorbed and are reflected (therefore, leaves look green). There are six types of chlorophylls (*a, b, c, d, e,* and *f*) out of these only two types occur in chloroplasts of higher plants, i.e. chlorophyll *a* and *b*. Chlorophyll *c* and *d* are found only in algae while chlorophyll *e* and *f* are found only in bacteria.

> **Do you know?**
>
> There are two types of carotenoids, i.e. Carotenes and Xanthophylls.
>
> **Carotenes (Red to Orange):**
>
> Carotenes are hydrocarbons with a general formula of $C_{40}H_{56}$. Red colour of tomato and chilli are due to carotenes. The most common carotene is beta-carotene which is converted to vitamin A by animals and human beings.
>
> **Xanthophylls (Yellow to Orange):**
>
> Xanthophylls are yellow pigments that are oxygen containing derivatives of carotenes. Lutein and zeaxanthin ($C_{40}H_{56}O_2$) are the two primary xanthophylls found in green leafy vegetables and other foods like eggs. Yellow colour of leaves in autumn is due to lutein.
>
> The xanthophylls of brown algae is called fucoxanthin ($C_{40}H_{56}O_6$). Both carotenes and xanthophylls are lipid compounds, soluble in organic solvents like other lipids.

Chlorophyll *a*:

It occurs in all photosynthetic organisms except pigmented bacteria thus termed as universal photosynthetic pigment. It is also known as primary photosynthetic pigment because it involves in primary reaction during photosynthesis, i.e. convert light energy into chemical energy. Molecular formula of chlorophyll *a* is ($C_{55}H_{72}O_5N_4Mg$).

Chlorophyll *b*:

Chlorophyll *b* occurs in all photosynthetic organisms except brown, red and blue green algae. Molecular formula of chlorophyll *b* is ($C_{55}H_{70}O_6N_4Mg$).

Do you know?

Porphyrin is derivative of porphin, consists of four pyrrole like rings linked by four CH groups in an alternate double and single bonds. If Mg++ or Fe++ are added to porphin then known as Mg++ porphyrin in chlorophyll or Fe++ porphyrin in Heme and cytochrome.

Structure of Chlorophyll:

Each chlorophyll molecule has two main parts, one flat square part which absorbs light and hydrophilic head. The other part is long anchoring hydrophobic carbon tail.

The head of chlorophyll is composed of four pyrrole rings (pyrrole is five sided unsaturated nitrogen containing compound) having Mg^{++} in the center, thus it is Mg^{++} **porphyrin** with two side chains.

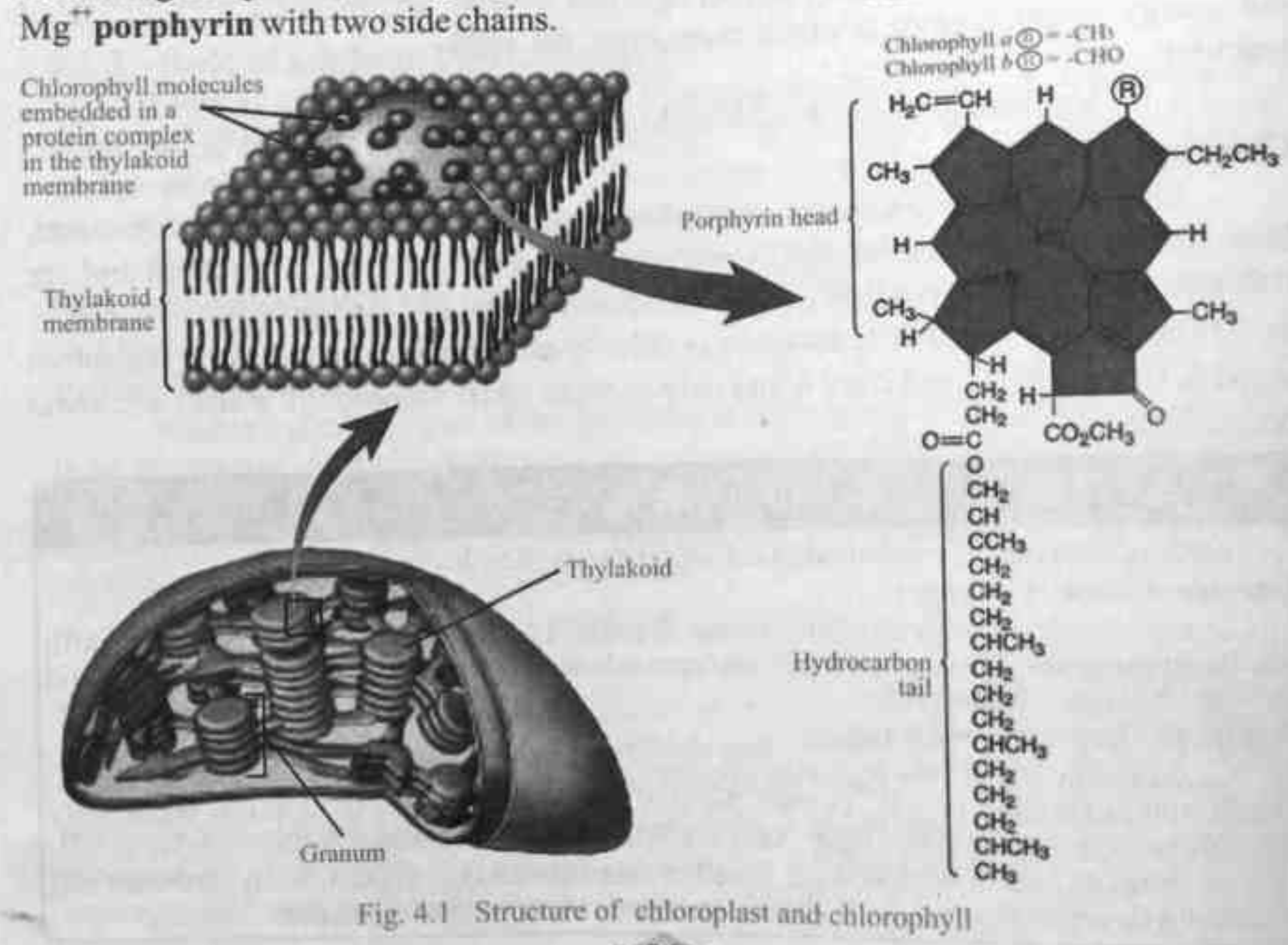


Fig. 4.1 Structure of chloroplast and chlorophyll

a. **Acid chain:** It is a methyl (CH_3) ester ($H_3C–O–C=O$).

b. **Hydrocarbon chain:** It is a long hydrocarbon tail which is attached to one of the pyrrole rings and is an alcohol phytol ($C_{20}H_{39}$) (it is an ester linkage with propionic acid) (CH_3-CH_2-COOH).

Phytol consists of four isoprene units. It is insoluble and serves to anchor the molecule in the membrane of the granum (molecular formula of isoprene is ($CH_2=C\text{-}CH_3\text{-}CH=CH_2$) ($C_5H_8$).

Differences Between Chlorophyll *a* And *b*:

There is only one difference between chlorophyll *a* and *b* that is one of functional group bonded to the porphyrin. In chlorophyll *a* methyl group (CH_3) while in chlorophyll *b* aldehyde group (-CHO) is present.

Role of Pigments in Photosynthesis

The clusters of photosynthetic pigments are called photosystem. Each pigment complex is composed of chlorophyll *a* and *b* molecules with accessory pigments. When these pigments absorb light they are said to be excited. The light energy is used to boost electrons to a higher energy level which is transferred into chemical energy. The excited state is unstable and molecules will tend to return to its unexcited state.

The energy which is released during this process can be passed from one chlorophyll molecule to another chlorophyll molecule. The instrument which is used to measure relative abilities of different pigments to absorb different wavelength of light is called **Spectrophotometer**.

4.1.3 Absorption Spectrum

It is a measure which exhibits the absorbed amount of the light of different wavelengths (different colours) from the visible spectrum of light. The main photoreceptors are chlorophyll *a* and chlorophyll *b* which absorb violet blue (430 nm) and red light (670 nm). The green light (550 nm) is least absorbed. The carotenoids absorb light between 430-470 nm of light spectrum and transfer it to chlorophyll *b* then to chlorophyll *a*. The chlorophyll *a* and *b* show different absorption spectra as shown figure 4.2 (a). Chlorophyll *a* shows absorption peaks at about 680 and 700 nm while chlorophyll *b* absorption peaks range between 450-475 nm.

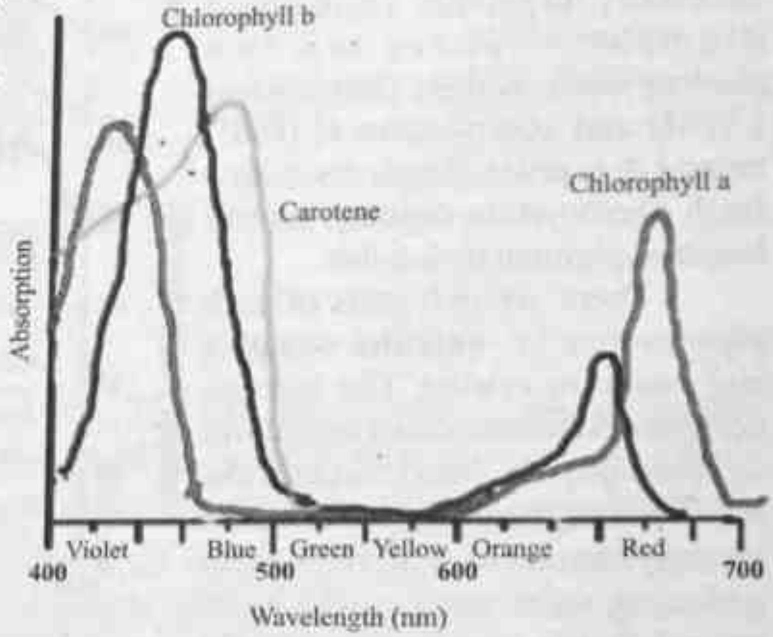


Fig. 4.2 (a) Absorption Spectra

4.1.4 Action Spectrum

A graph showing the measure of effectiveness of light of various wavelengths in driving photosynthesis is called action spectrum. Some of absorbed light is released as heat and rest of light is stored in organic compound as chemical energy. Action spectrum of a particular pigment can be calculated by measuring the rate of photosynthesis at each type of wavelength of light. A plant is illuminated with light of different wavelengths. During photosynthesis plant gives off oxygen. As photosynthesis produces oxygen and consumes CO_2, the rate of production of oxygen or consumption of CO_2 can be used as a measure of the rate of photosynthesis.

> **Do you know?**
> *Accessory pigments are photosynthetic pigments that trap light energy and channel it to chlorophyll "a" the primary pigment which initiates the reaction of photosynthesis. Accessory pigmants are carotenoids, phycobilin, some proteins and chlorophyll b, c and d.*

4.1.5 Arrangement of Photosynthetic Pigments in the form of Photosystem I and II

Light reaction takes place in the grana of chloroplast. It is initiated when photosynthetic pigments capture light energy. The clusters of photosynthetic pigment complex are composed of chlorophyll *a* and *b* molecules and accessory pigments (carotenoid pigments). There are two photosystems, namely photosystem I (PSI) and photosystem II (PSII) named so in order of their discovery. Each photosystem contains several hundred pigment molecules.

There are two parts of each photosystem i.e. **antenna complex** and **reaction center**. The antenna complex possesses many molecules of chlorophyll *a, b* and carotenoids. All these pigment molecules in the photosystem serve as an antenna for gathering solar energy, which is passed from one pigment to the other and finally transferred to the

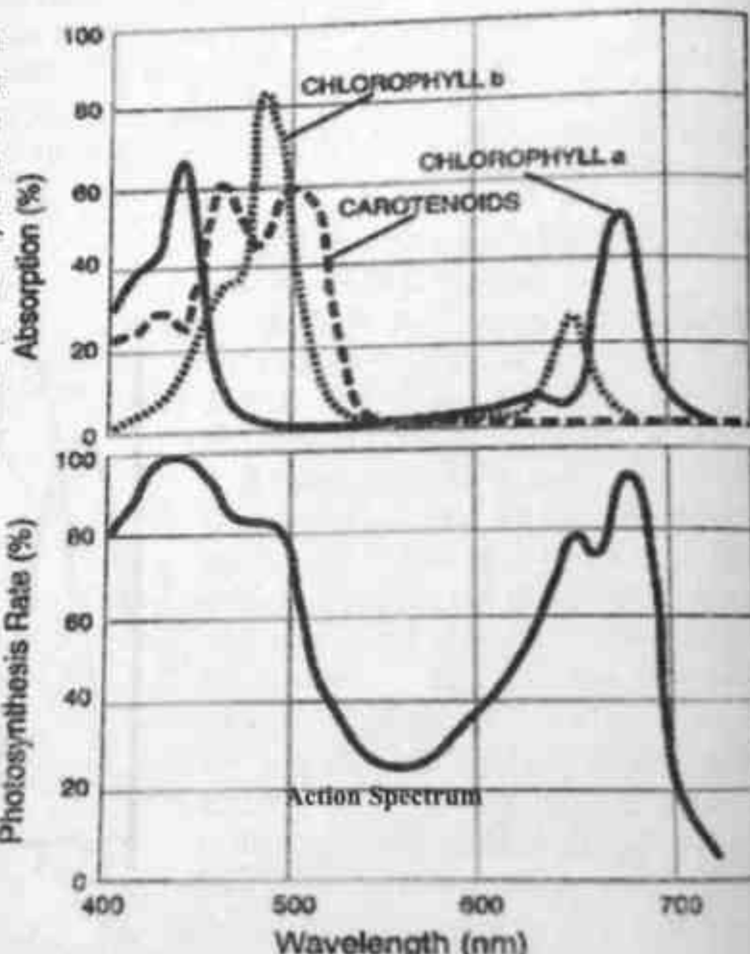


Fig. 4.2 (b) Absorption and Action spectra of different pigments

reaction center. **Reaction center** contains one more molecule of chlorophyll *a* alongwith primary electron acceptor and electron carriers of electron transport system. Electron transport system plays a role in the generation of ATP by **chemiosmosis.** The PSI absorbs light of 700 nm and is called P700 while the PSII absorbs light of P680 nm and is called P680. The **primary electron acceptor** traps the electrons from the reaction center and then passes them on to the series of electron carriers. Electrons have two pathways in the light reaction of photosynthesis; The non-cyclic electron pathway (flow) and cyclic electron pathway. The cyclic is less common and generates only ATP while non-cyclic is predominant and generates both ATP and $NADPH_2$.

Do you know?

The action spectrum is somewhat different from absorption spectrum of chlorophyll. It is more in some wavelengths, such as in 500-600 nm is more than the absorption of green light by chlorophyll. This is because the carotenoids absorb light in this region and pass on some of this absorbed light to chlorophyll, which converts light energy into chemical energy. Similarly when equal intensities of light are given, there is more photosynthesis in red than in blue part of the spectrum.

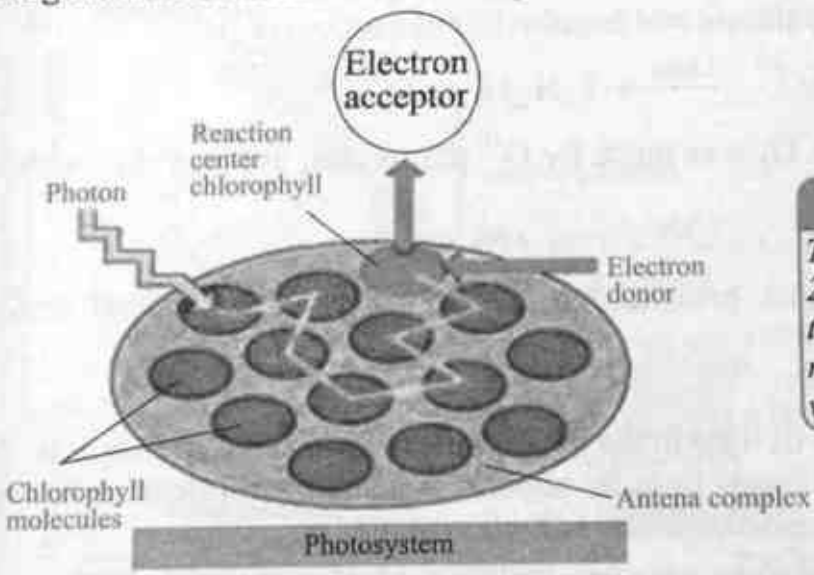


Fig. 4.3 Structure of Photosystem

Thinking Question

The stomata cover only 1 to 2% of the leaf surface but they allow proportionally much more gas to diffuse, why?

4.1.6 Role of CO_2 in Photosynthesis

Air contains about 0.03 to 0.04 % of CO_2. This CO_2 is used by terrestrial plants for photosynthesis while aquatic plants use dissolved CO_2 and carbonates present in water as source of carbon. The chloroplasts of guard cells of stomata absorb CO_2, some of which react with water to form carbonic acid.

$$CO_2 + H_2O \longrightarrow H_2CO_3$$

In the presence of solar energy carbonic acid in the guard cells is decomposed again into water and CO_2.

$$H_2CO_3 \longrightarrow H_2O + CO_2$$

Water and carbondioxide are rapidly used in photosynthesis to synthesize organic substances. The entry of CO_2 into the leaves depends upon the opening of stomata.

4.1.7 Role of Water in Photosynthesis

Water is one of the raw materials used in photosynthesis. A film of water present around mesophyll cells of leaf helps to absorb CO_2. The water molecule is broken down into hydrogen and oxygen by the P_{680} during **photolysis**. The hydrogen combines with CO_2 to form organic food and molecular oxygen is released into atmosphere during photolysis of H_2O. Earlier it was thought that the oxygen released in the process of photosynthesis comes from CO_2. Van Neil 1903, was first who observed that water splits during photosynthesis, hydrogen released from water is used to synthesize glucose while O_2 is removed as byproduct. The idea of Van Neil was also supported by another scientist named Hill. In first experiment water was made of O^{18} and algae were grown in it. The oxygen evolved during photosynthesis was found to be radioactive (O^{18}).

> **Tit bits**
>
> *Photolysis is the splitting of a chemical compound by means of light energy i.e., photons e.g., photolysis of water in photosynthesis produces H^+ and O_2.*

$$6CO_2 + 12H_2O^{18} \xrightarrow{\text{Light}} C_6H_{12}O_6 + 6O_2^{18} + 6H_2O$$

In second experiment CO_2 was made by O^{18} the oxygen evolved was without isotope.

$$6CO_2^{18} + 12H_2O \xrightarrow{\text{Light}} C_6H_{12}O_6^{18} + 6H_2O^{18} + 6O_2$$

Thus above experiments proved that source of oxygen evolved during photosynthesis was water.

4.1.8 Light Reaction

It occurs in the presence of light in the thyllakoids of granum of chloroplast. The light reaction involves absorption of light by photosystems, flow of electron through electron transport chain i.e. chemiosmosis and reduction of NADP.

Photophosphorylation: In light reaction addition of phosphate to ADP in the presence of light is called photophosphorylation. There are two pathways:

(i) Cyclic photophosphorylation (ii) Non Cyclic photophosphorylation

Cyclic Photophosphorylation: The cyclic photophosphorylation is less common and generates only ATP while non-cyclic photophosphorylation is predominant and generates both ATP and $NADPH_2$.

Non-Cyclic Photophosphorylation: During non-cyclic photophosphorylation electrons move from water through PS-II to PS-I then to NADP.

Photosystem II:

When light strikes the chlorophyll molecules in PSII (p680) its energy causes the chlorophyll molecule to be activated. The activated chlorophyll loses its two electrons and the positively charged chlorophyll molecule is left in the photosystem with a gap of two electrons. The high energy electrons instead of falling back into the photosystem are captured by primary electrons acceptor of first electron transport chain. The **primary electron acceptor is pheophytin** which then passes the electrons to a plastoquinone (PQ). Now from primary electrons acceptor, the electrons pass along a series of electron acceptor molecules from one to another in oxidation process. These electron acceptors are two **cytochromes** (cytochrome *b* and *f*) and **plastocyanin** (PC) (a copper containing protein).

Production of ATP:

When electrons are passed through electron transport chain, they lose energy. Some of the energy lost by electrons between cytochrome *b* and cytochrome *f* is used to make ATP from ADP and Pi. This ATP, which is generated by PS-II will provide energy for Calvin cycle where CO_2 is fixed to synthesize sugar.

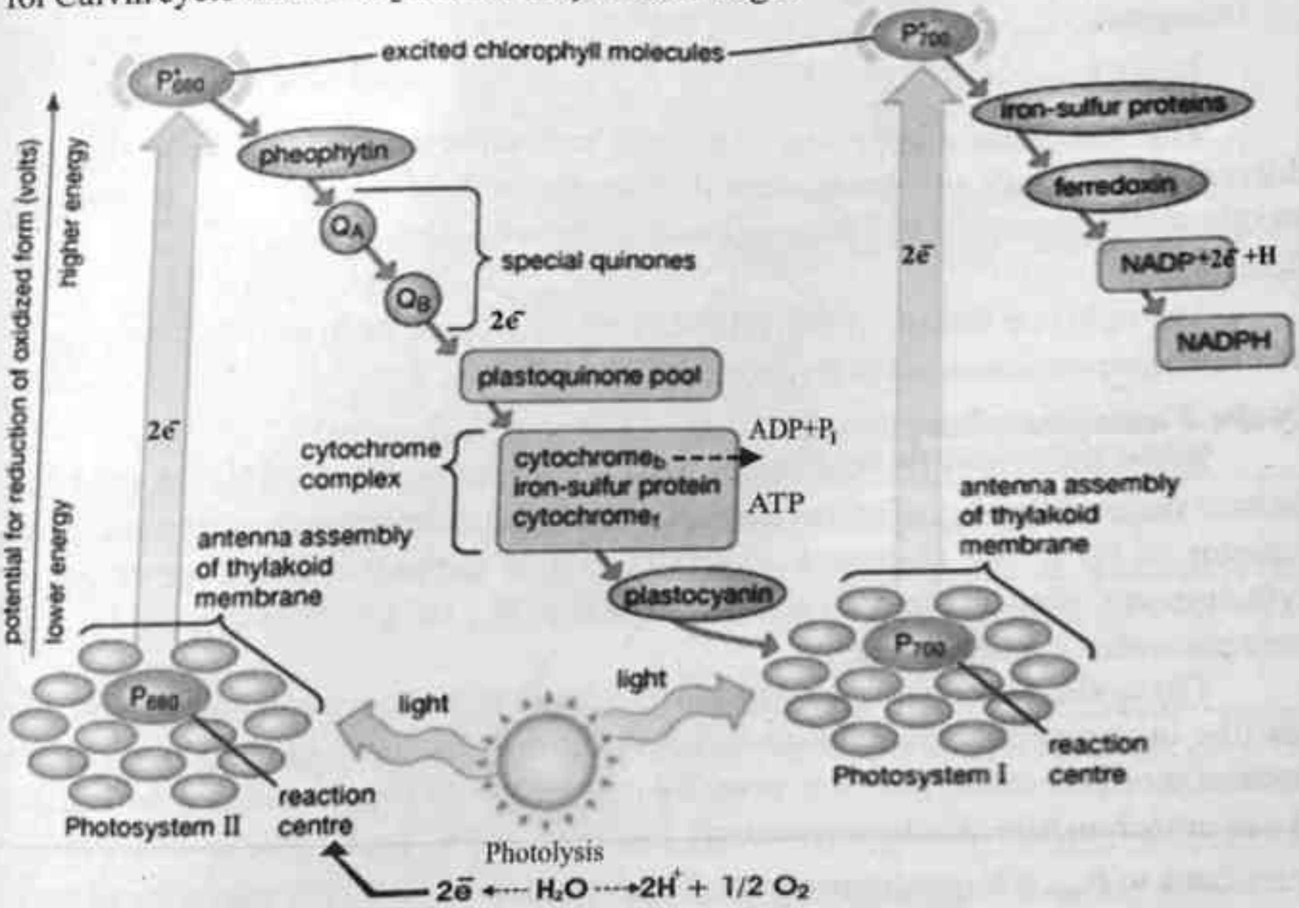


Fig. 4.4 Non- cyclic photophosphorylation (Z-scheme)

Activity

1. *Why do we consider the leaves in plants as food factories?*
2. *Trace out the environmental factors that affect the rate of photosynthesis?*

Photosystem I:

The electrons from PS II pass to PS I. The electrons from plastocyanin are received by another photosystem called photosystem I (P_{700}), where these electrons are boosted to high energy state by absorbing a photon of light.

The photoexcited electron of PS I enters in the second electron transport chain. Here electrons are accepted by ferredoxin (FD), which is also an iron containing protein. The enzyme NADP reductase (flavo protein enzyme) by a redox reaction transfers the electrons from ferredoxin to NADP. The NADP combines with electrons and hydrogen to form $NADPH_2$.

ATP and NADPH are used in Calvin cycle to produce sugar.

$$NADP^+ + 2e^- + 2H^+ \longrightarrow NADPH + H^+$$

When photosystem II absorbs light water molecule splits into **OH^-** and **H^+**. The **OH^-** ions react to form some water and release oxygen and electrons.

$$4H_2O \longrightarrow 4H^+ + 4(OH^-) + 4e^-$$

$$4(OH^-) \longrightarrow 2H_2O + O_2$$

The electrons from water molecule are accepted by positively charged chlorophyll molecule of photosystem II, thus the emptied hole is filled by the two energized electrons while PS I receives electrons from PS II.

Z-Scheme:

The light reaction of the PS II and PS I follows zigzag path, therefore, non-cyclic electron transport is also called Z-scheme of light reaction.

Cyclic Photophosphorylation (Cyclic Electron Transport):

It consists of only PS I and occurs in rare condition i.e. when PS II is blocked. The electrons released by P_{700} of PS I in the presence of light are taken up by primary electron acceptor of PS I. The electron acceptors consist of ferredoxin (FD), cytochrome *b*, Cytochrome *f*, plstocyanin (PC) and finally back to P_{700} i.e. electrons come back to the same place after cyclic movement.

The **cyclic photophosphorylation** also result in the formation of ATP molecules just like in non-cyclic photophosphorylation. As the electrons move downhill in the electron transport chain, they lose potential energy and ATP molecules are formed (just like in mitochondrion during respiration). Electrons of PS I do not pass to NADP instead come back to P_{700}. It is important to note that oxygen and $NADPH_2$ are not formed during cyclic photophosphorylation.

Which conditions lead to cyclic electron pathway?

1. When production of ATP is low thus Calvin cycle does not begin.
2. Due to slow rate of Calvin cycle, $NADPH_2$ do not oxidize into NADP.

3. There are many other enzymatic reactions which use ATP in stroma, thus Calvin cycle becomes slow.
4. Limited supply of CO_2 also affects carbohydrate synthesis .

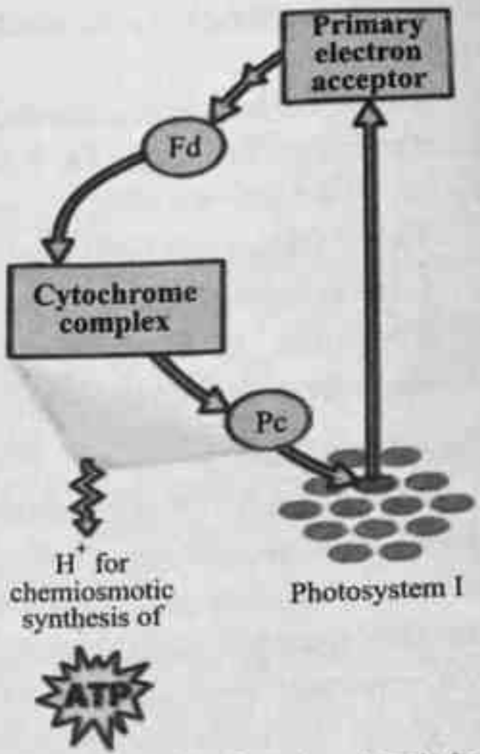


Fig. 4.5 Cyclic photophosphorylation

Summary of Light Reactions:

Requirements:

1. Light
2. Enzymes needed for different reactions in the chloroplast
3. H_2O
4. NADP
5. ADP and Pi (inorganic phosphate)

Products:

1. Oxygen
2. ATP
3. $NADPH_2$

Activity

1. Draw the Z-scheme for explaining the events of light dependent reactions.
2. Draw the labelled structure of chloroplast.

Table 4.1 Comparison between cyclic and non-cyclic photophosphorylation

Non-cyclic photophosphorylation	Cyclic photophosphorylation
Elections do not come back to the same molecule.	Electrons come back to the same molecule.
First electron donor is water.	First electron donor is P_{700} (PS I).
Involves both PS I and PS II.	Involves PS I only.
Last electron acceptor is NADP.	Last electron acceptor is (P_{700}).
The net products are ATP, $NADPH_2$ and O_2.	The Product is ATP only.

4.1.9 Light Independent Reaction or Dark Reaction

The light independent reaction was discovered by Melvin Calvin and coworkers (1950) at the University of California. He was awarded Noble prize in 1961 for his work. Therefore, this cycle is also called **Calvin cycle.** They used radioactive isotope of C^{14} in CO_2. Light independent reactions do not need direct energy of sunlight. It may occur during day time but it is called dark reaction, so as to differentiate it from the light reaction.

Calvin cycle occurs in the stroma of chloroplast by a series of reactions in which CO_2 is fixed into carbohydrate **$(CH_2O)n$** in the absence of light.

The **Calvin cycle** is completed in three stages:

i) Carbon fixation

ii) Reduction

iii) Regeneration of ribulose bi-phosphate.

Do you know?

Rubisco is the most abundant protein on earth.

Do you know?

Oxidation is the loss of electron from an atom or molecule while reduction is the gain of electrons by an atom or molecules.

Tit bits

9 ATP and 6 $NADPH_2$ from light reaction are used in Calvin cycle to produce one PGAL, which can be used to form glucose, fructose etc.

Carbon Fixation:

It is first step of dark reaction in which **CO_2** from air combines with pre-existing five carbon phosphorylating sugar known as ribulose biphosphate (RuBP). As a result an unstable 6-carbon intermediate compound is formed. The enzyme that speeds up this reaction is called RuBP carboxylase; also known as **Rubisco.**

The six carbon intermediate molecule exists for such a brief time that it cannot be isolated and thus named as an intermediate compound.

Formation of PGA:

The unstable intermediate compound splits into two molecules of three carbon containing phoshoglyceric acid (PGA). It is first identifiable product in dark reaction. Therefore, Calvin cycle is also called **C_3 Cycle**.

$$CO_2 + RuBP(C_5) \longrightarrow C_6 \text{ (intermediate compound)} \longrightarrow 2\ PGA(C_3)$$

The carbon that was part of CO_2 molecule is now a part of organic molecule. This is called CO_2 fixation.

Reduction (Formation of PGAL or G3P):

In this step the product of light reaction that is ATP and $NADPH_2$ are used. Each molecule of phosphoglyceric acid (PGA) receives energy from ATP and H^+ from $NADPH_2$ forming 3 carbon phosphoglyceraldehyde (PGAL). In this step water is also formed. In reduction process fixed carbon is reduced into a 3-carbon sugar molecule of PGAL.

$$PGA + ATP + NADPH_2 \longrightarrow PGAL + ADP + Pi + NADP + H_2O$$

ADP and Pi and NADP return back to light reaction where ADP is converted into ATP and NADP is reduced into $NADPH_2$.

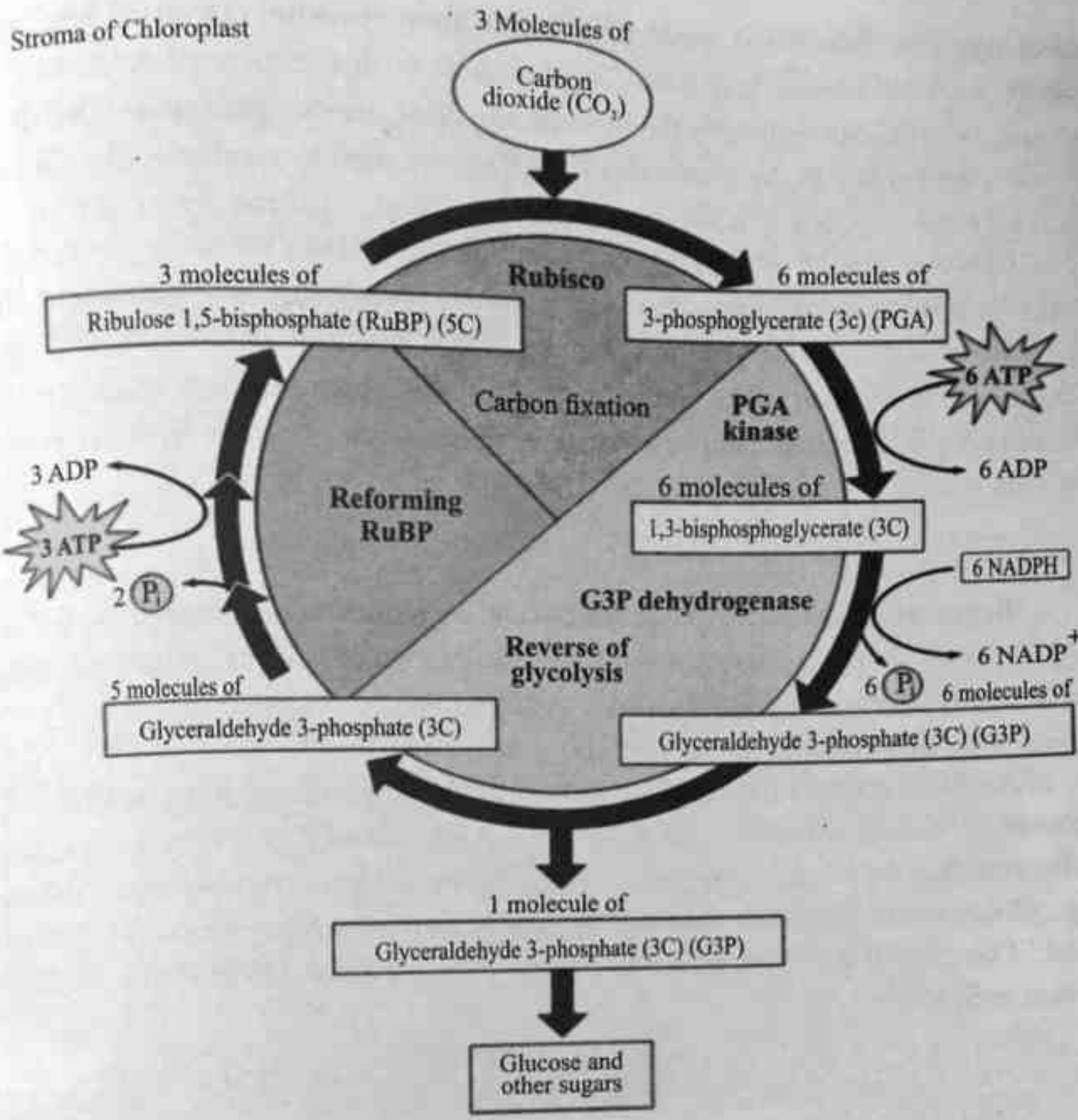


Fig. 4.6 Calvin cycle

Regeneration of RuBP (Formation of glucose and other organic compounds):

For every turn of Calvin cycle five molecules of PGAL are used to reform three molecules of RuBP, so that cycle can continue. It also uses ATP of light reaction.

$$5\ PGAL + ATP \longrightarrow ADP + Pi + 3\ RuBP$$

Thus out of every six molecules of PGAL formed in the reduction stage, only one molecule leaves the cycle, which is to be used by plant for making glucose and other organic compounds.

Use of PGAL

From PGAL 3C, 4C, 5C, 6C and 7C compounds are produced, all are interconvertible. Two PGAL molecules from Calvin cycle are converted into glucose phosphate within chloroplast. Glucose phosphate is then converted to starch. Fixed carbons leave the chloroplast in the form of dihydroxyacetone phosphate (DHAP). It is formed from PGAL.. In the cytoplasm DHAP can be used to synthesize the six carbon sugars, glucose and fructose, which are then joined to form sucrose.

Glucose is also used to synthesize cellulose. Glucose is readily converted into amino acids (with the addition of nitrogen). Other compounds like organic acids that is fatty acids and glycerols appear quite rapidly in the cell during photosynthesis. Glucose accumulates more than other compounds, so it was observed more readily by early investigators in chemical analysis. Other compounds can be seen by more sensitive methods.

4.2 Cellular Respiration

Respiration is a series of complex oxidation reduction reactions in living things. In this process cells get energy through the break down of various organic substances. There are two types of respiration aerobic and anaerobic.

Aerobic Respiration: (Gk. "*Aeros*" air)

Aerobic respiration takes place in the presence of molecular oxygen. Glucose is a high energy molecule and its breakdown product is CO_2 and H_2O, which are low energy molecules thus the stored energy is released. The electrons are removed from substrate (e.g., glucose) and eventually received by oxygen atom which combines with H^+ to form water. The overall equation of aerobic respiration for breakdown of glucose can be written as follows:

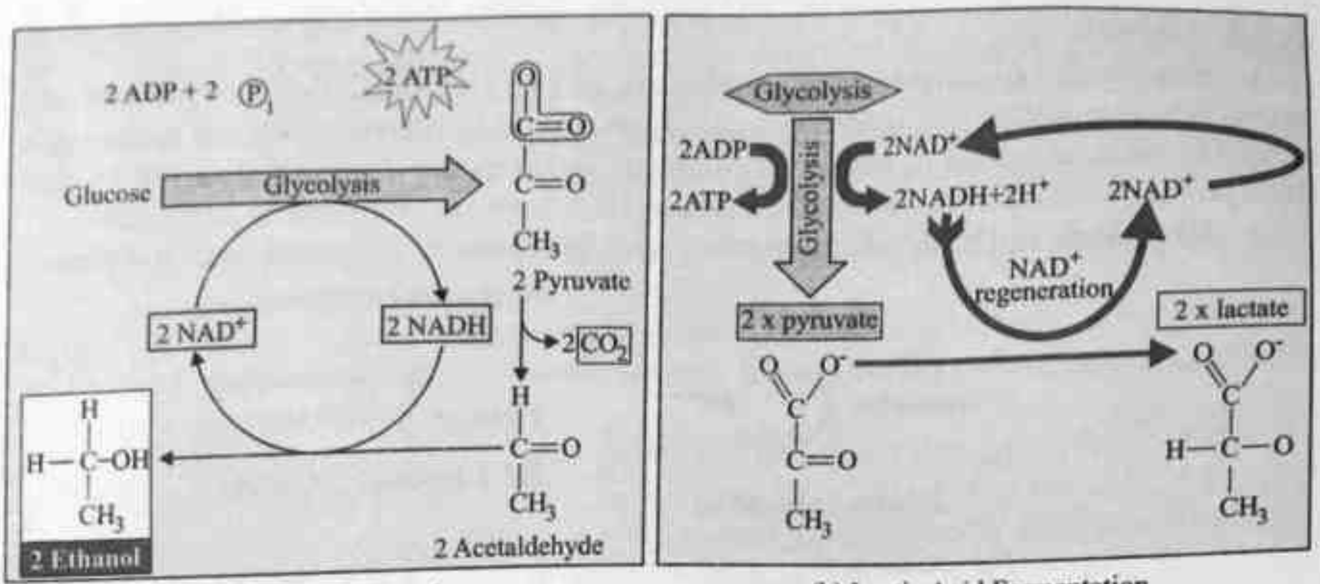
$$C_6H_{12}O_6 + 6O_2 + 36ADP + 36Pi \xrightarrow{\text{Enzymes}} 6CO_2 + 6H_2O + 36ATP$$

Anaerobic Respiration:

Anaerobic respiration takes place in the absence of molecular oxygen, it is also known as **fermentation**. It is incomplete oxidation reduction reaction. The energy released from the substrate (glucose) is a result of its molecular rearrangement and some of this energy is available to the cell. The NADH is oxidized to NAD, it is called fermentation because glycolysis is followed by the reduction of pyruvate by NADH to either alcohol and CO_2 or lactate.

Alcoholic Fermentation:

In primitive cells and cells of some eukaryotic organisms such as yeast and plants, pyruvate is further broken down by alcoholic fermentation into alcohol and CO_2.



(a) Alcohol Fermentation (b) Lactic Acid Fermentation

Fig. 4.7 Fermentation

Lactic Acid Fermentation:

It takes place in many bacteria, animals and muscles of human. Each pyruvate molecule is converted into lactic acid in the absence of molecular oxygen.

Process of cellular respiration:

It takes place in four steps.

1. Glycolysis
2. Oxidation of pyruvic acid
3. Krebs cycle
4. Electron transport chain

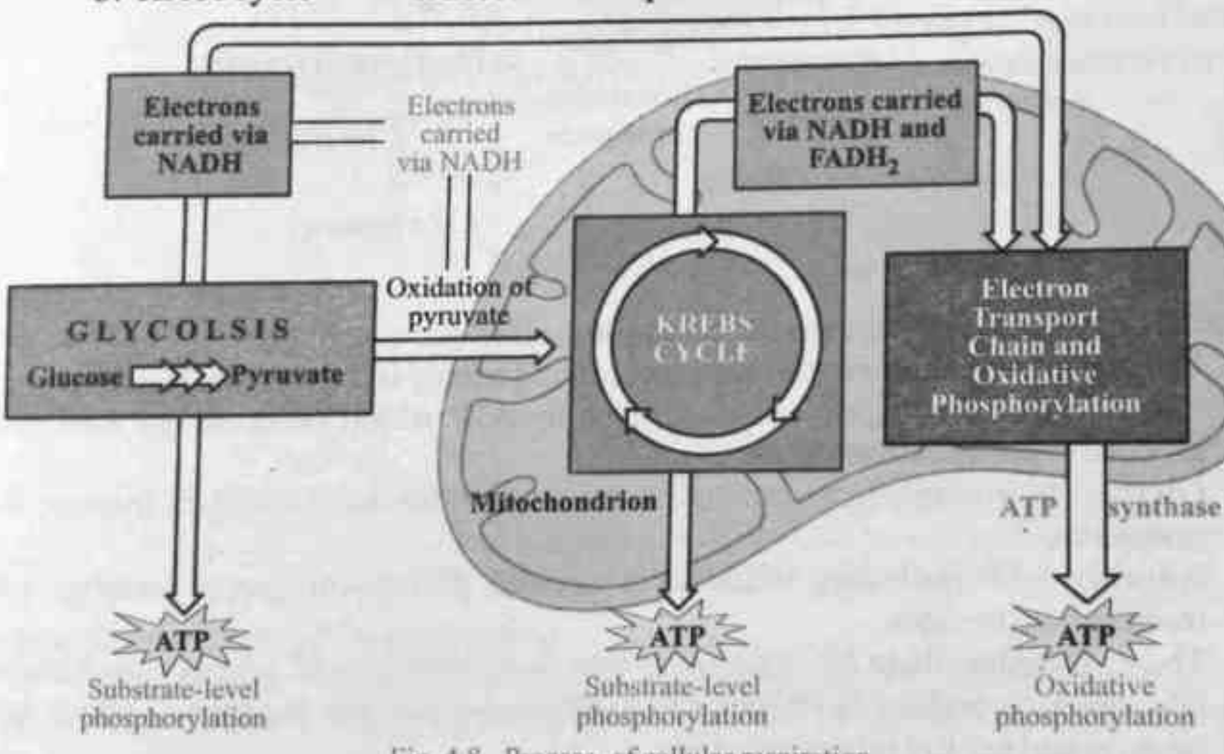


Fig. 4.8 Process of cellular respiration

4.2.2 Glycolysis

Glycolysis takes place in the cytoplasm and it is the break down of glucose into two pyruvate molecules. It is found in all organisms and evolved before the krebs cycle and ETC. This occurs in cytosol of cytoplasm and does not require molecular oxygen (thus probably first life was anaerobic bacteria). Each step is catalyzed by an enzyme.

Glycolysis can be divided into two stages, preparatory phase and oxidative phase.

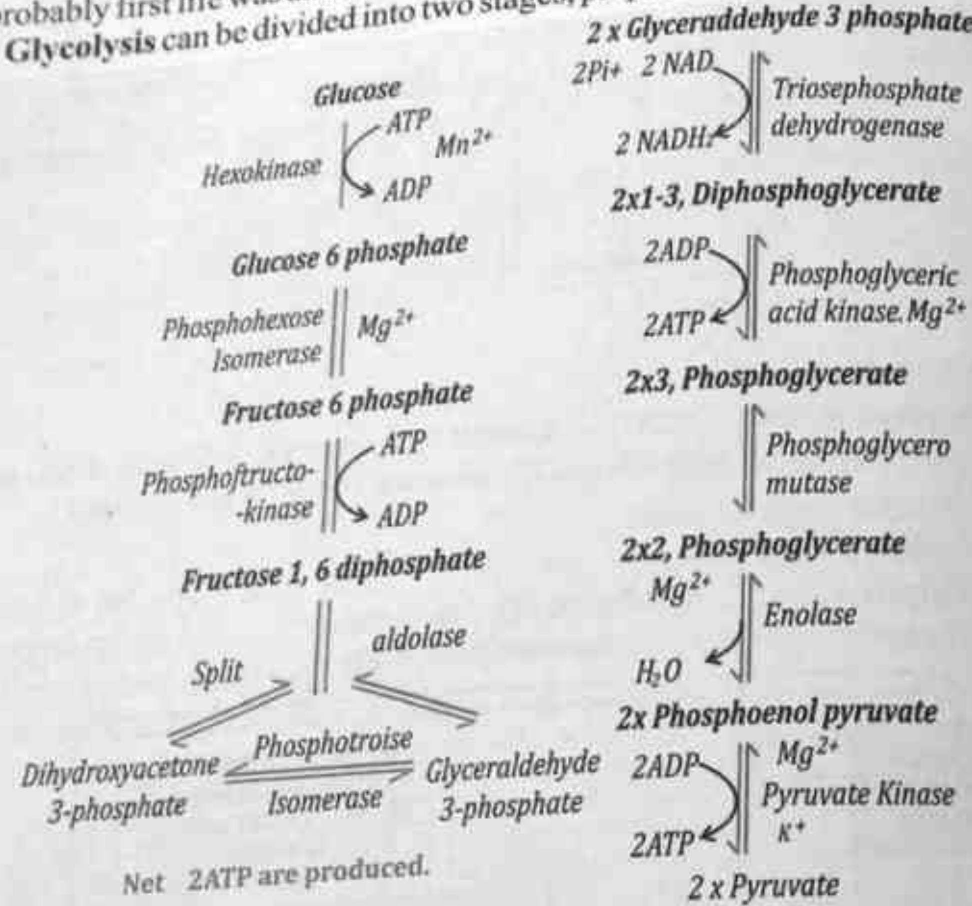


Fig. 4.9 - Glycolysis

Preparatory Phase (energy investment phase):

In this phase breakdown of glucose occurs and energy is utilized, the steps are:

1. Phosphorylation of glucose takes place by ATP which produces an activated glucose 6- phosphate molecule.
2. Glucose 6- phosphate is converted by an enzyme to its isomer fructose 6- phosphate.
3. Another ATP molecule transfers a second phosphate group forming 1,6 biphosphate fructose.
4. The 1, 6 biphosphate fructose splits into two molecules of 3-carbon molecules (Phosphoglyceraldhyde (PGAL) and dihydrooxyacetone phosphate) which are isomers and readily interconvertible.

Oxidative Phase (Energy yielding phase):

1. Two electrons or two hydrogen atoms are removed from the molecule of PGAL which is oxidized and these electrons are transferred to a molecule of NAD which is reduced. Inorganic phosphate is present in the cell, from which a second phosphate is donated to the molecule forming 1,3 bi or diphosphoglycerate (BPG or DPG).
2. DPG is converted to 3 phosphoglycerate (3-PGA). Meanwhile a phosphate bond is transferred from DPG to ADP forming ATP.
3. 3 PGA is converted to 2 phosphoglycerate (2PGA).
4. From 2 PGA a molecule of water is removed and phosphoenol pyruvate (PEP) is formed.
5. PEP then gives up its high energy phosphate which converts ADP to ATP. The product is pyruvate or pyruvic acid ($C_3H_4O_3$). It is equivalent to half glucose molecule that has been oxidized to the extent of losing two electrons as hydrogen atoms.

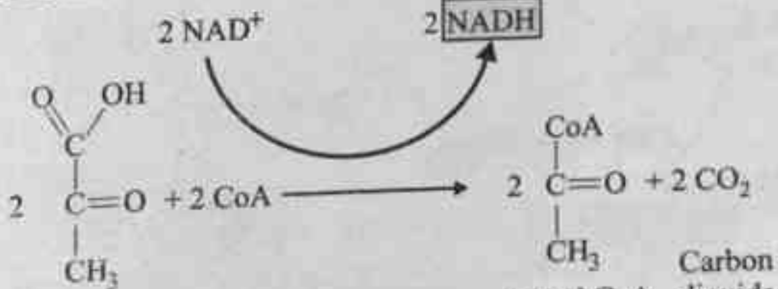
4.2.3 The Oxidation of Pyruvic Acid

It takes place into two stages.

1. Oxidation of pyruvic acid to form Acetyl Coenzyme A.
2. Oxidation of Acetyl Coenzyme A.

Oxidation of Pyruvic Acid:

It is a transition reaction during which CO_2 is released. The oxidation of pyruvic acid is called **transition reaction** because it connects glycolysis and krebs cycle. In this reaction pyruvate is converted to 2-carbon acetyl Co A by attaching coenzyme A. It gives off carbon dioxide. This is an oxidation reaction in which electrons are removed from pyruvate by dehydrogenase that uses NAD as a coenzyme. This reaction occurs twice for each original glucose molecule.



2 Pyruvate + 2 CoA ⟶ 2 Acetyl CoA + 2 Carbon dioxide

Fig. 4.10 Oxidation of Pyruvic Acid

Oxidation of Acetyl Co enzyme A:

It takes place through krebs cycle. As a first step 4-C compound oxaloacetate binds with 2-carbon acetyl CoA to become 6-carbon compound. This 6-carbon compound passes through a series of electron yielding oxidation reactions. Two carbon dioxide molecules are given off. Finally regenerating 4-carbon compound which is free to bind another acetyl Co A. This cycle is called citric acid cycle or krebs cycle.

> **Do you know?**
> *Krebs cycle is also called Tricarboxylic acid cycle because each of its first three reaction has three molecules of carboxylic acid.*

4.2.4 Citric Acid Cycle or Krebs Cycle

This is cyclic metabolic pathway located in the matrix of mitochondria. The krebs cycle was named after Sir Hans krebs a British scientist who discovered it in 1930.

Steps of the Krebs cycle:

1. At the start of this cycle the (2-C) acetyle group (produced by transition reaction) joins with a (4-C) oxaloacetate molecule, forming 6-carbon citrate molecule.
2. Citrate is converted to an isomer called isocitrate.

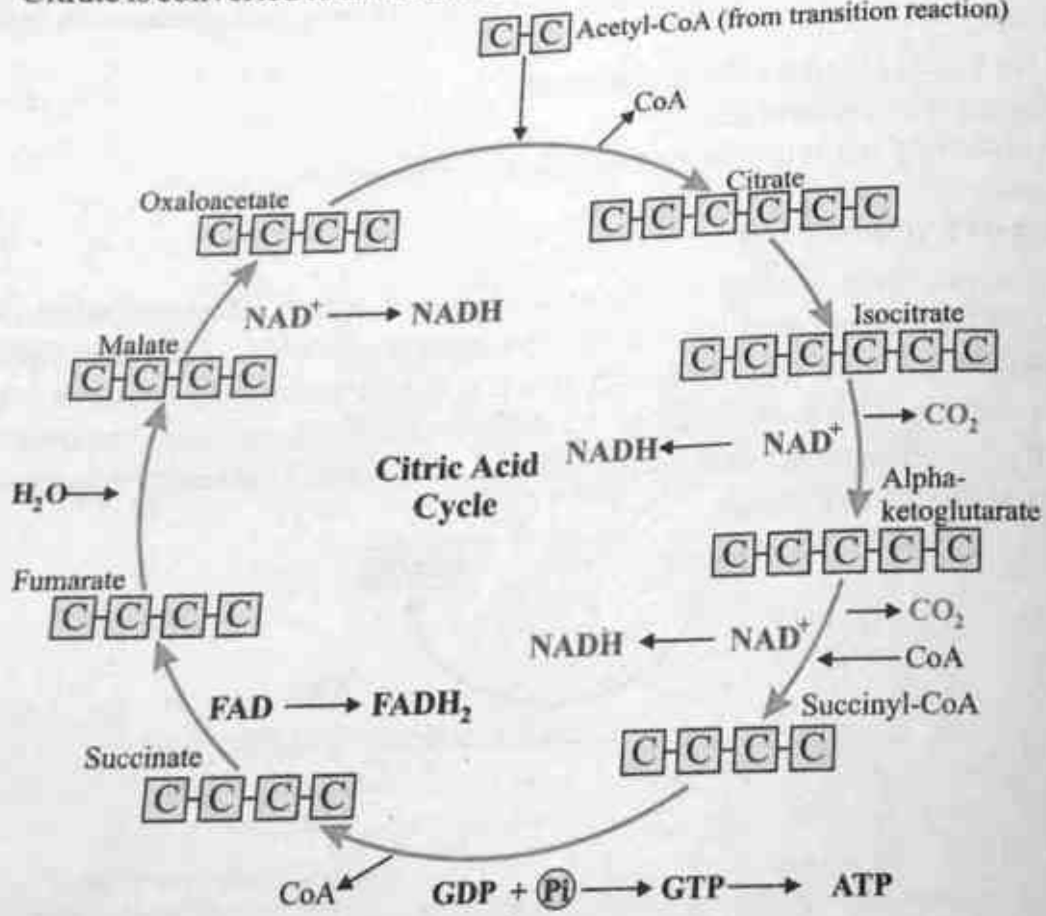


Fig. 4.11 Krebs cycle

Input	Output
2 acetyl groups	$4CO_2$
2ADP + 2Pi	2ATP
6NAD	6 $NADH_2$
2FAD	$2FADH_2$

3. Isocitrate is oxidized by NAD to 5-C alpha-ketoglutarate, NAD is reduced into $NADH_2$ and CO_2 is released.
4. Alpha-ketoglutarate is converted into 4-carbon succinyl CoA and NAD is reduced to $NADH_2$, another molecule of carbon dioxide is removed.
5. 4-carbon Succinyl CoA is oxidized to 4-C molecule, Succinate. GTP is formed which reacts with ADP to form ATP.
6. Now Succinate is converted to 4-carbon Fumarate and FAD is reduced into $FADH_2$.
7. Fumarate combines with water to produce 4 -carbon Malate.
8. Malate is oxidized by NAD to Oxaloacetate and $NADH_2$ is formed.
9. Oxaloacetate is again ready to combine with Acetyl CoA to start a new citric acid cycle.

4.2.5 Electron Transport Chain (ETC)

The ETC is located in cristae of mitochondria. It consists of series of carriers that pass electrons from one to the other. The electrons that enter the ETC are carried by NADH and $FADH_2$ formed during krebs cycle and glycolysis.

Whenever hydrogen is removed from a substrate there are seven intermediate hydrogen acceptors to catch the atom. They are NADH reductase complex (FMN and Fe-S), FADH reductase or co-enzyme Q or Ubiquinone (UQ) and four cytochromes that is b, c, a and a_3 (cytochromes become pink in color when they are reduced. They are protein plus pigment molecules containing iron. They have ability to gain or lose electron. While ubiquinone is not protein it is lipid soluble and water insoluble). Electrons are passed to ubiquinone, at this step an electron is split off the hydrogen atom. The proton becomes free and electron is passed successively from coenzyme Q to cytochrome b, c, a and a_3.

Do you know?

In krebs cycle the extracted electrons are temporarily housed within NADH and $FADH_2$ molecules. These enter in electron transport system where H^+ are removed, ATP and H_2O are formed.

Thinking Questions

Each NADH + H^+ gives 3 ATP in electron transport chain, while each $FADH_2$ gives 2ATP. Can you guess why?

Steps of Electron Transport Chain:

1. The substances in the chain event are alternately oxidized and reduced.
2. Oxidation is accomplished by the loss of hydrogen in case of NAD, FAD and the coenzyme while oxidation is accomplished by loss of electrons from cytochrome b, c, a and a_3.
3. Since two hydrogen atoms are released at a time and cytochrome b through a_3 can accept only one electron at a time so there are two cytochrome systems to capture

the electrons.

4. An electron and proton are brought together after the final transfer from cytochrome a_3. It produces hydrogen.

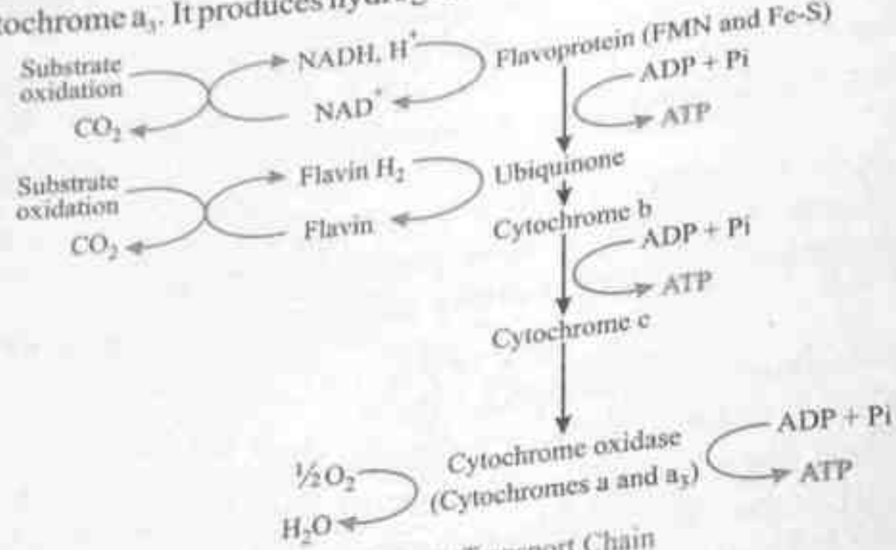


Fig. 4.12 Electron Transport Chain

5. Molecular oxygen is the hydrogen acceptor and water is the final product.

$$O_2 + 4H^+ + 4e^- \longrightarrow 2H_2O$$

6. Energy is released at three steps, flavoprotein to ubiquinone cyt. b to c, a to a_3. The released energy is captured by ADP to form ATP.

7. Electron transport chain is the main producer of ATP.

4.2.6 Chemiosmosis

Chemiosmosis is the synthesis of ATP from ADP and Pi in the electron transport chain through the joint event of chemical and osmotic processes. The chemiosmotic theory was proposed by Peter Mitchell who got Nobel prize in 1978 for his chemiosmotic theory of ATP production in mitochondria and chloroplasts.

The chemiosmosis can also be defined as the coupling reaction in which synthesis of ATP molecule occurs during the movement of H^+ across a proton gradient. Chemiosmosis generates more ATP as compared to substrate level ATP phosphorylation.

> **Tit bits**
>
> *Chemiosmosis is the movement of ions across a semipermeable membrane, down their electrochemical gradient. For example, generation of ATP by the movement of H^+ across a membrane during cellular respiration or photosynthesis.*

Mechanism of Chemiosmsis:

1. The mitochordrial membranes have transmembrane channels. These channels can pump protons. The flow of electron induce a change in the shape of protein, thus

proton move out of the inner compartment of mitochondria. As a result the proton (H^+ conc.) in the outer compartment of the mitochondrion becomes greater than that of inner compartment.

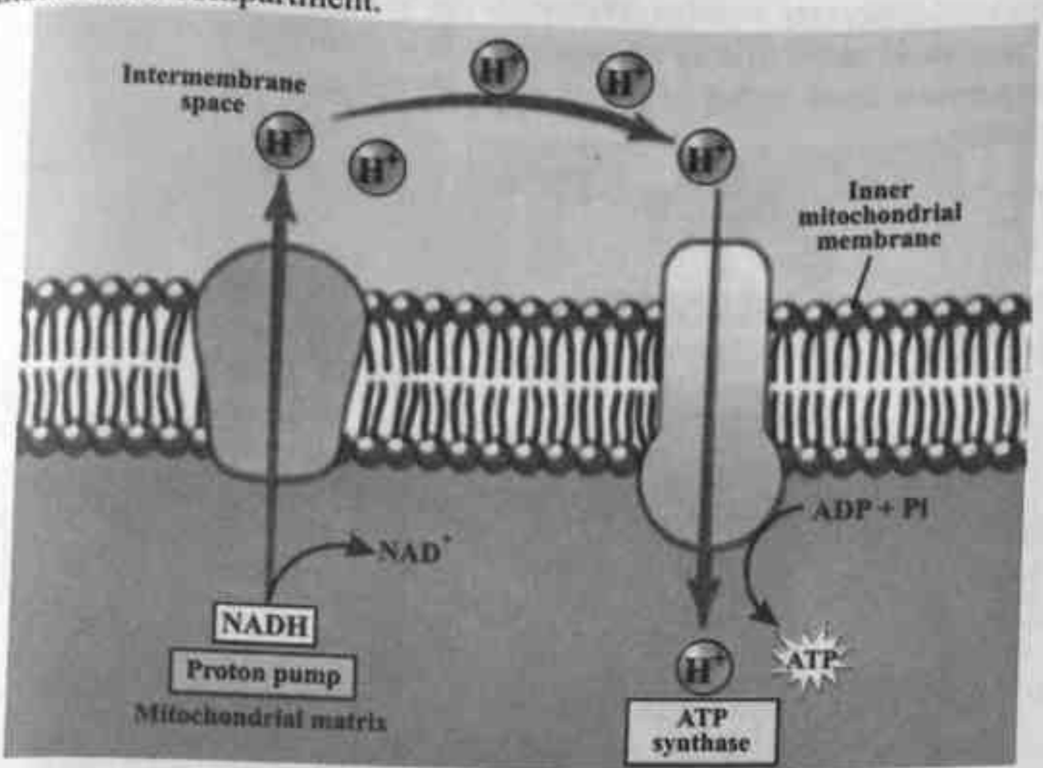


Fig. 4.13 Chemiosmosis

2. Electrical-chemical proton gradient is established between outer and inner membrane. This gradient drives the outer proton across the membrane. Thus the proton move down this gradient between the inner and outer mitochondrial compartments. Their movement induce the formation of ATP from ADP and inorganic phosphate. This process is controlled by an enzyme ATP synthase.
3. The electrons are obtained from the chemical bonds of food molecules in all organisms. This electron removing process needs free oxygen, so it is called aerobic respiration.

Activity

1. Make a list of differences between photosynthesis, respiration and photorespiration.
2. Draw different steps of ETC.

4.2.7 Substrate level phosphorylation

Substrate level phosphorylation occurs in the cytoplasm of the cell during glycolysis and in mitochondrion during the krebs cycle under both aerobic and anaerobic conditions.

ATP formation from ADP and Pi needs input of energy. The energy comes from breakdown of organic molecules in the cells. This type of reaction which releases energy is called **exergonic reaction.** An enzyme transfers a phosphate group to ADP from a substrate, so ATP molecule is formed. The energy from exergonic reaction is greater than the energy input necessary to drive ATP synthesis. The substrate level phosphorylation appeared very early in the history of organisms. It is recorded in all organisms because initially organisms used carbohydrate as an energy source. Moreover first organisms were anaerobic.

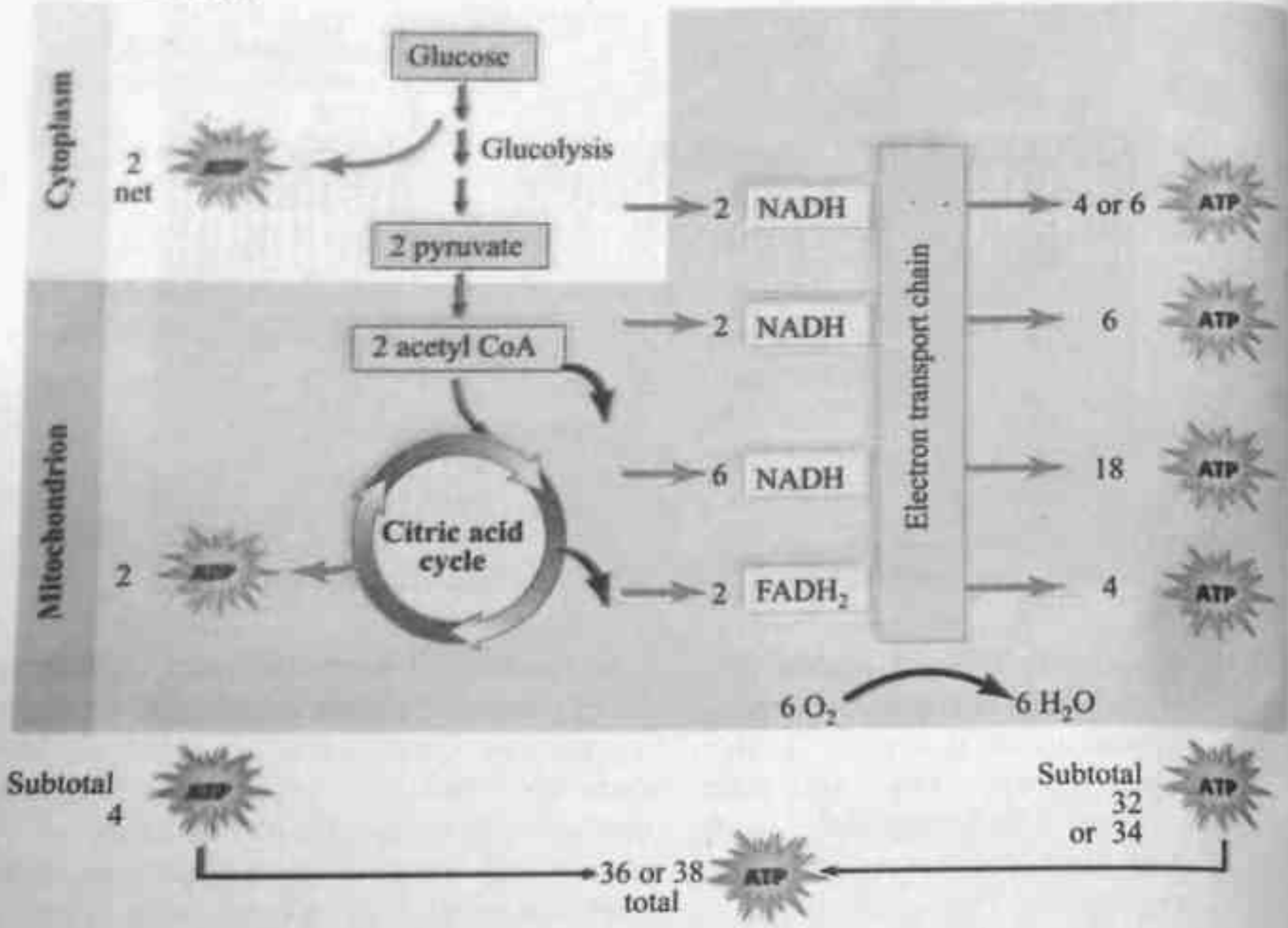


Fig. 4.14 Energy yield per glucose molecule

4.2.8 Importance of PGAL

The preparatory phase of glycolysis completes with the splitting of fructose bi-phosphate into PGAL and Dihydroxyacetone phosphate (DHAP) and both are inter-convertible.

The oxidation of glyceraldehydes 3-phosphate produces 1,3 biphosphoglycerate and 2 NADH molecules which lead to the formation of pyruvic acid.

PGAL is also formed during the Calvin cycle of photosynthesis, one PGAL molecule leaves Calvin cycle. It is converted into glucose phosphate within chloroplast which is converted into starch.

Fixed carbons leave the chloroplast in the form of dihydroxyacetone phosphate. It is formed from PGAL. The DHAP can be used to make the six carbon sugars, glucose and fructose which become a disaccharide, called sucrose. Now sucrose is transported to other parts of the plants.

4.2.9 Cellular Respiration of Proteins and Fats

Animals and humans besides glucose also consume fats and proteins to harvest energy. Fats are broken down into glycerol and three fatty acids. First the glycerol is phosphorylated then enters the glycolytic pathway at the level of glyceraldehyde 3-Phosphate (PGAL) while fatty acids $(2\text{-C})_n$ enter in the mitochondrion where their carbons are removed. They form acetyl CoA (2-C) which is entry point for krebs cycle (an 18-carbon fatty acid results in nine acetyl CoA molecules). One gram fat provides about 2.5 times more energy than carbohydrates or proteins.

Animals digest proteins into amino acids, if it is in excessive quantity or body is starved then amino acids can be used as fuel. The size of R-group determines whether the carbon chain is oxidizing in glycolysis (Pyruvate) or in the Krebs cycle or cetyl CoA.

Amino acids are degraded, the amine group is removed to yield ammonia this process is called deamination reaction.

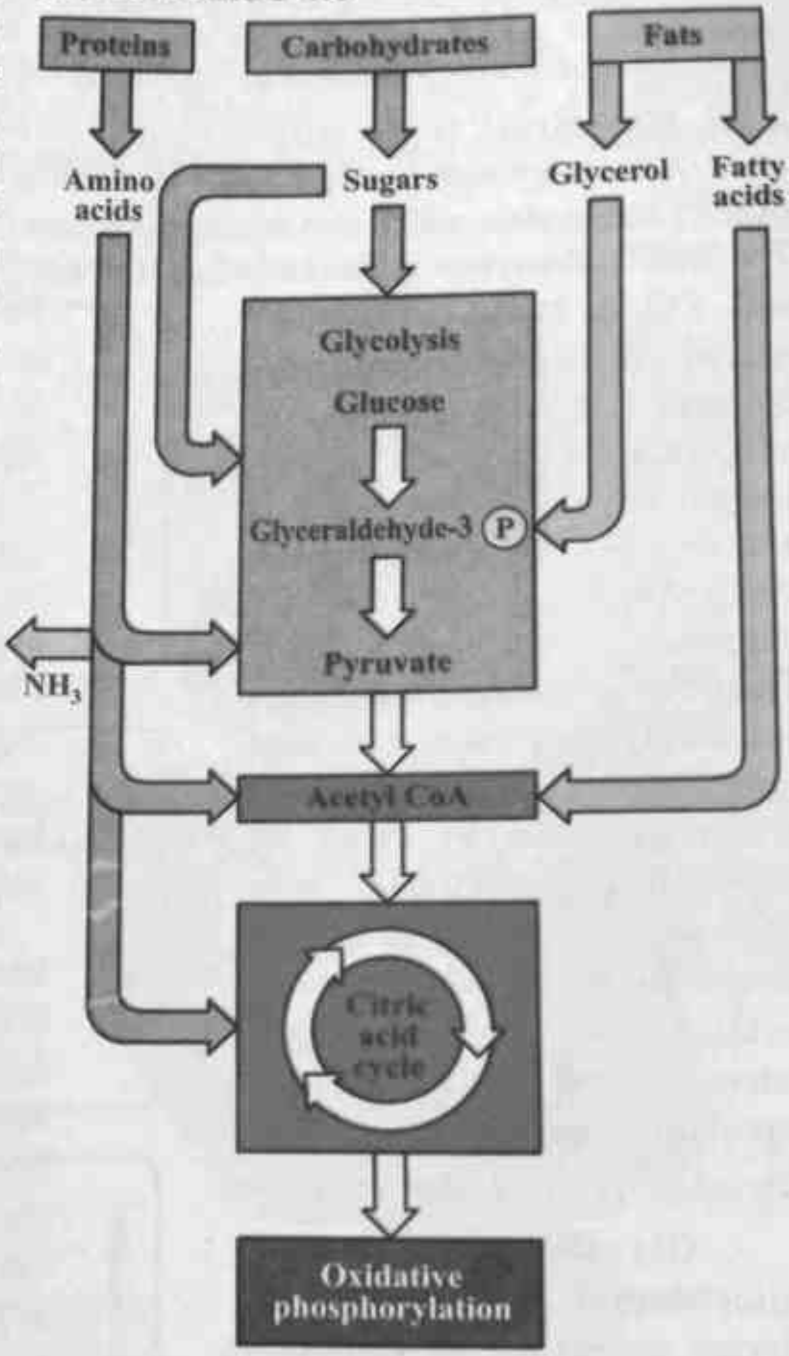


Fig. 4.15 Cellular Respiration of Proteins and Fats

4.3 Photorespiration

This process occurs only in photosynthesizing cells of the plants. It is opposite to photosynthesis, because in it oxygen is used instead of CO_2 and instead of oxygen, carbon dioxide is released (like respiration). It differs from ordinary respiration of cell which occurs in mitochondria at night and in non-green tissues of plant while photorespiration takes place in the presence of light and only in photosynthetic cell. The oxygen is absorbed but unlike respiration do not produce energy (ATP).

4.3.1 How RuBP reacts with oxygen in photorespiration?

Photorespiration is related to the functioning of the enzyme ribulose biphosphate (RuBP) carboxylase which also acts as oxygenase (combines with O_2 instead of CO_2). The RuBP carboxylase is also known as **Rubisco**. When rubisco acts as carboxylase it adds CO_2 to RuBP (an acceptor molecule) to produce two molecules of PGA while during oxygenase, it adds oxygen to RuBP and produces one molecule of PGA and one phosphoglycolate. The phosphoglycolate loses its phosphate to become glycolate. There are some algae which can excrete glycolate but higher plants cannot excrete it. Therefore, plants must convert it back to intermediate in the Calvin cycle. The conversion of glycolate into glycine amino acid takes place by a series of reactions in mitochondria, chloroplast and other cellular parts especially in peroxisomes.

Glycolate $\longrightarrow$ glycine amino acid

Glycine diffuses into mitochondria where every two glycine molecules are converted into serine amino acid and CO_2.

2 glycine $\longrightarrow$ Serine + CO_2

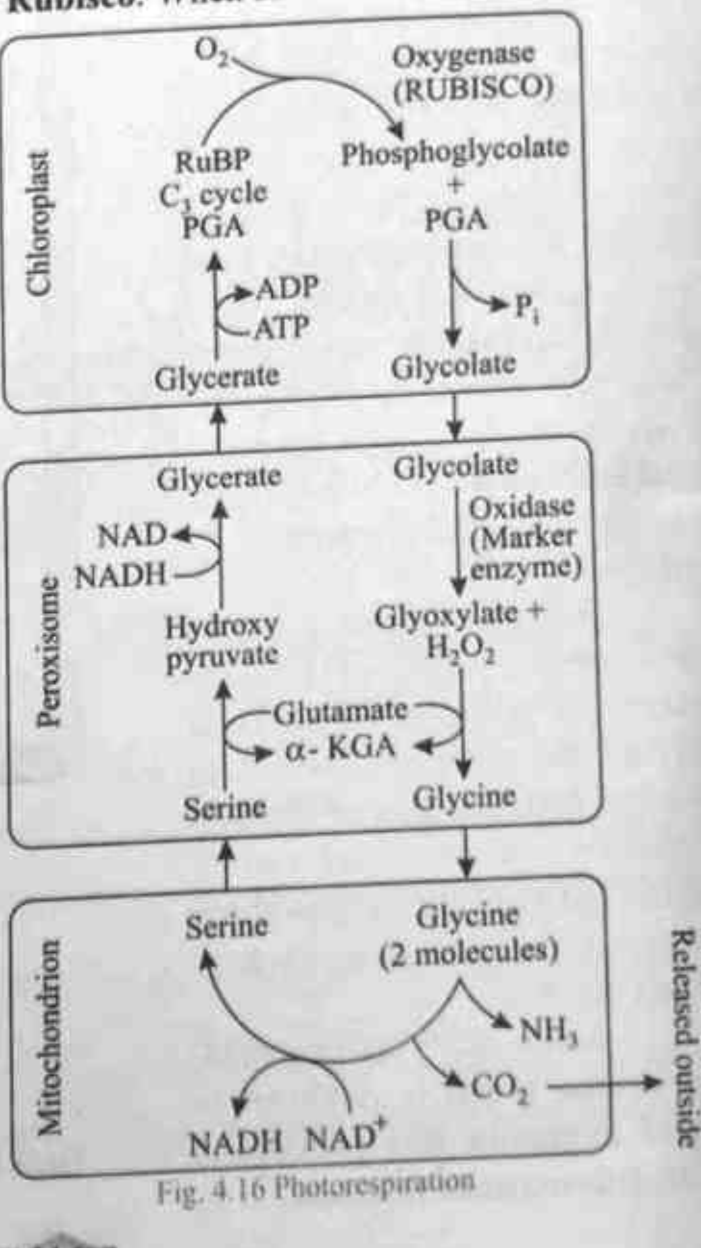


Fig. 4.16 Photorespiration

This entire pathway is called photorespiration in which RuBP is converted into serine and CO_2 which uses ATP and $NADPH_2$ produced during light reaction like Calvin cycle.

4.3.2 Disadvantages of photorespiration

It is reverse to Calvin cycle (here CO_2 is released instead of being fixed into carbohydrates). Photorespiration reduces the amount of carbon fixation into carbohydrates by 25%. The role of photorespiration in plants is not thoroughly understood. It is presumed that photorespiration may be necessary for the assimilation of nitrates from the soil.

4.3.3 Photosynthesis in C4 plants

In normal process of photosynthesis a 3-C compound called PGA is formed as a first detectable product of photosynthesis. Therefore, these plants are called C_3 plants. However, there are some plants growing in dry and hot conditions which produce a four carbon compound (C4) called oxaloacetate as the first product of photosynthesis in dark reaction. These plants are called C4 plants and this type of photosynthesis is called C4 photosynthesis.

C3 plants use rubisco to react CO_2 with RuBP, on the other hand C4 plants use a different enzyme called phosphoenol pyruvate carboxylase **(PEPCO)** to fix CO_2 to a compound known as phosphoenol pyruvate (PEP). The PEP is reduced into another molecule called malate. The malate carry CO_2 to a special type of cells called bundle sheath cells where Calvin cycle proceeds.

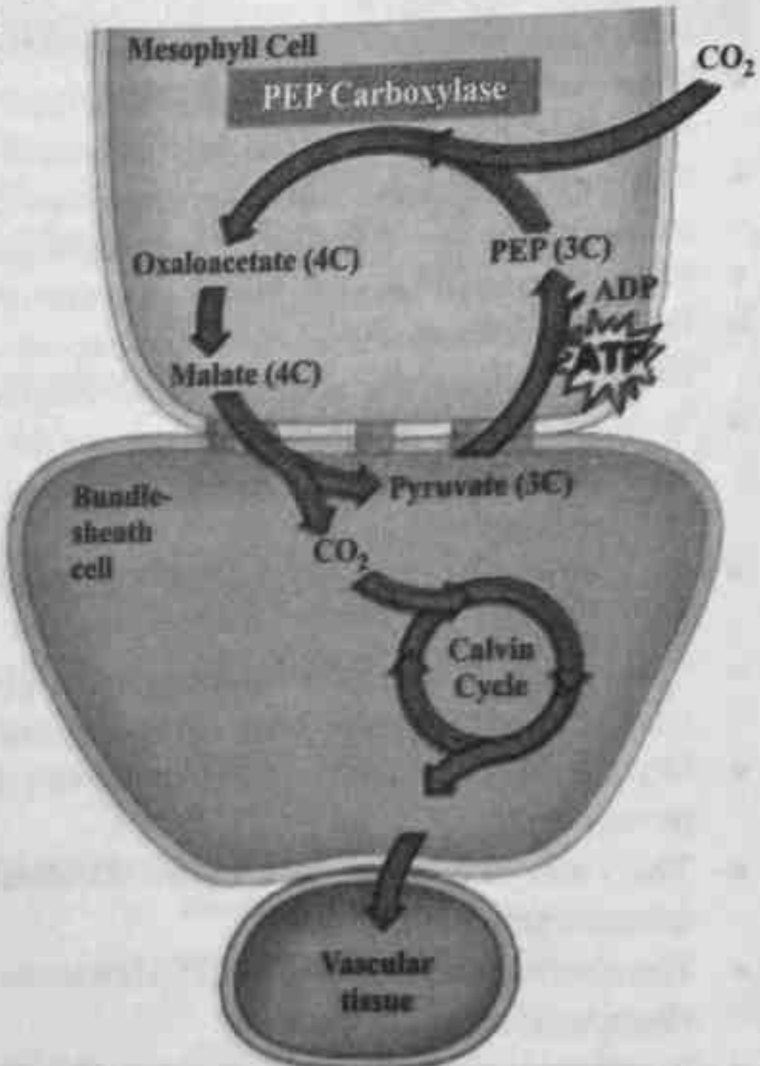


Fig. 4.17 C4 pathway

Table 4.2 Comparison between C_3 and C_4 Plants

C_3 Plants	C_4 Plants
In C_3 chloroplasts are located only in mesophyll cells of leaf.	In C_4 chloroplasts are present both in mesophy cells as well as in bundle sheath cells.
In these plants all the mesophyll cells carry out Calvin cycle.	In these plants only mesophyll cells fix CO_2 l using PEPCO while the bundle sheath cells car out Calvin cycle.
In high temperature photosynthesis is low.	In high temperature the rate of photosynthesis high.
Example: Most of the plants are C_3 plants such as pea, wheat, rice and all woody trees.	*Example:* They are found only in angiosperm such as sugar cane, maize and mostly grasses.

SUMMARY

- Photosynthesis is the only biological process that captures energy of sunlight converts it into organic compounds (carbohydrates).
- The internal membranes of chloroplasts are organized into sac-like thylakoids wh are stacked on one another in columns called grana.
- Photosynthesis takes place in two steps: they are light reaction and dark reaction.
- Each photosystem consists of a light-harvesting complex and a core complex. E core complex contains a reaction center with the pigment (either P700 or P680).
- To build organic molecules, cells use raw materials provided by the light reacti ATP provided by cyclic and noncyclic photophosphorylation while NAD provided by photosystem I.
- Cellular respiration is the process in which cells acquire energy by breaking down organic compounds.
- Cellular respiration involves four phases: glycolysis, the preparatory reaction, citric acid cycle, and the electron transport chain.
- Glycolysis is the breakdown of (6-carbon) glucose into two (3-carbon) pyru molecules.
- The citric acid cycle is a cyclic metabolic pathway located in the matrix mitochondria.

EXERCISE

Section 1: Objective Questions

Multiple Choice Questions

A. Choose the best correct answer from the following.

1. Which among the following conditions is favourable for cyclic photo-phosphorylation:
   (a) Aerobic
   (b) Aerobic and low light intensity
   (c) Aerobic and optimum light
   (d) Anaerobic and low light intensity
2. During the dark reaction of photosynthesis:
   (a) Water is split off
   (b) CO_2 is reduced to organic compounds
   (c) Chlorophyll is activated
   (d) Glucose is broken down
3. The enzyme that fixes atmospheric CO_2 in C4 plants is:
   (a) PEP carboxylase (b) Rubisco
   (c) RuBP carboxylase (d) Hydrogenase
4. The number of carbon atoms in RuBP which accepts CO_2 are in C3 plants is:
   (a) 2 (b) 3
   (c) 5 (d) 6
5. Chlorophyll *a* differs from chlorophyll *b* in having a:
   (a) -CHO group (b) -COOH group
   (c) $-CH_3$ group (d) $-NH_2$ group
6. NADP is:
   (a) An enzyme (b) A part of rRNA
   (c) A coenzyme (d) A part of tRNA
7. The compound that enters the Krebs cycle from glycolysis is:
   (a) Citric acid (b) Oxaloacetate
   (c) Pyruvic acid (d) Acetyl coenzyme A

B. Fill in the blanks.

1. Breakdown of water molecule during PS II of light reaction is called______.

2. ATP production during light reaction is called as ____________.
3. In peroxisomes glycolate is converted into ____________.
4. The addition of inorganic phosphate to any organic molecule is known as ____________.
5. Citrate is converted into ____________ in Krebs cycle.
6. Anaerobic respiration is also known as ____________.
7. Calvin cycle is also called ____________ pathway.
8. Plastocyanin is a copper containing ____________ in nature.
9. Hydrocarbon chain of chlorophyll is a long chain of alcohol ____________.

Section II: Write short answers.

1. Write few lines about absorption spectrum.
2. Briefly describe role of CO_2 in photosynthesis.
3. Write the names of electron acceptors of PS II and PS I.
4. Draw the Z-scheme of light reaction.
5. Explain the reduction phase of Calvin cycle.
6. Define aerobic and anaerobic respiration.
7. Write first three steps of Krebs cycle.
8. What is the importance of PGAL?

Section III: Extensive Questions.

1. Explain the mechanism of photosynthesis.
2. Briefly describe the four phases of cellular respiration.
3. What are the main events of glycolysis? How ATP is formed?
4. What is fermentation, and how does it differ from glycolysis?
5. What are the main events of the citric acid cycle?
6. Describe different steps of Electron Transport Chain.

Section 02

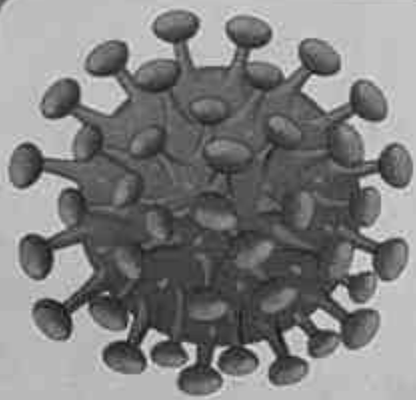
BIODIVERSITY

UNIT 5

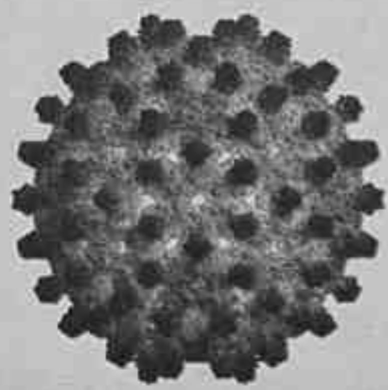
ACELLULAR LIFE

Major Concepts

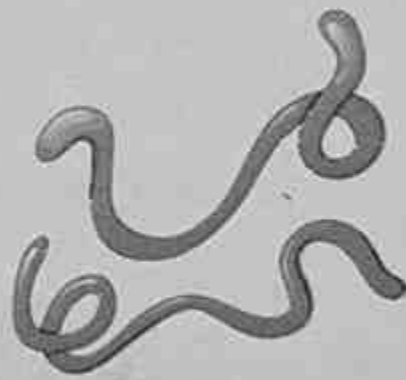
5.1 Viruses: Discovery and Structure
5.2 Life Cycle of Bacteriophage
5.3 Life Cycle of Human Immunodeficiency Virus (HIV)
5.4 Parasitic nature of Viruses
5.5 Viral Diseases
5.6 Viroids and Prions



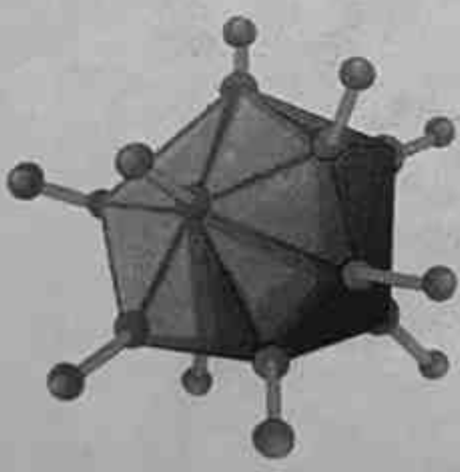
HIV



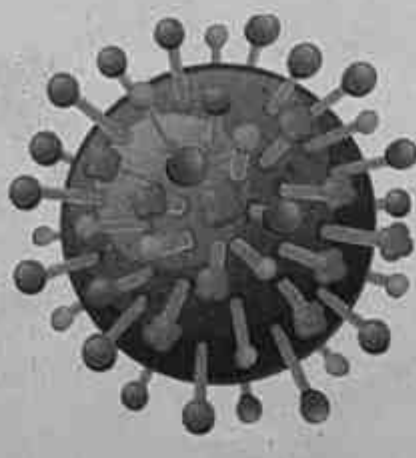
Hepatitis B



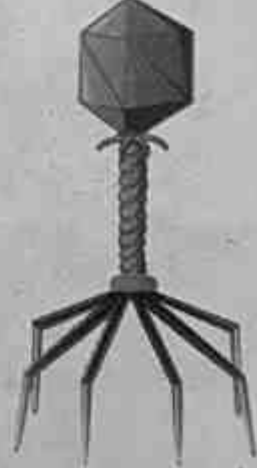
Ebola Virus



Adenovirus



Influenza



Bacteriophage

Students Learning Outcomes

On completion of this unit students will be able to:

- Justify the status of viruses among living and non-living things.
- Trace the history of viruses since their discovery.
- Classify viruses on the basis of their hosts and structure.
- Explain the structure of a model bacteriophage, flu virus and HIV.
- Justify why a virus needs a host cell to parasitize in order to complete its life cycle.
- Explain how a virus survives inside a host cell and protect itself from the host immune system.
- Determine the method a virus employs to survive/pass over unfavourable conditions when it does not have a host to complete the life cycle.
- Describe the Lytic and Lysogenic life cycles of a virus.
- Outline the usage of bacteriophage in genetic engineering.
- Explain the life cycle of HIV.
- Justify the name of virus, i.e., "Human Immunodeficiency Virus" by establishing T-helper cells as the basis of the immune system.
- Reason out the specificity of HIV on host cells.
- List the symptoms of AIDS.
- Explain the opportunistic diseases that may attack an AIDS victim.
- Describe the treatments available for AIDS.
- List some common control measures against the transmission of HIV.
- Describe the causative agent, symptoms, treatment and prevention of the following viral diseases: hepatitis, herpes, polio and leaf curl disease of cotton.
- List the sources of transmission for each of the above-mentioned diseases.
- Assess from the given data the economic loss from viral infections (cotton leaf curl virus disease and bird flu virus) in Pakistan. Describe the structure of prions and viroids.

Introduction

The life form which exists without a cellular structure is known as **acellular** or non-cellular life. The primary candidates for non-cellular life are viruses. Majority of biologists consider viruses are non living because they are not capable of **autopoiesis** (ability of reproduction) without host. The other examples of acellular life are **viroids** which are smallest infectious agents consisting solely of short strands of circular single stranded RNA without protein coat. The **prions** are infectious agents composed entirely of protein, capable of multiplying itself and transferable from one host to another.

5.1 Viruses Discovery and Structure

A virus is a biological agent that reproduces only inside the cells of living host. Viruses can infect all type of life forms i.e., from animals and plants to microorganisms including bacteria.

In 1884 the French microbiologist **Charles Chamberland** made a filter paper for filtration of bacteria. In 1892, Russian biologist **Ivanovsky** used this filter to determine the cause of **tobacco mosaic disease.** In his experiment he proved that tobacco mosaic disease was not caused by bacteria but caused by other infectious agent which can pass through filter paper. He called these filterable viruses. His view was confirmed by American virologist **W.M. Stanley in 1935,** when he observed tobacco mosaic virus under Electron Microscope.

In the early 20^{th} century (1915, 1917) **Twort and Herelle** discovered bacteriophages (viruses that infect bacteria). Since then thousands of species of viruses have been discovered and microbiologists speculate that there are millions of species of viruses still to be discovered.

5.1.1 Viruses Living or Non Living

Viruses show the characteristics of both living and non-living things. The **living characteristics** of viruses include:

- They have their own genetic material.
- They undergo mutation.
- Can reproduce inside host cell by using host metabolic machinery.
- Get destroyed by ultraviolet radiations and chemicals.
- Occur in different varieties or strains.

The **non-living characteristics** of viruses include:

- They are non-cellular particles.
- Generally lack enzymes and co-enzymes and depend upon host enzymes and coenzymes for their metabolic activities.
- Can be crystallized and stored in laboratory.
- Do not respire and use the energy of host for their activities.
- Therefore, depending upon the ambivalent(fluctuating) nature of characteristics possessed by the Viruses; they are considered on **boundary line between living and non living things.**

5.1.2 Classification of Viruses

Viruses may be classified on the basis of morphology, type of host they infect, presence or absence of outer covering and types of nucleic acid.

Classification of viruses based upon structure (morphology):

1. **On the basis of capsid:**

- Some viruses have helical capsid such as tobacco mosaic virus (TMV).
- Many have polyhedral capsid, contain a glycoprotein spike at each vertex, such as adenovirus.
- Viruses possess an outer envelope studded with glycoprotein spike, such as Influenza viruses.
- Viruses like bacteriophage possess complex capsid consisting of a polyhedral head and tail apparatus.

2. On the basis of genome (DNA and RNA):

- Double stranded DNA viruses (dsDNA Viruses). e.g., Adenoviruses, Herpes viruses, Pox viruses.
- Single stranded DNA viruses (ssDNA Viruses), e.g., Paroviruses (small viruses of vertebrates and invertebrates) cause rash.
- Double stranded RNA viruses (dsRNA viruses), e.g., Reoviruses, cause diarrhoea.
- Single stranded RNA reverse transcribing viruses template for DNA (ssRNA-RT viruses), e.g., HIV (retrovirus).

> **Do you know?**
> *Bacteriophages are ubiquitous viruses found wherever bacteria exist. It is estimated that number of Bacteriophages is more than any other organism on earth.*

Classification of viruses on the basis of host they infect:

- **Bacterophages** attack bacteria.
- **Plant viruses** which cause more than 2,000 types of plant diseases such as TMV, Potato yellow dwarf virus.
- **Animals viruses** cause many diseases to animals and human such as mouth and foot disease in livestock, papovavirus causes mumps and measles. Rous sarcoma virus causes cancer.

5.1.3 Structure of Model Viruses

A virus particle (virion) consists of nucleic acid core surrounded by a protective coat of protein called capsid. The nucleic acid found in viruses is either DNA or RNA but

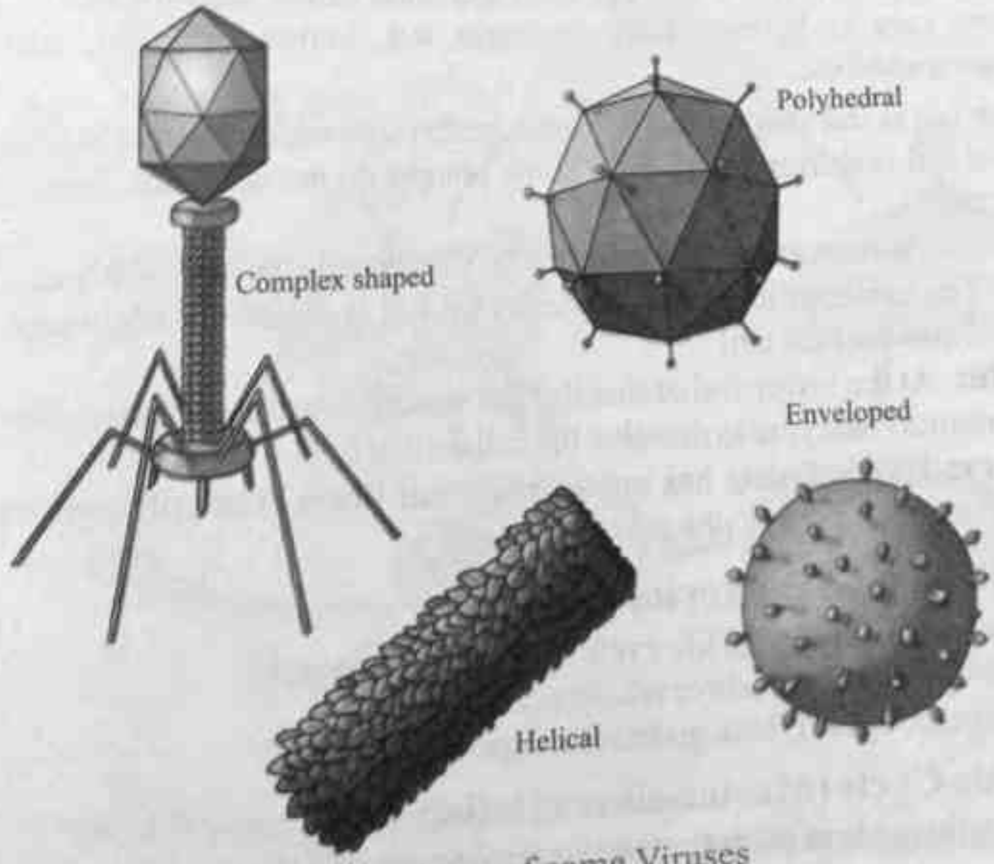


Fig. 5.1 Shape of some Viruses

not both. The **capsid** is made of many smaller, identical protein molecules called **capsomeres.** Their number and arrangement varies in different types of viruses. Some viruses have an **envelope** of lipid outside the protein coat. This envelope is derived from host cell and such viruses which have envelope are called enveloped viruses. The viruses have different shapes like enveloped, tadpole or complex shaped, polyhedral, spherical, helical etc.

Structure and life cycle of some viruses (Bacteriophages, flu virus and HIV):

5.1.4 Structure of Bacteriophage

A Bacteriophage is a virus that infects and replicates within a bacterium. They vary in size from 24 to 200 nm in length. A bacteriophage consists of two main parts, i.e., head and tail.

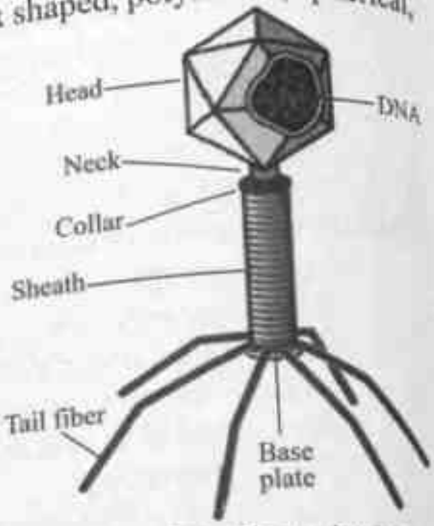


Fig. 5.2 Bacteriophage

Head: The head (nucleocapsid) is further divided into two parts, inner core of nucleic acid and outer coat of protein. The nucleic acid may be mostly DNA, however, some have RNA . The number of genes in a bacteriophage genome vary from few to over 100.

The protein coat or capsid of bacteriophage is usually **hexagonal** like prism shaped. The capsid is made up of protein sub units called **capsomeres**. The number of capsomeres vary in different bacteriophages, e.g., herpes virus 162, adenovirus 252, ambidensovirus 60 etc.

Tail: The tail is rod shaped and hollow tube through which nucleic acid passes in host. The size of tail is different and even some phages do not have tail. The tail consists of following parts.

Neck: It is the narrow area of the tail without sheath and attached with head.

Sheath: The contractile protein covering on tail is called sheath, which pushes the nucleic acid into the host cell.

Base Plate: At the lower end of sheath a flat structure is present called end plate or basal plate. It contains lysozyme to dissolve the cell wall of host.

Tail Fibers: The end plate has one to many tail fibers. The tail fibers and base plate involve in the attachment of phage with host cell.

5.2 Life Cycle of Bacteriophage

There are two types of life cycle of bacteriophages.

i) Lytic cycle (Master-slave relationship)

ii) Lysogenic cycle (Host-guest relationship)

5.2.1 Lytic Cycle (Master-slave relationship)

The lytic cycle of bacteriophage consists of following steps.

Attachment:

In first step, bacteriophage attaches to the cell wall of host that is bacterium at a specific site known as receptor site. The attachment occurs by tail fibers.

Penetration:

The tail of virion releases an enzyme known as lysozyme which dissolves a small portion of bacterial cell wall. Now the tail sheath contracts and injects DNA into the host cell. The protein coat of virus remains out side of the cell.

Multiplication of virion:

After entering host cell the virion DNA takes over the control of biosynthetic machinery of host cell and forces the host cell to synthesize necessary viral components, i.e., DNA and protein. In this way virus starts multiplying. After 25 minutes of initial infection about 200 new bacteriophages are found in bacterial cell.

Lysis:

In this final step the new daughter phages exert pressure on the bacterial cell wall and enzyme lysozyme also attacks the cell wall from the inner side. Eventually cell wall bursts and progeny of viruses are released. This process is called lysis of bacterium. Newly formed phages are now ready to attack new host to start the lytic cycle again.

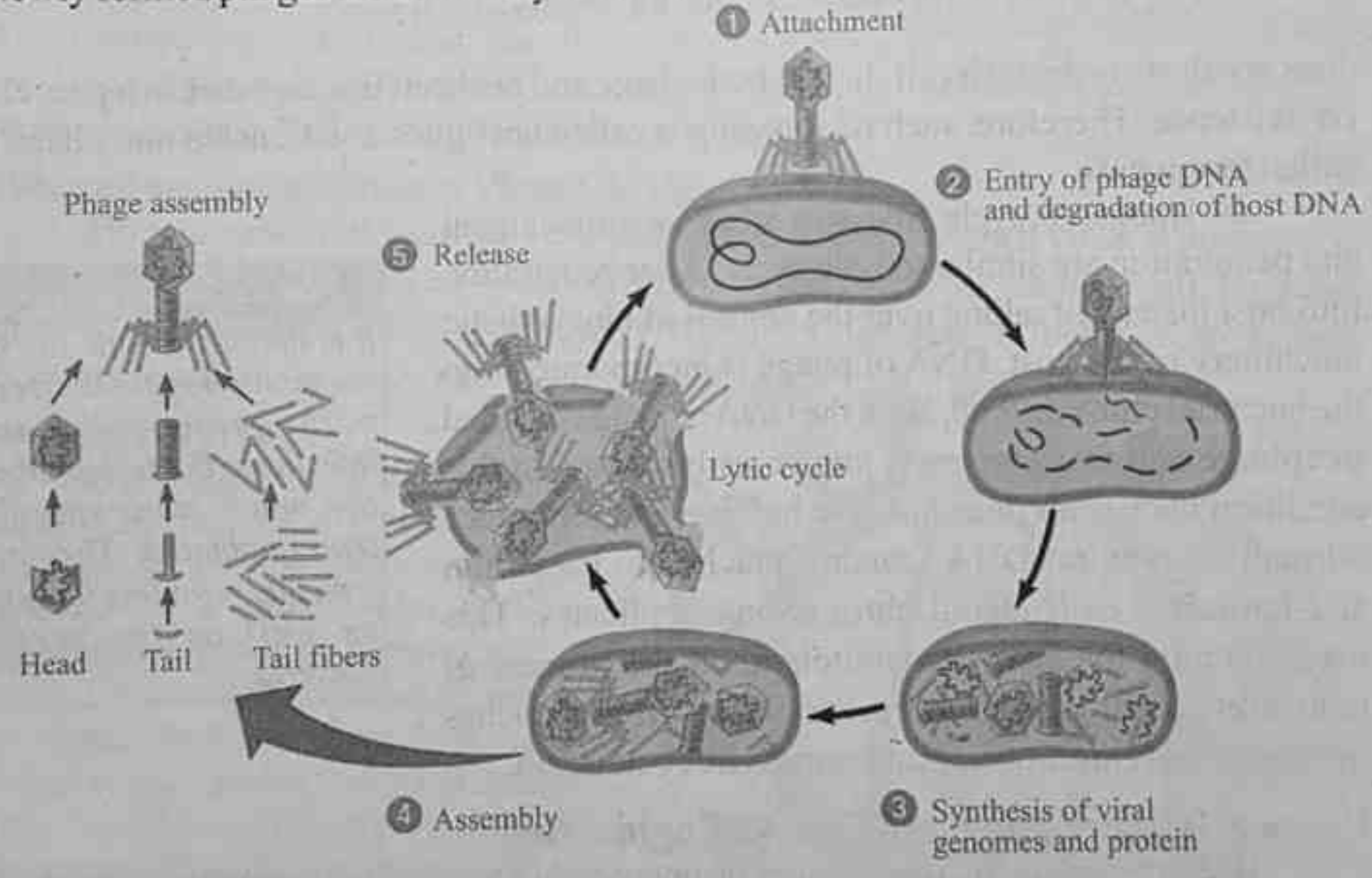


Fig. 5.3 Lytic cycle

5.2.2 Lysogenic Cycle: (Host-Guest Relationship)

All bacteriophages do not cause lysis of bacterium. In lysogenic cycle the phage

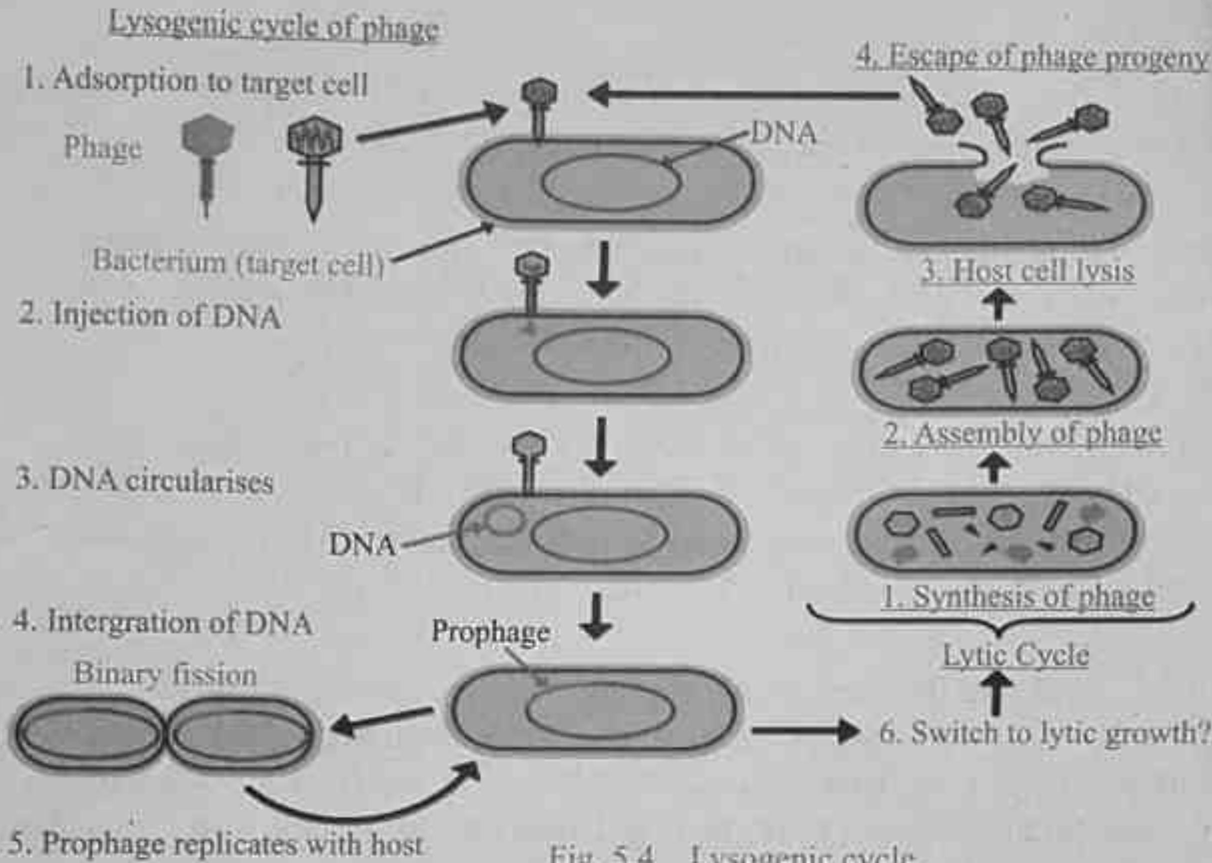


Fig. 5.4 Lysogenic cycle

does not destroy the host cell. In fact both phage and host cell live together in a peaceful co-existence. Therefore, such relationship is called host-guest relationship and phage is called **temperate**.

In lysogenic cycle first two steps i.e., attachment and penetration are similar to lytic cycle. After penetration into host instead of taking over the control of biosynthetic machinery of the host, DNA of phage is incorporated into the bacterial chromosome. Now the DNA of phage is called **prophage** and this process is known as lysogeny. In this condition bacterium does not lyse but live and reproduce normally. The viral DNA remains attached to bacterium and replicates as bacterial chromosome replicates. This may continue for many generations until the process of induction takes place. In this process viral DNA detaches from bacterial chromosome and starts lytic cycle again.

> **Phage Therapy**
>
> *It is the therapeutic use of bacteriophages to treat pathogenic bacterial infections. Bacteriophages are much more specific than antibiotics. They are typically harmless for host as well as for useful bacteria.*

Usage of Bacteriophages in Genetic Engineering

Bacteriophages are used in genetic engineering as vectors alongwith plasmids. In genetics a vector is a DNA molecule use as a vehicle to artificially carrying foreign genetic material into another cell where it can be replicated and expressed.

The bacteriophage vector is called lambda and they are more efficient than bacterial plasmid. The phage vector can carry larger fragments of DNA usually 15-50 base pairs.

The enzymes of viruses like holins and lysins are used to degrade the bacterial cell wall so bacteriophages have been proposed as alternative to antibiotics for many antibiotic resistant bacterial strains.

5.2.3 Influenza or Flu Virus

It is an RNA enveloped virus, belongs to family orthomyxoviruses. It includes seven genera but out of seven three genera usually cause influenza in humans and some other vertebrates. These three genera are influenza virus A, influenza virus B and influenza virus C. Each genus include only one species, i.e., influenza A, B and C virus.

The **influenza** A and C cause infection in different vertebrates including humans but **influenza** B almost exclusively infects human.

Vaccines and drugs are available for the treatment of influenza virus infection but flu viruses develop resistance against these vaccines and drugs. Therefore, vaccines and drugs have to be reformulated regularly.

Do you know?

The total genome length of flue virus is 12000-15000 nucleotides and the genome contains 6-8 segments or pieces of varying lengths.

Symptoms of influenza

include fever, shivering, dry cough, chill, loss of appetite, body-ache, nausea, irritation in throat and nose etc.

Human Immunodeficiency Virus (HIV):

Human immunodeficiency virus (HIV) is an RNA enveloped virus. It is spherical in shape. It is a retrovirus, i.e., it can convert its RNA into DNA in host cell. It causes aquired immunodeficiency syndrome (AIDS) in humans. It belongs to family retroviridae and genus lentivirus.

Structure of HIV:

It is roughly spherical in shape, about 120 nm in diameter. HIV consists of two strands of RNA enclosed by a conical capsid. The capsid is surrounded by an envelope.

The envelope is formed when the capsid buds off from host cell, taking some of the host cell membrane with it. The envelope contains glycoprotein receptors responsible for binding to and entering the host cell. Several enzymes like reverse transcriptase, protease and integrase are also present.

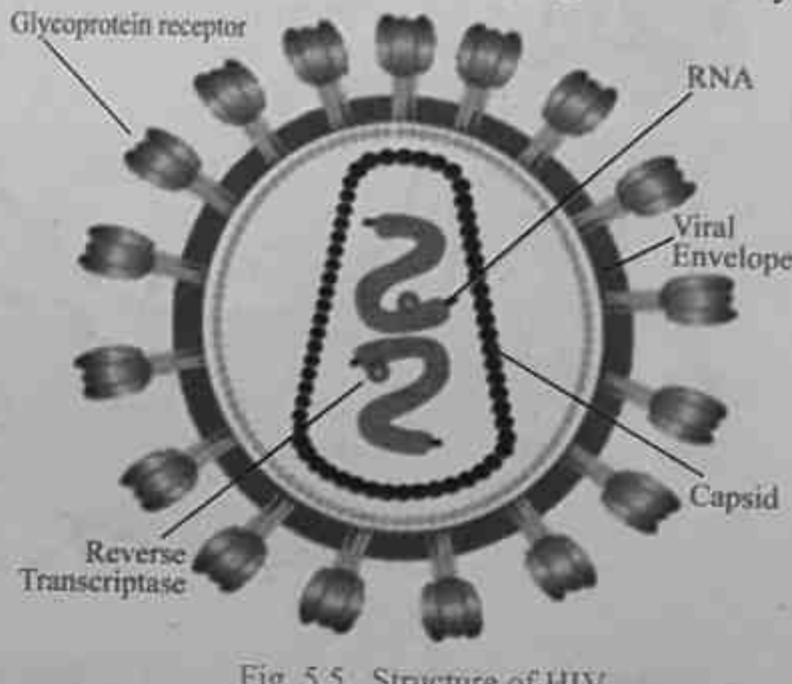


Fig. 5.5 Structure of HIV

5.3 Discovery of HIV

HIV causes AIDS (Acquired immunodeficiency syndrome). The HIV was first identified in 1984 in France and USA. The name HIV (Human immune deficiency virus) was given to this virus in 1986. HIV attacks on some special type of white blood cells (macrophages, lymphocytes). These cells are known as T4 cells and are the primary hosts of HIV.

5.3.1 Life cycle of HIV (How does HIV recognize T4 cells?)

The HIV has glycoprotein receptors on its envelope while T4 cells have CD4(Cluster of differentiation) receptor, during travelling in blood HIV glycoprotein receptors stick with T4 cells on CD4 protein receptors.

> **Tit bits**
>
> *HIV screening test is done by ELISA. However, ELISA test is relatively less authentic, so PCR test is recomended which is more authentic.*

Once HIV binds to a host cell, the viral envelope fuses with the cell membrane, the RNA and enzymes of virus enter into the host cell. Three types of enzymes of HIV which come into host cell along with RNA are reverse transcriptase, integrase and protease. The reverse transcriptase converts viral RNA into DNA. The enzyme **integrase** then facilitates the delivery of this viral DNA into the host DNA.

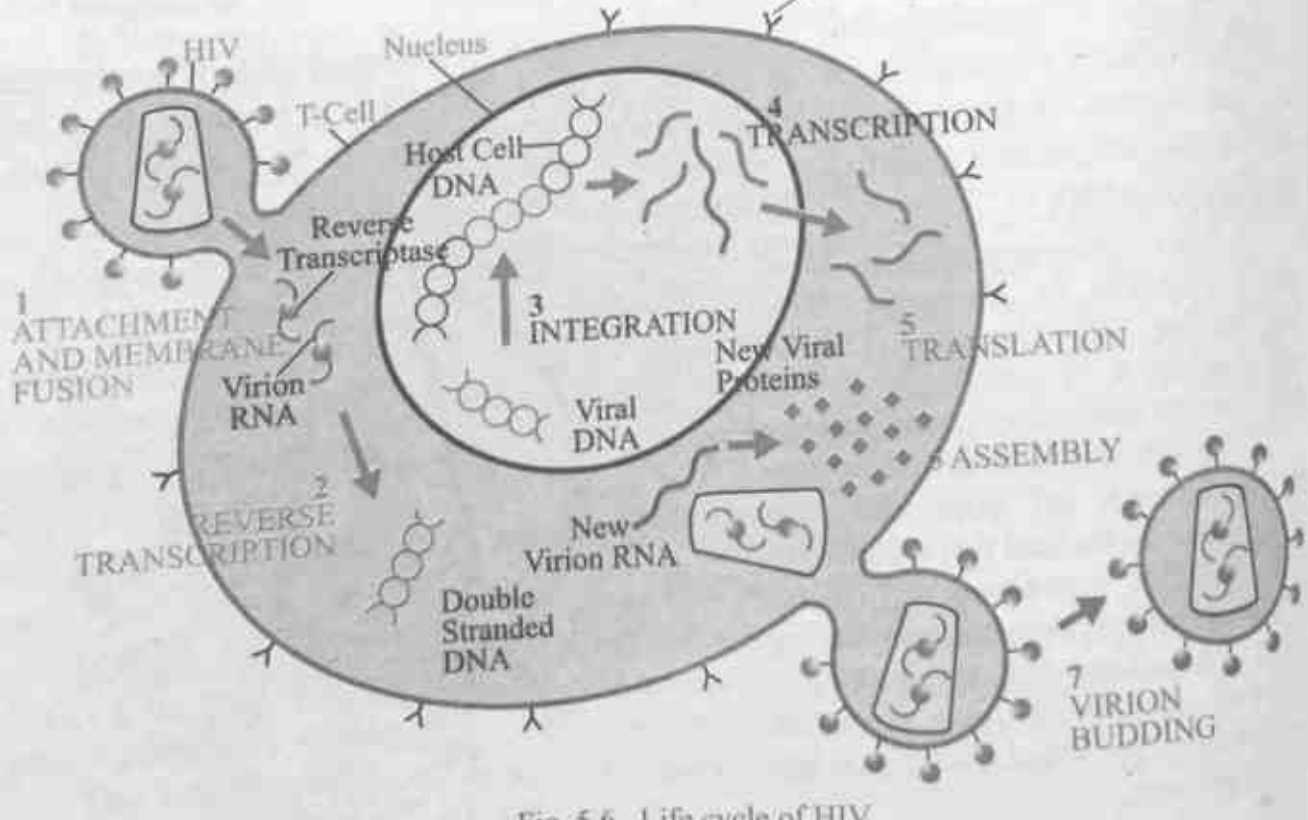


Fig. 5.6 Life cycle of HIV

The integrated DNA is now called provirus. Virus mRNA is transcribted in host cell by host cell polymerase. This mRNA is translated into proteins. These proteins are large in size which are then cleaved by the protease enzyme to form virion structural proteins. Thus immature virion is produced which is budded off from cell membrane. As it buds off, it takes the covering of host cell membrane and becomes mature infectious virion. A cell infected with retrovirus does not necessarily lyse the cell when its replication takes place. In HIV infection T4 cells are destroyed thus immunity is decreased and patient becomes susceptible to other diseases. As it causes immune system deficiency so it was called HIV (Human Immunodeficiency virus).

Tit bits

There are two species of HIV, i.e., HIV-I and HIV-II. HIV-I is most common pathogenic strain while HIV-II is not widely recognized outside Africa.

Symptoms of AIDS:

The infection of HIV may be divided into three stages. **The first** stage is known as primary infection. In this stage symptoms like fever, swollen lymph nodes, inflammation of throat, night sweating occur. However, these symptoms disappear after some days and there are no symptoms for about nine months, therefore, this first stage is called **asymptomatic carrier.**

The second stage known as **AIDS related complex**. In this stage some of early symptoms of acute infection reappear like swollen lymph nodes under the armpit, neck region, groin region, fever, aches etc. Some other symptoms like persistent cough, persistent diarrhoea, flu, night sweating, loss of memory, loss of judgment and depression, weakness etc. This stage may continue from few months to many years.

The last stage of HIV infection is called **full blown AIDS.** This stage is characterized by severe weight loss, weakness and opportunistic infections such as **kaposi's sarcoma** (skin cancer), **cervical cancer** and **cancer of lymphatic** system. Opportunistic infections are such infections which are caused by very weak pathogens which usually never cause infection as our immune system can easily destroy them.

Red Ribbon

The red ribbon is a symbol for solidarity with AIDS patients.

Transmission of AIDS:

The HIV is transmitted by three main routes i.e., sexual contact, body fluids and mother to child.

The sexual contact is most frequent cause of HIV transmission. The second most common mode of HIV transmission is **body fluid,** it includes blood transfusion, surgical instruments, contaminated syringes, razors, blades etc. **The mother to child** transmission may occur during pregnancy, during delivery or breast feeding.

World AIDS Day

1st December is world AIDS Day, it is being observed every year since 1988. It is dedicated to raising awareness about AIDS prevention.

Prevention of AIDS:

There is currently no cure or vaccine to prevent or cure HIV infection. A treatment known as **highly active antiretroviral therapy** (HAART) is given but no significant improvement is observed. Therefore, prevention is the only cure for AIDS. The following **preventive measures** are recommended to avoid HIV infection.

i) Avoid immoral sexual contacts and follow Islamic teachings in order to live clean and healthy life.
ii) Surgical instruments must be sterilized before use.
iii) Disposable syringes should be used. Blood must be screened before transfusion.
iv) Do not share razor blades and tooth brushes.
v) HIV positive mothers should avoid breast feeding.

5.4 Parasitic Nature of Viruses

Viruses are obligate parasites i.e., they cannot reproduce and live outside living cells. It is because viruses lack metabolic enzymes, ribosomes, mitochondria etc for making protein and energy. Therefore, viruses must need a host cell for their life cycle.

Viruses are highly specific with respect to their hosts, e.g., HIV attacks on T4 cells of human. Polio virus infects spinal nerve cells. Hepatitis virus attacks on liver cells. Bacteriophages attack only bacteria etc. However, some viruses have a broad range of specificity e.g., rabies virus can infect all mammalian cells.

When any foreign agent enters inside the body it is destroyed or killed by macrophages and neutrophils or antibodies produced by Bursa lymphocytes. But in some capsule, protein and fibrin do not bind by geg (swing) like substances secreted by Bursa lymphocytes which are used by macrophages and neutrophils. That is why viruses are saved from being phagocytized. Some viruses cover with host proteins, therefore, body immune system is unable to detect them as foreign body and they remain protected. Many viruses continuously change their shape and appearance as a result body immune system and vaccine becomes ineffective against new types, e.g., influenza and HIV viruses also remain safe in the body when immune system gets weak as in AIDS.

How viruses tolerate unfavorable conditions outside host cell?

Outside the host cell viruses are changed into crystals. In crystal form they are seen dead and show no activities. Upon reaching the host cell, i.e., in favorable condition they become active again and start reproducing by using host enzymes and proteins. The crystals of viruses may be present in saliva, respiratory droplets, feces etc.

5.5 Viral Diseases

A disease caused by virus is known as viral disease. Viruses cause number of diseases in plants, animals and human beings. A brief introduction of some viral diseases is given below.

Hepatitis:

Hepatitis is the inflammation of liver (Gk. *Hepa* = Liver, *itis* = inflammation)

There are different causes of hepatitis such as alcohol, drugs and toxins. However, hepatitis is mostly caused by viral infections. There are several types of viral hepatitis like A, B, C, D and E.

Hepatitis A: It is caused by RNA virus called HAV. The HAV is non-enveloped icosahedral shaped virus which cause a mild, short term disease. It is transmitted by contact with feces from infected person and drinking sewage contaminated water.

Vaccine is available for the prevention of HAV but no antiviral therapy is available.

Hepatitis B: Serum Hepatitis: It is caused by DNA enveloped virus called HBV. It is transmitted by blood, sexual contact, contaminated blood transfusion and by infected mothers to their babies, saliva etc. It may cause liver cirrhosis and death if not treated timely. The vaccine for HBV is available. **Alpha interferon** and some nucleoside analogues are effective treatment for HBV.

Hepatitis C: It is caused by RNA enveloped virus called HCV. It is a chronic and fatal disease, may cause cirrhosis, hepatocellular carcinoma and death if left untreated. The mode of transmission is via blood, sexual contact, breast feeding, sharing needles, tooth brushes etc. No vaccine is available for HCV, however, antiviral therapy is available usually a combination of interferon and ribavirin is given to the patients.

Hepatitis D: It is caused by HDV also called delta virus. This virus is only active in the presence of HBV, so it can be treated or prevented by treating HBV. Its mode of transmission is also same as HBV. It is small spherical enveloped viroid.

Hepatitis E: It is caused by HEV. It is non-enveloped single stranded RNA virus. The symptoms of HEV are similar to HAV. But it can be more fulminant in some cases such as pregnancy. No vaccine or antiviral drugs available.

Herpes: There are two types of herpes viruses which cause herpes, i.e., herpes simplex virus I and II. These are double stranded DNA viruses having large genome covered with protein coat and envelope. Herpes simplex-I is known as cold sore while herpes simplex-II is known as genital herpes. Herpes-I is transmitted by saliva while herpes-II is transmitted by sexual contact. The symptoms include water blisters in the skin or mucous membranes of mouth, lips, nose, genitals and skin lesions. Herpes can be treated by using antiviral drugs and may be prevented by avoiding sexual contacts and physical contacts with infected persons.

> **Tit bits**
>
> *Polio virus is usually spread by infected fecal matter entering the mouth. It may also spread by food and water contaminated by faeces or saliva.*

> **Tit bits**
>
> *Polio has been almost eradicated from world. However, Pakistan, Afghanistan and Nigeria are the countries where polio cases are identified.*

Poliomyelitis (infantile paralysis)

It is highly infectious viral disease that can lead to paralysis, breathing problem or even death. This virus was first identified by Karl Landsteiner in 1908. Primarily, it is transmitted by contaminated water of infected fecal material but may also be transmitted by sneezing and coughing. There are many different symptoms of polio. These symptoms may be divided in two types.

i) **Non-paralytic polio symptoms:** These include flu, weakness, fever, sore throat, headaches, vomiting, fatigue, muscle tenderness etc.

ii) **Paralytic polio symptoms:** These include loss of muscle reflexes, severe muscle pain spasm and damage to motor nerve etc.

Tit bits

Prions have different structure than normal protein of body. Therefore, they are resistant to protease enzyme

There is no cure for polio, however, it can be prevented by vaccination. Two types of polio vaccines are available, i.e., inactivated polio vaccine (IPV) and oral polio vaccine (OPV).

Leaf Curl Virus Disease

Leaf curl is a plant disease characterized by curling of leaves, darken veins and veins swellings. The disease mainly affects the cotton plant which is one of the most important crop of Pakistan, accounting for over 60% of foreign exchange earnings.

In Pakistan this disease was first reported in Punjab region near the city of Multan in 1985. Now it is spread in other parts of Pakistan and the neighbouring countries. It is a main threat to cotton crop. It is caused by a cotton leaf germinivirus (CLCuV). The vector of this virus is whitefly *Bemisia tabaci*. Therefore, this disease can be prevented by protecting the cotton seedlings from the attack of whiteflies. The infected plants should be burnt and healthy seeds should be used for sowing.

Fig. 5.7 Cotton Leaf Curl Disease

Bird Flu in Pakistan

Bird flu is also called avian influenza. It is a viral infection that can infect not only birds but also humans and other animals. However, most forms of virus are restricted to birds.

H_5N_1 is the most common form of bird flu. It is deadly disease of birds and it can also easily affect humans and other animals that come in contact with infected birds. H_5N_1 are capable to survive for long

Fig. 5.8 Birds infected from birds flu virus

period of time. The infected birds continuously release the virus in their faeces and saliva, so touching the contaminated surfaces may spread the infection.

The symptoms of bird flu include cough, diarrhea, fever, headache, runny nose, sore throat etc.

Multiple poultry outbreaks of H_5N_1 influenza have been reported in Pakistan, majority of outbreaks have been reported in poultry belt of Khyber Pakhtunkhwa province, particularly in Abbottabad and Mansehra. Some cases of bird flu have also been reported in Islamabad.

In Pakistan poultry sector is playing an important role in bridging the gap between the demand and supply of dietary protein. Pakistan to some extent, has remained successful in controlling infections of avian influenza. However, further steps are needed to prevent the outbreaks of bird flu in Pakistan.

Activity

Relate enzyme activity with antibiotics by searching internet and find out the reason why antibiotics are not effective against viruses.

5.6 Prions

Prions are proteinaceous infectious particles which cause transmissible neurodegenerative disease. Stanely in 1982 discovered these particles. The prions affect the nervous system of human and other mammals.

The transmission of prion is mainly by unhygienic way of feeding, contaminated food. Some prions diseases of human are **creutzfeld Jacob disease (CJD), kuru, fatal familial insomnia (FFI).** These diseases are caused by eating beef products obtained from cattle with prions diseases. **Scrapie** is a common disease of bovine caused by prion. It is also known as **mad cow disease**. Loss of memory, paralysis, destruction of nerve tissues are symptoms of prion disease. No effective treatment is available and illness is progressive and always fatal.

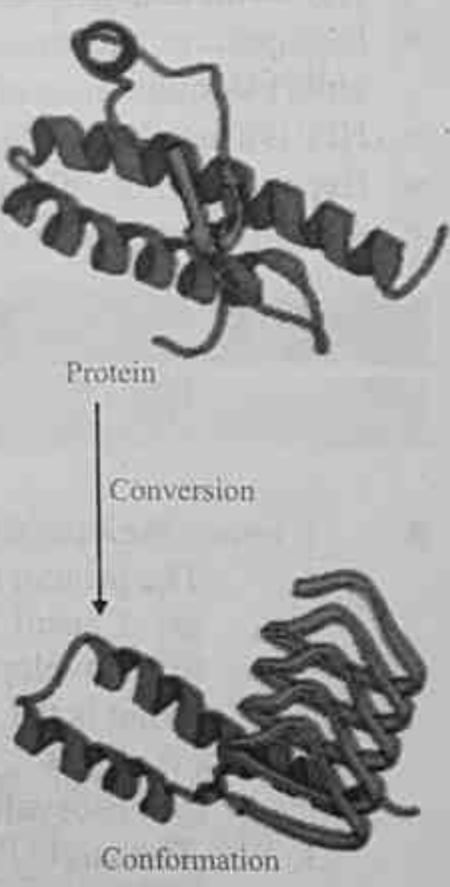


Fig. 5.9 Structure of Prion

Viroids

Viroids are single molecules of circular RNA without a protein coat or envelope so they are called simple RNA. These are smaller in size than virus, ranging from 246-270 nucleotides.

Viroid was first discovered by T. O. Diener in 1971. Viroids cause diseases in plants such as **potato spindle tuber** disease, **cucumber pale fruit.**

The mechanism of viroids replication is unclear so far.

SUMMARY

- Viruses are sub-microscopic, obligate intracellular parasites.
- All viruses have a protein capsid or shell, that surrounds the nucleic acid in the central core. and collectively known as the nucleocapsid.
- The capsid of any virus is constructed from a number of identical protein subunits called capsomeres.
- Some proteins form a binding layer between the envelope and capsid of the virus, and glycoproteins (proteins bound to a carbohydrate) remain exposed on the outside of the envelope. These protruding molecules, called spikes or peplomers, are essential for the attachment of viruses to the next host cell.
- Bacteriophage means to eat bacteria, and are called so because virulent bacteriophage can cause the complete lysis of a susceptible bacterial culture.
- Lytic or virulent phages are phages, which multiply in bacteria and kill the cell by lysis at the end of the life cycle.
- Lysogenic or temperate phages are those that can either multiply via the lytic cycle or enter a dormant state in the cell.
- HIV is a member of the group of viruses known as retroviruses.
- Hepatitis means inflammation of the liver.
- A highly contagious disease is caused by the herpes simplex virus, either type I or II.

EXERCISE

Section I: Objective Questions

Multiple Choice Questions

A. Choose the best correct answer.

1. The protein coat of a virus is called the:
   (a) Capsid (b) Capsomere
   (c) Envelope (d) Viral membrane
2. What is the second step of bacteriophage infection
   (a) Lysis (b) Attachment
   (c) Biosynthesis (d) Penetration
3. The viral DNA incorporated into a lysogenic cycle is called.
   (a) Prophage (b) Latent phage
   (c) Bacteriophage (d) Oncogenic virus
4. Prions cause disease by
   (a) Altering normal proteins (b) Altering genes
   (c) Activity of a reverse transcriptase (d) Produce poison

5. What type of infectious agent causes potato spindle tuber disease?
   (a) Prion (b) Virino
   (c) Viroid (d) Virus
6. Prion diseases can be acquired in all of the following ways except by
   (a) Transplantation (b) Inherited
   (c) Direct contact (d) Ingestion
7. Carbohydrate-protein complexes that project from the surface of some viruses are
   (a) Caspid (b) Capsomeres
   (c) Envelope (d) Spikes

B. Fill in the blanks.

1. Prions are infectious particles which are composed of only___________.
2. Viroids consist of only a single molecule of circular_______without protein coat.
3. Polio virus is transmited by the_________.
4. Master-slave relationship of bacteriophage is called___________cycle.
5. Host-guest relationship of bacteriophage is called___________cycle.
6. The tail of phage secretes an enzyme named_________.
7. HEV is non enveloped single stranded__________virus.

Section II: Short Questions.

Write short answers.

1. What is meant by an obligate intracellular parasite?
2. What is the capsid?
3. What is an enveloped virus, and how does the envelope arise?
4. Write short note on prion.
5. Define bacteriophages and explain their structure.
6. What is necessary for adsorption?
7. What is a prophage or temperate phage?
8. What is the principal effect of the agent of Creutzfeldt-Jakob disease?
9. What are viroids?
10. Why the viral diseases are more difficult to treat than bacterial diseases?

Section III: Extensive Questions.

1. Explain the lytic phase of life cycle of bacteriophage.
2. What is HIV? Which disease it causes and how it is transmitted?

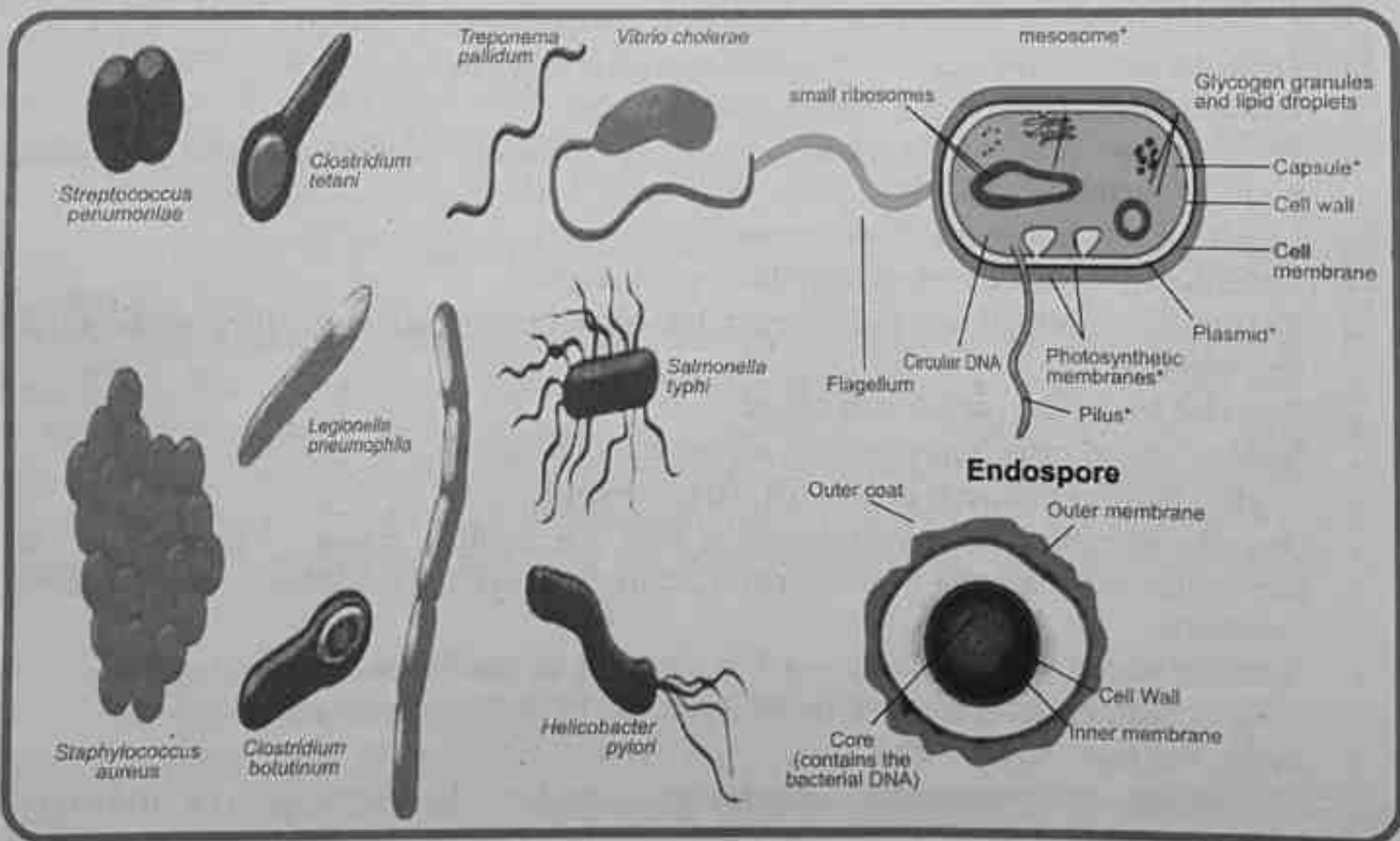
3. Write a note on different infectious diseases caused by viruses.
4. Describe several types of hepatitis.
5. Write note on prions and viroids.
6. Explain parasitic nature of viruses.
7. Explain differences between lytic and lysogenic cycle.

UNIT 6

PROKARYOTES

Major Concepts

6.1 Taxonomy of Prokaryotes
6.2 Archaea
6.3 Bacteria (Ecology and Diversity)
6.4 Bacteria (Structure, Shape and Size)
6.5 Bacteria (Mode of Nutrition)
6.6 Bacteria (Growth and Reproduction)
6.7 Importance of Bacteria
6.8 The Bacterial Flora of Humans
6.9 Control of Harmful Bacteria
6.10 Cyanobacteria



Students Learning Outcomes

On completion of this unit students will be able to:

- Outline taxonomic position of prokaryotes in terms of domains archaea and bacteria and in terms of kingdom monera.
- Explain the phylogenetic position of prokaryotes.
- List the unifying archaeal features that distinguish them from bacteria.
- Explain that most Archaea inhabit extreme environment.
- Justify the occurrence of bacteria in the widest range of habitats.
- List the diagnostic features of the major groups of bacteria.
- Justify why cyanobacteria are considered as the most prominent of the photosynthetic bacteria.
- Describe detailed structure and chemical composition of bacterial cell wall and other coverings.
- Compare cell wall differences in Gram-positive and Gram-negative bacteria.
- Explain the great diversity of shapes and sizes found in bacteria.
- Justify the endospore formation in bacteria to withstand unfavourable conditions.
- Explain motility in bacteria.
- Describe structure of bacterial flagellum.
- Describe genomic organization of bacteria.
- Classify bacteria on the basis of methods of obtaining energy and carbon.
- Describe autotrophic and heterotrophic nutrition in bacteria.
- Explain the pigment composition in cyanobacteria.
- Differentiate between the photosynthesis mechanisms in cyanobacteria and other photosynthetic bacteria.
- List the phases in the growth of bacteria.
- Describe different methods of reproduction in bacteria.
- Explain how mutations and genetic recombinations lend variability to bacterial reproduction.
- Describe bacteria as recyclers of nature.
- Outline the ecological and economic importance of bacteria.
- Explain the use of bacteria in research and technology.
- Describe important bacterial diseases in man, e.g. cholera, typhoid, tuberculosis, and pneumonia; emphasizing their symptoms, causative bacteria, treatments, and preventive measures.
- Describe important bacterial diseases in plants in terms of spots, blights, soft rots, wilts and galls; emphasizing their symptoms, causative bacteria, and preventive measures.
- Define the term normal flora.
- List the important bacteria that make the normal bacterial flora residing in the oral cavity, respiratory and urinogenital tracts and large intestine of man.
- Describe the benefits of the bacterial flora of humans.
- List the chemical and physical methods used to control harmful bacteria.

Introduction

A **prokaryote** (Gk. *Pro* = before, *Karyons* = nucleus) is a unicellular organism having simple structure that lacks a membrane-bound nucleus and other membrane-bound organelles like mitochondria, Golgi complex etc. Prokaryotes have great economic and environmental importance. They also greatly affect on human health and largely used in research and biotechnology.

6.1 Taxonomy of Prokaryotes

The A. V. Leeuwenhoek (Dutch scientist) first discovered bacteria in 1674 and called them **animalcules**. Ehrenberg introduced the name **bacterium** in 1828 (Gk: bacterion means small staff or rod). The taxonomic position of bacteria and other prokaryotes have witnessed continuous changes since their discovery.

6.1.1 Taxonomic position of Prokaryotes as kingdom(Monera)

According to two kingdom system of classification all microorganisms were included in kingdom **Plantae.** In 1861 **John Hog** proposed a separate kingdom **Protista** for all microorganisms including **bacteria.** In 1866 **Ernst Haeckel** made a separate group the **Monera** for Prokaryotes within same kingdom Protista. In 1938 **Herbert Copeland** separated group Monera from Protista and formed the **kingdom Monera** in which he had placed only prokaryotic organisms. **Robert H. Whittaker** an American biologist in 1969 proposed five kingdom system of classification for living things. **Lynn Margulis** and **Karlene Shwartz** in 1988 modified five kingdom classification. They distinguished between kingdoms according to cellular organization and mode of nutrition. They had placed all prokaryotes in kingdom monera, whereas eukaryotes were classified into four kingdoms *viz*. Protista, Plantae, Fungi and Animalia.

6.1.2 Taxonomic position of prokaryotes as "Domain Bacteria" and "Domain Archaea"

Earlier the term bacteria was used for all microscopic unicellular prokaryotes but later molecular systematics studies exhibit that prokaryotic life consists of two separate **domains**. Thus, both these domains have superceded the kingdom as a broadest taxonomic group. Bacteria and Archaea evolved independently from an ancient common ancestor. These two domains, along with Eukarya, are the basis of the three domain system, which is currently the most widely used classification system in bacteriology.

6.1.3 Phylogenic position of prokaryotes

Phylogeny is the evolutionary relationship among various groups of organisms (e.g., Species or populations). The study of phylogenic evolutionary history of a species or group of related species is called **systematics**. The bacterial phylogeny was reconstructed in 1977. The new phylogenetic taxonomy is based on the discovery of genes encoding ribosomal RNA because there is little or no change in ribosomal RNA generation after generation. **Thus ribosomal RNA are commonly recommended as**

molecular clock for reconstructing phylogenies. Now prokaryotes are divided into two evolutionary domains as part of the three domain system, **Archaea Eubacteria** and **Eukaryotes.** The genes sequence studies indicate that bacteria diverged first from the archaeal/ eukaryotic lineage.

Most scientists hold view that bacteria and archaea probably evolved from **hyperthermophile** that lived about 2.5 to 3.2 billion years ago.

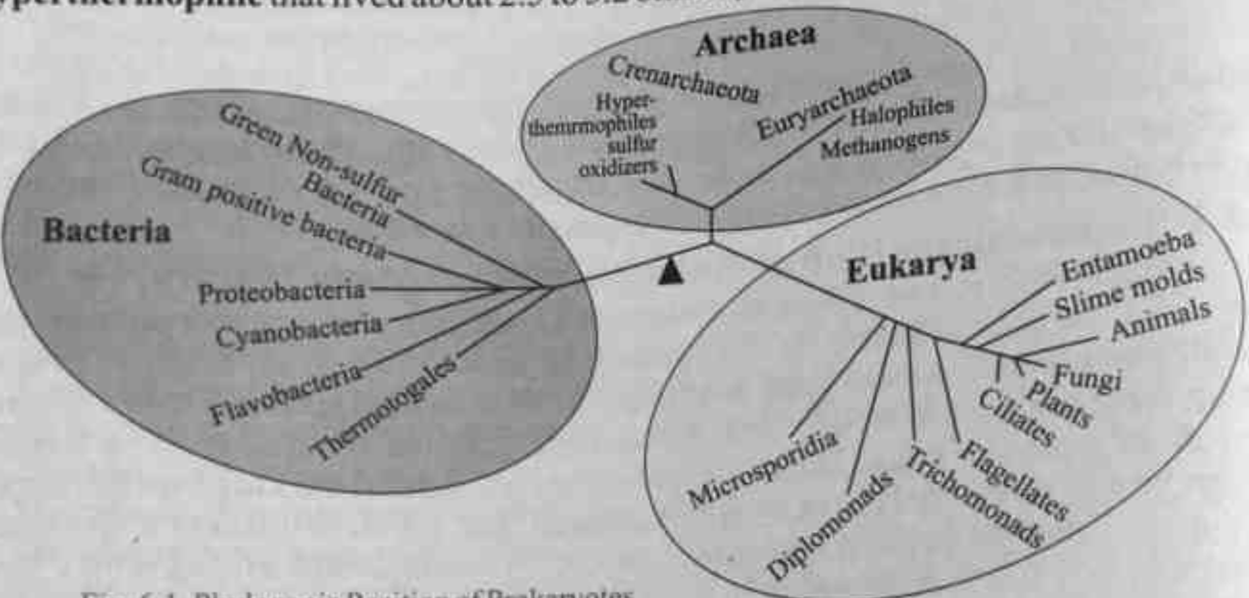


Fig. 6.1 Phylogenic Position of Prokaryotes

6.2 Archaea

The microorganisms belong to domain archaea are unicellular prokaryotes, previously known as **archaeobacteria**. Archaea exhibit similarities both with bacteria as well as eukaryotes.

They also differ from bacteria and possess unifying features thus placed in separate domain. The **unifying archaeal features** are:

1. Their **plasma membrane** contains different kinds of lipids than bacteria which allows them to function at high temperature.
2. The **cell wall** in bacteria is made up of carbohydrate-protein complex called **peptidoglycan** but the cell wall of archaea lacks this complex. Their cell wall is largely composed of polysaccharides or pure protein.
3. The **rRNA** of archaea is unique, i.e., different from that of bacteria.
4. **Lipid** of bacteria contain glycerol with fatty acids while lipid of archaea contain glycerol linked to branched chain of hydrocarbons.
5. A unique ability of **methanogenic** archaea is formation of methane.
6. Archaea are mostly **autotrophs**.

6.2.1 Habitat of Archaea

Most live in extreme environments. There are three types of archaea:

(i) Methanogenic archaea (ii) Halophiles

(iii) Thermoacidophilies.

The **methane** (Biogas) producing archaea are known as **methanogen,** which inhabit anaerobic environments like marshes, swamps, digestive tract of animals and human. These archaea produce biogas (methane) from hydrogen gas and CO_2 coupled to the formation of ATP (example of methanogen is *Methanobacterium formicom*).

The **halophiles**, inhabit salty environment where other organisms can not live such as salty meat, example of halophiles is *Halobacterium halobium*.

The **thermoacidophiles** inhabit extreme hot and acidic environments. Their example is *Pyrolobus fumarii*, recorded in hot springs, geysers, volcanoes etc.

6.3 Bacteria Ecology and Diversity

Bacteria have a wide range of habitat. They exhibit diversity in their size, shape and mode of nutrition.

6.3.1 Occurrence

Bacteria are found everywhere in this planet where life exists such as body of living and dead organisms, water, soil, milk, skin, humid forests etc.

6.3.2 Major Groups of Bacteria

Dr. Hans Christian Gram (1884) has divided bacteria into two major groups by using staining technique, i.e. **Gram positive and Gram negative.** His grouping depends upon chemical makeup, permeability, metabolism, presence of endospores, physiological characteristics, growth and nutrition in bacteria.

Table 6.1 Comparison between Archaea and Bacteria

Basis of comparison	Archaea	Bacteria
Habitat	Unusual environment like hot springs, ocean depth, salt brine.	Everywhere like soil, water, living and non living organisms.
Cell wall	Psuedopeptidoglycan, largely composed of polysaccharide or pure protein.	Peptidoglycan with muramic acid or lipopolysaccharide.
Membrane	Branched carbon chain.	Unbranched carbon chain.
Types	Methanogen, Halophiles, Thermoacidophiles	Gram positive and Gram nagetive.
Other features	No thymine in tRNA. Introns are present. Non-pathogens RNA polymerase is complex similar to eukaryotic, mostly autotrophic but no photosynthesis.	Thymine in the tRNA. Introns are absent. Some are pathogens. RNA polymerase simple and small, photosynthesis present but mostly heterotrophic.
Examples	*Sulfolobus acidocaldarius, Pyrococcus furiosus.*	*Streptococcus pneumonia, E.coli.*

6.4 Structure, Shape and Size of Bacteria

A typical bacterium consists of cell wall, cell membrane, nuclear region, cytoplasm and also other structures outside cell wall.

> **Tit bits**
> *Peptidoglycan is also called murein. It has long chains of sugars with short chains of amino acids (normally 4-5 amino acids).*

6.4.1 Structure and Chemical Composition of Bacterial Cell Wall

All bacteria possess cell wall except Mycoplasma. The cell wall protects the cell and also gives it a definite shape. It is made up of peptidoglycan (sugar-protein complex found in Prokaryotes) and is rigid.

6.4.2 The cell wall of Gram positive and Gram negative bacteria

Based on the variations in the chemical components of cell wall, Danish physician, **Hans Christian Gram**, developed a staining technique in 1884 and divided bacteria into two groups i.e., Gram positive and Gram negative bacteria.

Gram Positive: These bacteria are stained blue purple with crystal violet dye. They have thick wall of peptidoglycan. They retain dye when the cells are washed with an organic solvent like alcohol.

Gram negative: These bacteria have thinner layer of peptidoglycan. They lose the dye easily when rinsed with alcohol and stain pink. The thin peptidoglycan layer is externally covered with a layer of lipopolysaccharides, lipoproteins and phospholipid. Thus they are more resistant than gram-positive against antibiotics (lipopolysaccharide impedes the entry of antibiotics).

> **Tit bits**
> *In many bacteria cell membrane invaginates into cytoplasm to form folds called mesosome which helps in cell division and replication of DNA.*

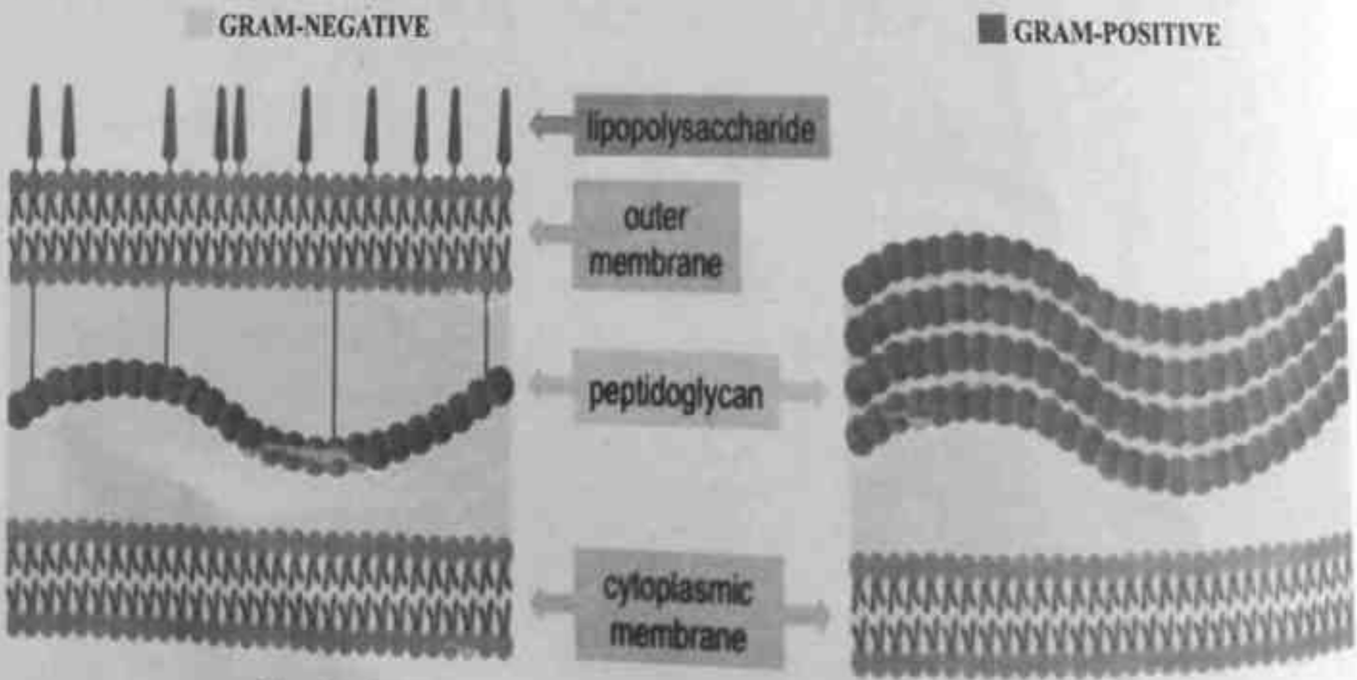


Fig. 6.2 Gram-positive and Gram Negative Bacterial Cell Wall

Table. 6.2. Differences between Gram-positive and Gram negative cell wall

Character	Gram Positive	Gram Neagative
Thickness	20 to 80 nm	8 to 10 nm
No. of Layers	One	Two
Porins proteins	Absent in all	Present in all
Peptidoglycan	More	Less
Lipid	Less	More
Outer membrane	Absent in all	Present in all
Chemical composition	Peptidoglycan, Teichoic acid, Lipoteichoic acids	Lipopolysaccharide, Lipoproteins and Peptidoglycan

Slimy Capsule:

Some bacteria contain additional protective outer envelope, secreted by the cell known as slimy capsule. It is made of polysaccharide which helps in defence and adhering to host tissues. The encapsulated bacteria cause disease while the same bacteria without capsule do not cause disease, e.g., *Diplococus pneumoniae* causes pneumonia.

6.4.3 Shape and Size of bacteria

There are three main shapes of bacteria; Spherical, Straight and Spiral shape.

Spherical or Cocci (Singular Coccus): Cocci are spherical in shape. They are non-motile because they lack flagella, may be single or colonial. The colonial may be diplococci (group of two cells) tetrad (group of four cells), octet (packet of eight cells), Streptococci (long chain of cells), Staphylococci (bunch of cells like grapes). Examples of Cocci are *Streptococcus pneumoniae, Neisseria meningitidis* etc.

Straight Shape or Bacilli (Singular Bacillus): Bacilli are straight or rod shaped bacteria. They posses flagella and are motile. Most of them occur either singly or colonial. They are found in pairs (diplobacillus), very short and oval shaped (coccobacilli), curved and coma shaped (Vibrio), stack (Pallisade). Examples of bacilli are *Bacillus subtilis, Escherichia coli* etc.

Spiral Shaped or Spirochetes: These are corkscrew shaped bacteria, flexible, motile and flagellated. They usually occur singly and seldom form colonies e.g., *Helicobacter pylori* and *Treponema pallidum.*

Most bacteria range in size about 0.1 to 600 micrometer over a single dimension.

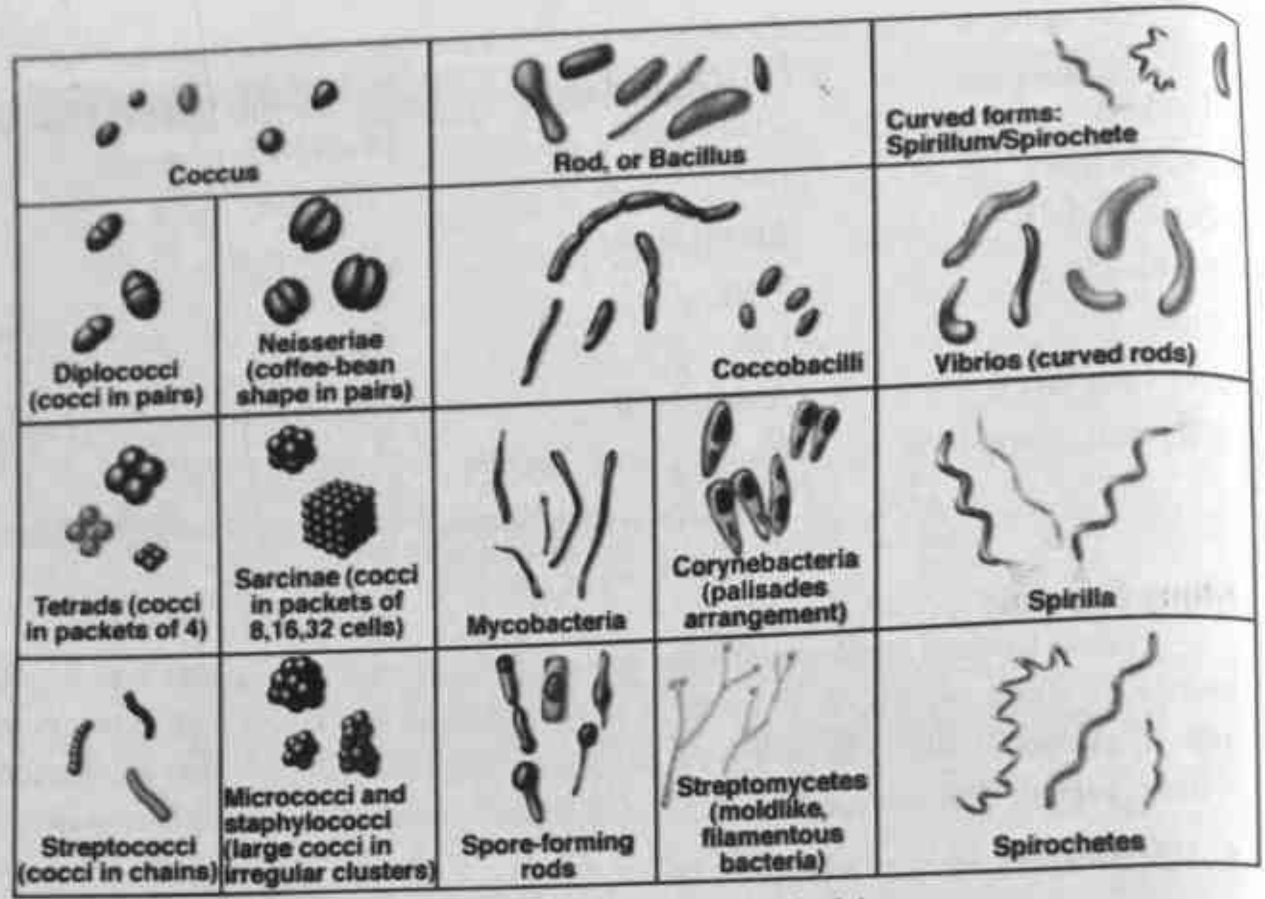


Fig. 6.3 Types of bacteria on the basis of shapes

6.4.4 Endospores

Some Gram-positive bacteria produce highly resistant structure known as endospore which during unfavorable conditions serves for the survival of the bacteria. It develops within vegetative cell, so named endospore. The original cell forms a copy of its chromosome and covers it with hard wall, water is removed and metabolism stops.

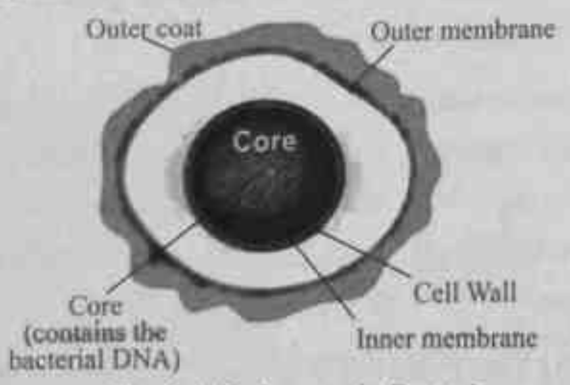


Fig. 6.4 Endospore in Bacteria

> **Do you know?**
> *Pili are small hollow appendages mostly present all around the body. Their role is attachment of bacteria to host tissue, mating (conjugation) and chemotaxis.*

Endospores remain dormant but viable for centuries. The parent body disintegrates. At the return of favorable conditions endospores are reactivated to normal form and restart division cycle.

6.4.5 Locomotion in Bacteria

Most bacteria possess flagella as locomotary appendages, which help in gliding, twitching motility or change of buoyancy. The spirochetes have helical body which help them to twist about as they move. During twitching motility pili help in anchoring. Flagella are commonly found in bacilli and spirilla while most cocci are without flagella known as atrichous. There are two types of arrangement of flagella, i.e., polar and peritrichous.

Polar flagella are situated at one end or both ends of bacteria and divided into following types.

Monotrichous: single flagellum at one end, e.g., *vibrio*.

Lophotrichous: a cluster of flagella at one, end e.g., *spirillum*.

Amphitrichous: flagella at both poles.

Amphilophotrichous: tuft of flagella at both ends.

Peritrichous: flagella are arranged all around the body e.g ., *Salmonella typhi*.

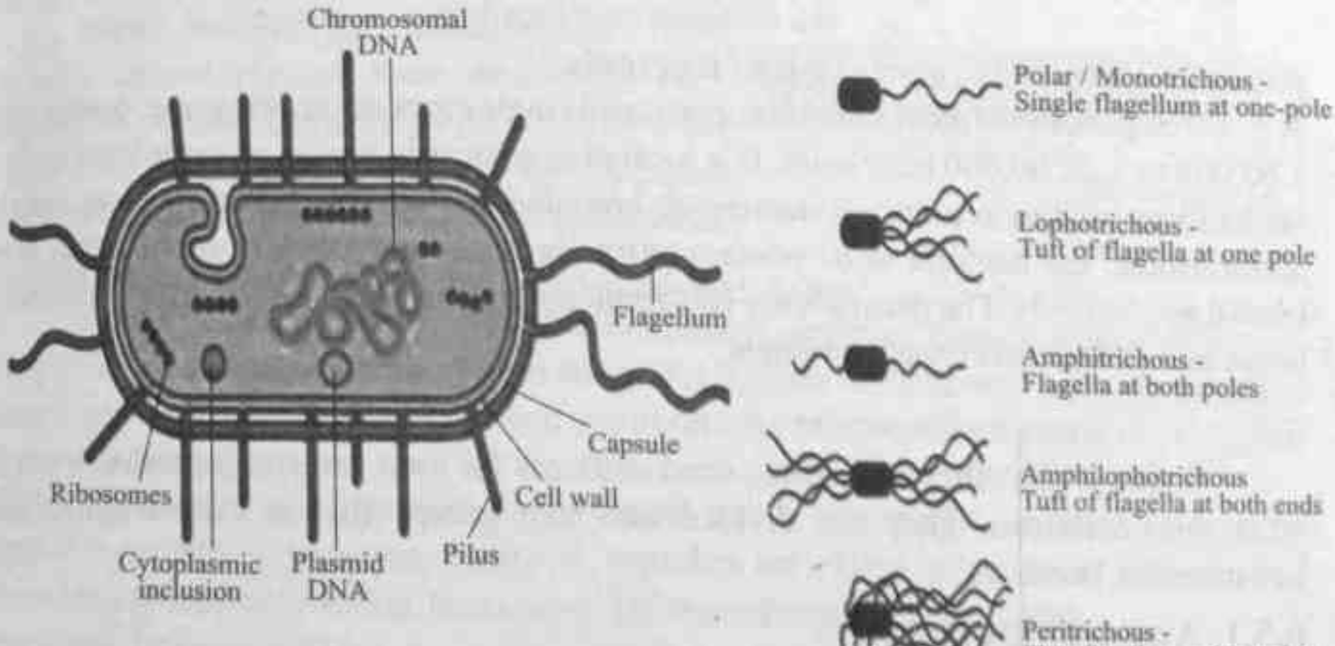


Fig. 6.5 Generalized structure of bacterium and types of flagellar arrangement

6.4.6 Structure of Flagella

A flagellum is made of three parts, i.e., basal body, a short curved hook and a helical filament, consists of several protein chains. Protein of flagella is flagellin.

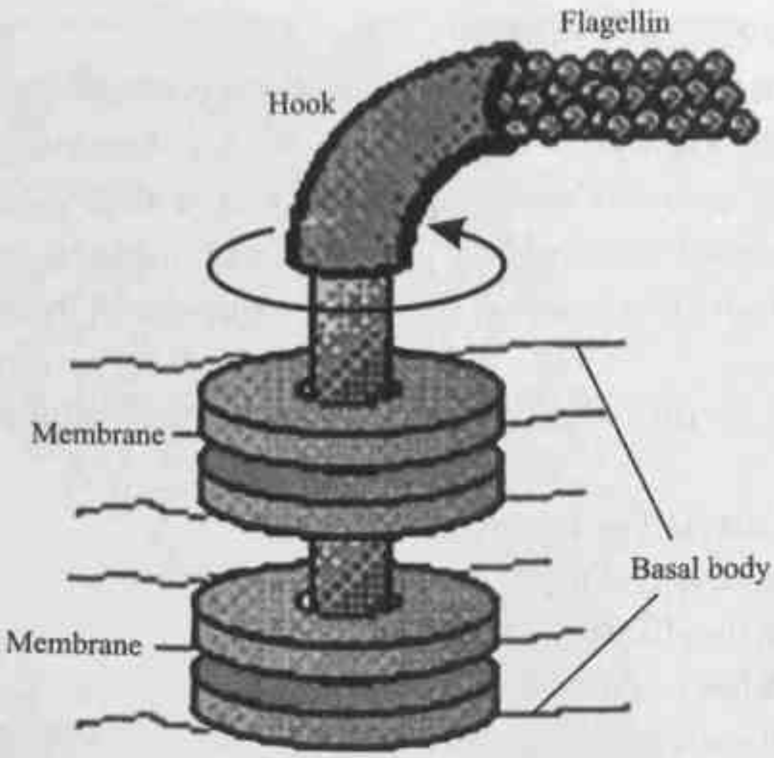


Fig. 6.6 Structure of flagellum

6.4.7 Genomic Organization of Bacteria

The genome of most bacteria consists of a single circular chromosome, containing 1,60,000 to 1,22,00,000 base pairs. It is located in a specific region of cytoplasm called nucleoid or nuclear region (no membrane bounded nucleus). In addition to its single chromosome, the bacteria also possess extra chromosomal DNA rings of small size known as plasmids. The plasmids are self-replicating, contain genes for drug resistance, heavy metals and insect resistant genes.

6.5 Nutrition in Bacteria

Bacteria like other organisms, need nutrients for their growth, reproduction and other vital activities. They are divided into two groups that is autotrophic and heterotrophic bacteria.

6.5.1 Autotrophic bacteria

These bacteria synthesize their own food from simple inorganic substances. They obtain all the carbon from inorganic carbon compounds such as carbon dioxide. The autotrophic bacteria are further divided into two groups namely photoautotrophic and chemoautotrophic.

Photoautotrophic or Photosynthetic Bacteria:

These bacteria possess chlorophyll, located either in the membrane of their mesosomes or freely dispersed in cytoplasm. Bacteria have unique type of chlorophyll that is chlorophyll *e* and *f* are known as **bacteriochlorophylls**. Photoautotrophic bacteria use the energy of sun light, H_2S as "H" source (instead of H_2O) and liberate "S" instead of O_2 to make carbohydrate (organic food) from CO_2.

$$2H_2S + CO_2 \xrightarrow[\text{Chlorophyll}]{\text{Sunlight}} \underset{\text{Carbohydrate}}{(CH_2O)_n} + H_2O + 2S$$

Examples of photosynthetic bacteria are purple sulphur bacteria, green sulphur bacteria, purple non-sulphur bacteria.

Chemoautotrophic or Chemosynthetic Bacteria:

These bacteria do not have chlorophyll thus do not use sunlight as source of energy. They derive energy by oxidation of inorganic substances such as H_2S, NH_3, NO_2, NO_3 and iron compounds. The energy of above inorganic substances is used to synthesize carbohydrates.

$$2H_2S + O_2 \xrightarrow{\text{oxidized}} 2S + H_2O + \text{release energy}$$

The energy released is utilized to make carbohydrates.

$$2H_2S + CO_2 + \text{energy from oxidation} \longrightarrow (CH_2O)_n + H_2O + 2S$$

The example of chemosynthetic bacteria are denitrifying bacteria, sulphur bacteria.

Heterotrophic Bacteria:

Many bacteria are heterotrophic, these bacteria cannot prepare their own food. They depend on organic compounds prepared by other organisms. There are two types of heterotrophic bacteria that is saprotrophic and parasitic bacteria.

> **Do you know?**
>
> *Heterotrophs directly or indirectly depend on photosynthetic organisms.*

Saprotrophic Bacteria or Saprobs (Gk. Sapro = rotten)

These bacteria get their food from dead and decaying organic matter (Humus). They have a powerful enzyme system which helps in the breakdown of complex organic compounds into simple substances and use the energy released in the process. Examples: *Pseudomonas, Azobacter.*

(**Note:** The chemicals released during break down of organic substances become available to other organisms, therefore, saprobes are called recyclers of nature. They clean the earth by their action, thus also called the scavengers of the earth).

Parasitic Bacteria: These bacteria get their food from the host and depend on host enzymes to make food. Parasitic bacteria include pathogenic bacteria (disease causing) examples are *Mycobacterium, Streptococcus pneumoniae.*

Respiration in Bacteria:

Respiration in bacteria may be aerobic and anaerobic.

Aerobic bacteria need oxygen to breakdown food, e.g., *Pseudomonas.*

Anaerobic bacteria breakdown food without oxygen, e.g., *Spirochetes.*

Facultative bacteria grow either in the presence or absence of oxygen, e.g., *E.coli.*

Microaerophilic bacteria need a low concentration of oxygen for their growth, e.g., *Campylobacter.*

6.6 Growth and Reproduction in Bacteria

Growth in bacteria means the increase in the total population rather than increase in the size of organism. Their growth is very fast and depend on suitable temperature, availability of nutrients, pH and ionic concentration; If conditions are favorable then most bacteria divide after every 20 minutes, e.g., *E.coli.* The interval between two successive divisions is known as **generation time**. It is different in different species.

6.6.1 The Growth Phases of Bacteria

There are following four phases of growth in bacteria.

Lag phase (no growth): Bacteria prepare themselves for coming division i.e., adapting to its new environment and growth has not yet achieved its maximum rate.

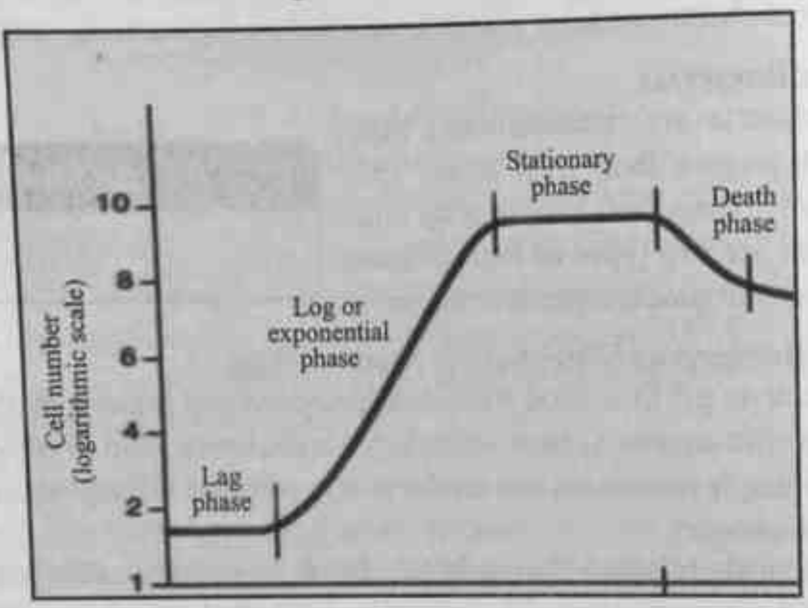


Fig. 6.7 Growth Curve of Bacterial Population

Log phase (rapid growth period): Fast growth occurs at this phase. In human the disease symptoms develop during the log phase because the bacterial production attains such a high level which damage the tissues.

Stationary phase (equal birth and death rate): After log phase, the growth slows down because of shortage of nutrients. Thus rate of reproduction and death of bacteria becomes equal.

Death phase (decline phase): In this phase death rate increases and reproduction rate decreases. It is due to exhaustion of nutrients and accumulation of toxic wastes.

6.6.2 Reproduction in Bacteria

Bacteria reproduce both asexually and sexually.

Asexual Reproduction (Binary fission): All bacteria reproduce asexually by means of **binary fission.** There is a single chromosome, having a circular DNA molecule. First DNA is replicated and attached to the plasma membrane. After duplication the two chromosomes move towards their respective sides. The plasma membrane pushes inward at the center of the cell. The cell wall grows inwards to separate both daughter cells from each other thus two daughter bacteria are formed. In most bacteria, it takes 20 minutes, if conditions are favourable.

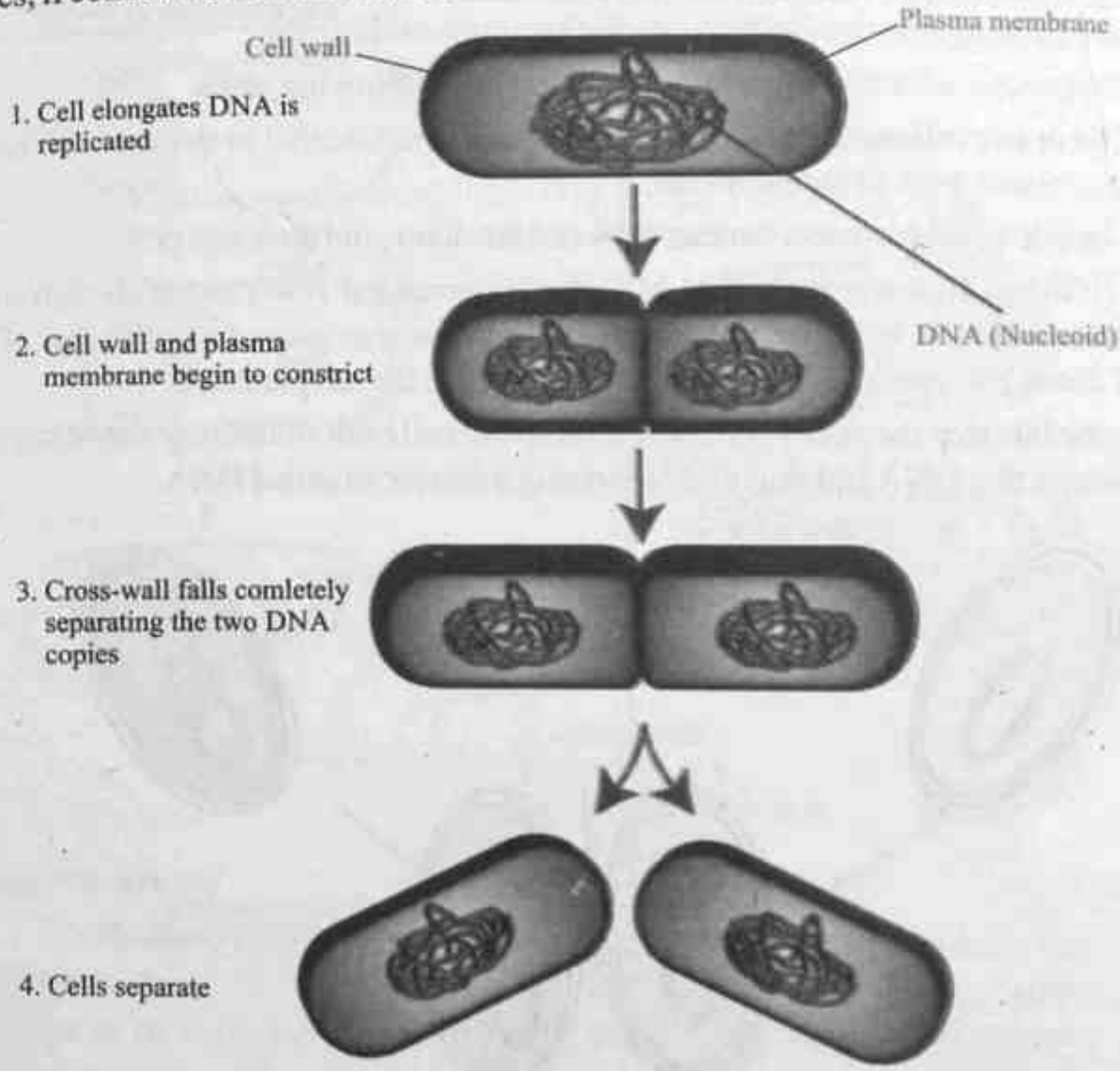


Fig. 6.8 Binary Fission in Bacteria

Sexual Reproduction in Bacteria:

Bacteria lack traditional sexual reproduction (gametogenesis). However, bacteria exhibit genetic recombination that is cells do not fuse, only piece of DNA or plasmid of donor cell is inserted in the recipient cell. This process occurs by conjugation, transduction and transformation.

Conjugation:

It is the process by which one bacterium transfers genetic material to another bacterium through a tube formed by pili called conjugating tube or bridge. The bacterium that gives the DNA is called **donor** and the bacterium that receives DNA is called the **recipient.** This process was first studied experimentally by Lederberg and Tatum in 1946 in *E. coli*. Later studies made with the help of electron microscope confirmed the close contact and the formation of conjugatory bridge between the bacterial cells.

> ***Tit bits***
>
> A cell possessing the F plasmid (F+, Male) can form a conjugation bridge to cell lacking the F plasmid (F-, Female) through which genetic material may pass from one cell to another. Now F- cell has its own fertility plasmid and it becomes an F+ cell.

The process of conjugation may be explained in following steps.

Step 1: The donor cell produces the pilus, which is a structure that projects out of the cell and begins contact with an recipient cell.

Step 2: The pilus enables direct contact between the donor and recipient cell.

Step 3: The donor plasmid consists of a double stranded DNA molecule forming a circular structure, it is attached at the both ends, an enzyme picks one of the two DNA strands of donor plasmid and this strand is transferred to the recipient cell.

Step 4: In the last step the donor cell and the recipient cell both containing single stranded DNA., replicate this DNA and thus end of forming a double stranded DNA.

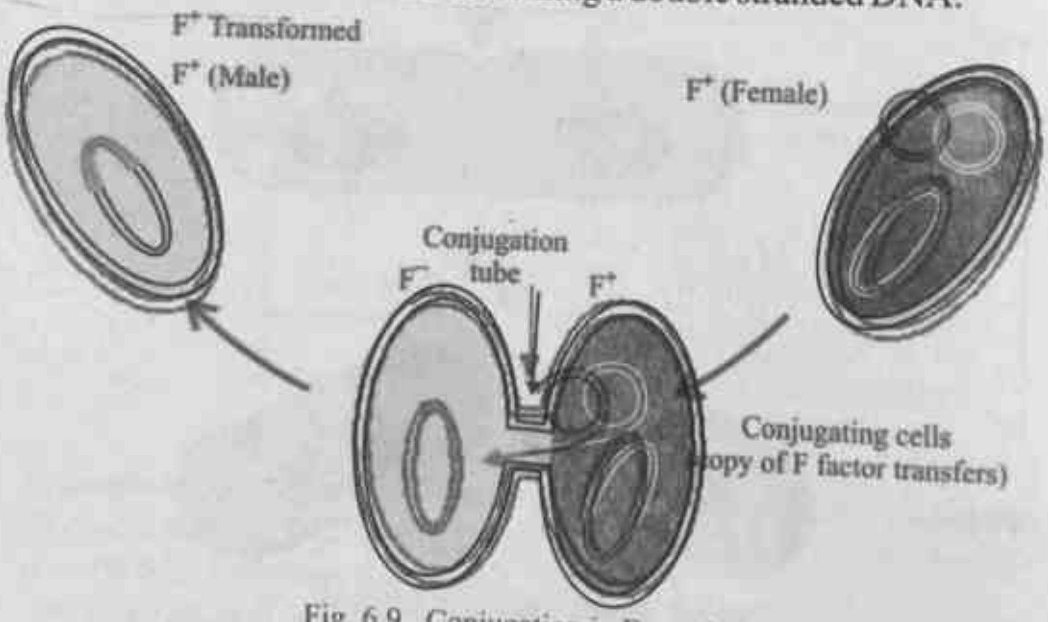


Fig. 6.9 Conjugation in Bacteria

Transduction:

It is a type of sexual reproduction, in which piece of DNA can be transferred from one bacterium (donor) to another bacterium (recipient) by a third organism, the bacteriophage. The process of transduction was discovered by Norton Zinder and Joshua Lederberg in 1952 while studying the genetic recombination in *Salmonella*.

In general transduction, any of the genes from the host cell may be involved in the process, in special transduction, however, only a few specific genes are transduced.

Tit bits

There are typically 40 million bacterial cells in a gram of soil and 1 million in 9 ml of fresh water and 5×10^{30} bacteria on earth.

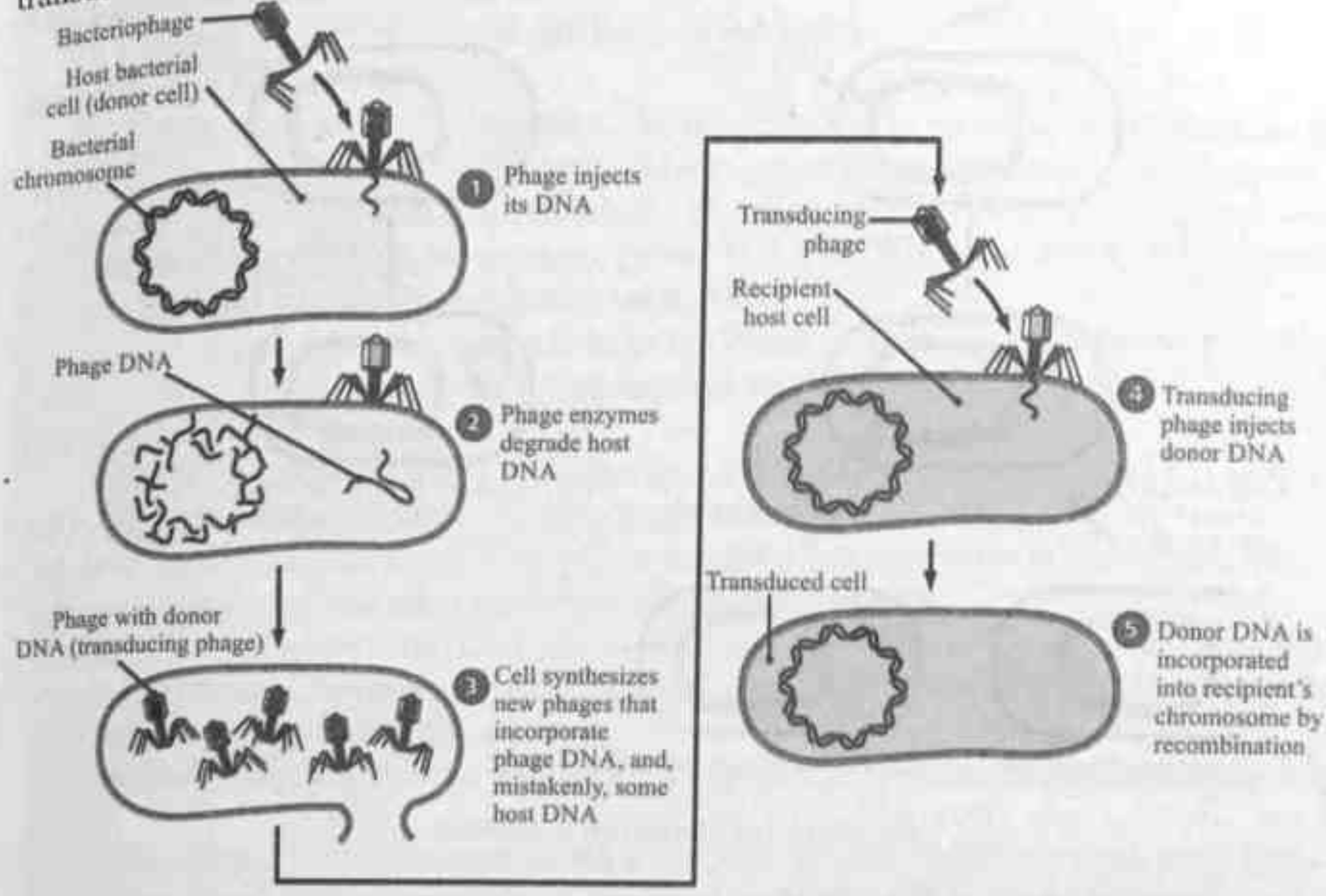


Fig. 6.10 Transduction in Bacteria

Transformation:

It is the absorption of DNA from a solution into a bacterium (cell). These cells are called transformed cells. The fragments of DNA are released after the death of a donor bacterium to its surrounding environment. Now if one of the released DNA fragment contacts a species of bacterium that is capable of transformation. The DNA fragment may be bound to recipient and is taken inside.

Griffith (1928) proved the process of transformation while experimenting on *Pneumococcus*, the bacteria which causes pneumonia.

Receptivity for transmission is present for a brief period when the cell have reached the end period of active growth. At this time they develop specific receptor site in the wall. Normally *E. coli* does not pickup foreign DNA but it can do so in the presence of calcium chloride.

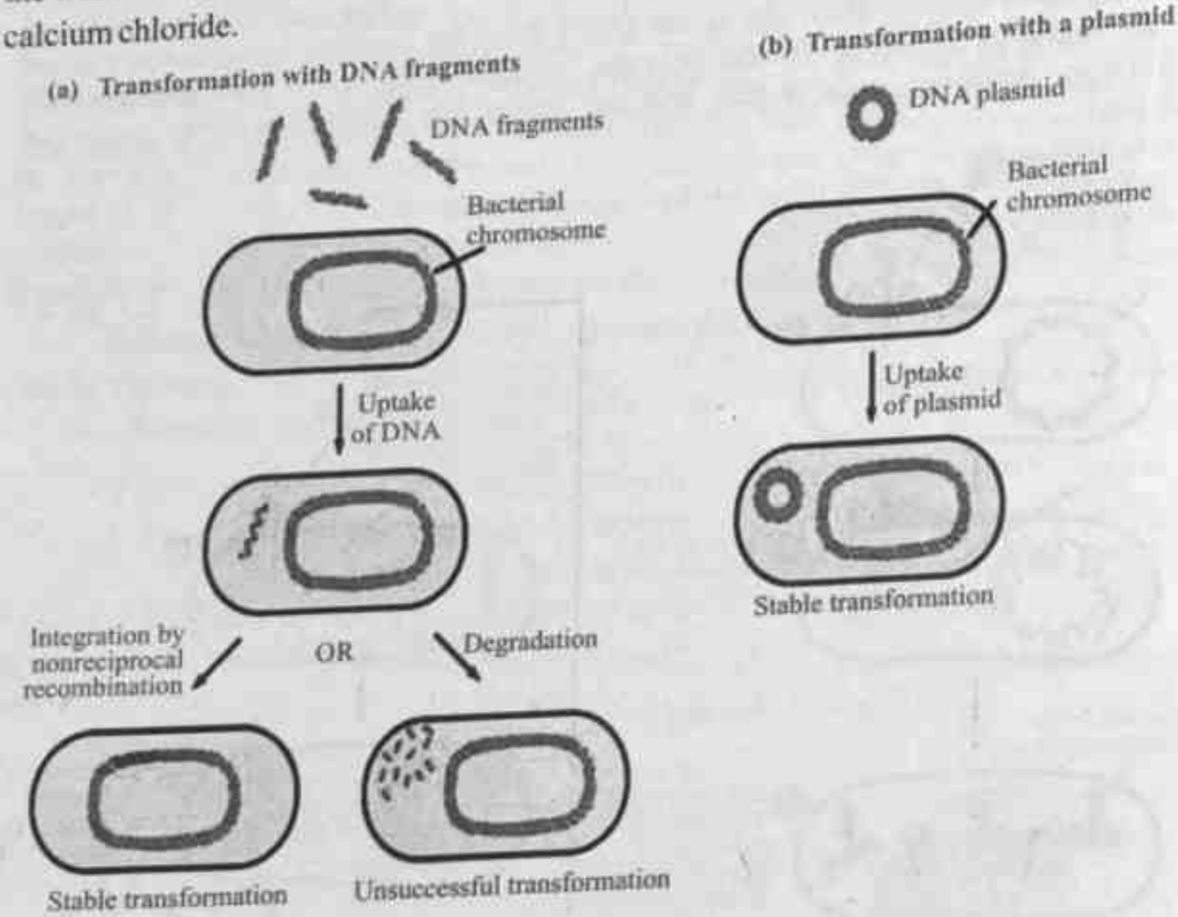


Fig. 6.11 Transformation in Bacteria

6.7 Importance of Bacteria

- Bacteria live everywhere because they have ability to survive in all conditions.
- They can adjust themselves according to environment, thus exhibit great ecological and economic importance, they are useful as **recyclers** of nature.
- Many bacteria involve in the steps of **nutrient cycles** e.g., carbon cycle are controlled by bacteria because of decomposition of remains of dead organisms. Denitrifying bacteria play role in denitrification .
- The genus *Rhizobium,* live in root nodules of legume plants converts nitrogen gas into nitrates.
- If bacteria were not present in universe, the CO_2 from the atmosphere would have diminished. Thus there would have been no photosynthesis and no possibility of life on earth.

6.7.1 Ecological Importance of Bacteria

The decomposition of dead organisms and wastes is carried out mostly by bacteria and fungi, which convert organic matter into humus. It contains nutrients and increases soil fertility for the growth of plants. Humus also retains water, thus increases water holding capacity of the soil. The **leguminous plants** have mutualistic association with the bacteria (Root nodules) which transform nitrogen into nitrates.

Economic Importance of Bacteria:

Bacteria are both beneficial and harmful to human.

Beneficial or Useful Bacteria:

Bioremediation and Decomposers: Bioremediation is removal of environmental pollutants by using living organisms. Most bacteria act as decomposing agents, decompose dead organisms and the wastes of animals to be reused by the plants and animals. Bacteria decompose sewage, garbage, dungs, stool and during this process produce methane gas or biogas, which is used as fuel.

Digestion: Some intestinal bacteria help to divide fats into small droplets in cattle, others produce cellulase, (in the gut of termites and cattle) which digest cellulose and starch.

Synthesis of Vitamins: Many intestinal bacteria produce vitamins, B and K. Bacteria are cultured to produce vitamin B_{12} on commercial scale.

Bacteria and Biogeochemical Cycles: Bacteria help in cycles of carbon, nitrogen, sulphur, phosphorus and other nutrients through the biosphere.

Bacteria in industry: Bacteria are used in the synthesis of vinegar (acetic acid), acetone, lactic acid, butanol (alcohol), several vitamins and flavoring tobacco. They are also used in leather and coffee industries.

In food industry: Used in the production of dairy products such as yogurt, cheese and butter.

Bacteria as Food: Provide most amino acids and vitamins to animals when enter in the alimentary canal through partially digested plant materials. A **single cell protein** is obtained from the large scale growth of microorganisms such as bacteria.

Antibiotics: Several antibiotics are obtained from actinomycetes group, e.g., streptomycin, teramycin and aureomycin.

Genetics: Bacteria are used for studying the principles of genetics, such as *E. coli*.

Harmful Bacteria:

Bacterial Diseases in Plants: Parasitic bacteria infect plants and cause various diseases, e.g., fire blight in apple and pear, ring disease in potato and crown galls.

Bacterial Diseases in Man: Many human diseases are caused by bacteria; like tuberculosis, diphtheria, tetanus, cholera, leprosy, typhoid fever, meningitis, sore throat, whooping cough etc.

Bacterial Diseases in Animals: Chicken cholera, anthrax, TB etc.

6.7.3 Role of Bacteria in Research and Technology

Nowadays bacteria are greatly used by human beings, for their beneficial role in research and technology. Bacteria play important role in biological research, medicines, mining, production of biodegradable plastic , food processing, sewage treatments etc.

1) Bacteria are used in study of genetics and genetic engineering. These were used in the discovery of DNA as hereditary material, semi conservative replication to produce clone of DNA of different genes of organisms.
2) Bacteria are used in mining industry to extract metal from low grade to high grade, i.e., a bacterium *Thiobacillus ferrooxidans* , help in leaching of rock through the metal sulphides (copper sulphate become soluble in water, i.e., to **2Cu++ and SO_4^{++}).** This bacteria and *Leptospirillum ferrooxidans* also help in leaching of gold and uranium .
3) Antibiotics, vitamins and many enzymes are commercially synthesized by recombinant bacteria. Moreover many dairy products are also synthesized by bacteria.
4) **Biodegradable plastic**, (Poly β hydroxybutyrate) are also produced by **transgenic bacteria.** Thus prevent from pollution because ordinary plastic are not decomposed by microorganisms.
5) Bacteria help in degrading harmful chemicals and pollutants (especially synthetic chemicals).

6.7.4 Bacterial diseases in Human

Several diseases are caused by bacteria. Some of these are as under:

Cholera:

Symptoms: Cholera is the classical example of severe watery diarrhea. Vomiting also occurs in most people.

Causative agent: It is caused by *Vibrio cholerae*. The fecally contaminated water, food, vegetables is the most common source of this disease.

Treatment of cholera: It depends on the rapid replacement of electrolytes, either orally or intravenous. The vaccine is also available.

Prevention: It depends largely on adequate sanitation and the availability of safe, clean, water supplies.

Typhoid fever:

Symptoms: It is generally characterized by diarrhea, abdominal pain, nausea, vomiting, in some cases intestinal rupture, internal bleeding, shock and even death.

Causative agents: It is caused by *Salmonella typhi*, can be contracted by animal sources.

Treatment: Antibiotics can be used. Vaccine is also available, which is 50 to 70% effective.

Prevention: Adequate cooking effectively kills this bacterium.

Pulmonary Tuberculosis:

Symptoms: It is lungs disease in which alveoli burst and replaced by inelastic connective tissues. The patient has cough, fever, pale face and sweating at night. Chest pain, breathlessness and weakness is also felt.

Causative agent: It is caused by bacillus ~~Bacteria known~~ as *Mycobacterium tuberculosis.*

Treatment: Use of antibiotics and vaccination against the bacteria for long time (six to nine months) or DOTS (Directly Observed Treatment Short Course) of only two months duration.

Prevention: It is contagious disease so patient should be kept in isolated environment. Vaccine is available which helps in partial resistance to tuberculosis.

Pneumonia:

Symptoms: The typical symptoms of pneumonia are cough, fever, chest pain and sputum is red brown or rusty color.

Causative agent: It is caused by *Streptococcus pneumonia* which is a Gram-positive diplococcus.

Treatment: Use of antibiotics, e.g., penicillin or erythromycin. Vaccine is also available.

6.7.5 Bacterial diseases in plants

Bacteria cause many diseases in plants; Here we will discuss few of these, e.g., leaf spots, blights, soft rots, wilts and galls.

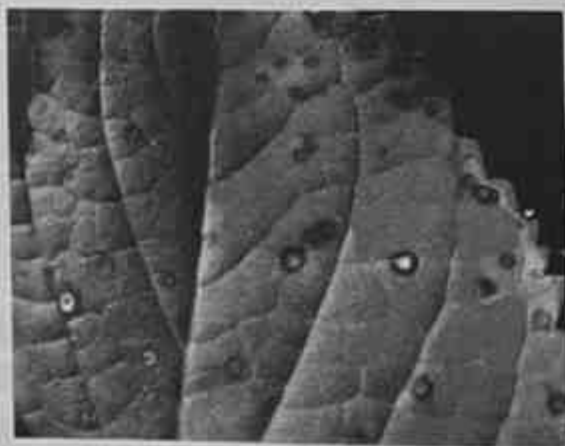


Fig. 6.12 Spots

Leaf spots:

Symptoms: It is most destructive plant disease of rice, tomato, potato, mustard and many other plants. The leaf blades of these plants are infected by bacterial spots, spreading a type of leision which turns brown and dry out.

Causative agent: The causative agent is the bacterium of the genus *Xanthomonas* in tomato and pepper.

Prevention: Avoid working in fields when plants are wet. Pathogens can spread mechanically through working hands and farms machinery, use disease free seeds.

Treatment: Spray the crops with copper fungicides at recommended rate.

Blights:

Symptoms: It is also known as bacterial blossom blight (pear), apical bud necrosis (mango), bacterial canker (stone fruit) and bacterial brown spot (bean). It is mostly termed as blight in maize, rice and oat etc.

Causative agent: Blights are caused by the bacterium *Xanthosomonas oryzae* to rice, *Pseudomonas syringae* and many other species to pear, apple, mango, etc.

Prevention: Use disease free seeds and avoid very susceptible varieties, remove the infected plants.

Fig. 6.13 Blights

Soft Rots:

Symptoms: It is very common disease in vegetables and fruits that can occur in field but more common during their storage and transport. In most plants rot type symptoms appear, their necrotized tissue become wet and soft hence termed soft rot.

Causative agent: *Erwinia* group cause this disease such as *Amylovora* to potato, *Corynebacterium* ear rot to wheat.

Prevention: Discard infected roots and damaged fruit.

Fig. 6.14 Apple Rot

Wilting:

Symptoms: The young leaves may rapidly dry and wilt and decline with severe leaf drop.

Causative agent: *Pseudomonas solanacearum* and some other bacteria.

Prevention: Use disease free seeds, do not plant in poorly drained sites. Ensure proper spacing between the plants.

Fig. 6. 15 Wilting

Activity

Make a list of human bacterial diseases common in our society and their causes. Share your information with your class fellows and friends.

Galls:

Symptoms: bacteria like *Agrobacterium tumefaciens* and *Pseudomonas savastanoi* are responsible for producing galls in plants. Also commonly called crown galls, are local small abnormal out growth on infected plants, thus called

Fig. 6. 16 Gall

galls.

Causative agent: *Rhizobium leguminosarum* causes galls in root nodules in legumes and *Agrobacterium tumefaciens* in root, twigs and branches of many shrubs.

Prevention: Remove galls in infected plants, practice crop rotation, or sterilize the soil using chemical, heat etc.

6.8 The Bacterial flora of human

Flora: It is the plant life occurring in a particular region at a particular time.

The **normal flora** is the population of micro-organisms routinely found growing on the body of healthy persons.

Resident flora: live for extended period in the body of infected person.

Transient flora: temporarily live.

Many microorganisms make up normal flora, which occur in large number. In fact, there are more bacteria in just one person's mouth than there are people in the world.

Table 6.3 Some Members of Normal Bacterial Flora

Members of Normal Flora	Anatomic Location
Clostridium species	Colon
Escherichia coli, Lactobacillus	Colon, vagina, outer urethra
Lactobacillus species	Mouth, colon, vagina, uterus
Staphylococcus aureus, Corynebacterium	Nose, skin, respiratory tract, tongue
Enterococcus faecalis, E. coli	Colon, (Predominantly intestinal bacteria)
Viridans streptococci	Mouth, nasopharynx.

Benefits of normal bacterial flora to Human

(1) Normal flora protects us against potentially harmful microorganisms.

(2) The normal flora also plays an important role in the development of immune responses.

(3) Produces some nutritional substances. Many intestinal bacteria produce vitamin B and K.

6.9 Control of Harmful Bacteria

Microorganisms can be controlled by physical or chemical methods.

Physical methods

Sterilization: This method is useful to kill all life forms, in which physical agents like steam, dry heat, gas filtration and radiations are used. It is the destruction of all life forms. It is used to sterilize surgical instruments. It is also used to preserve milk and meat on large scale.

High temperature: This method is used in microbiological laboratories in which both dry and moist heat are effective. Moist heat helps in coagulation of proteins and kills the microbes. Dry heat causes oxidation of chemical constituents of microbes and kill them.

Radiation: Microbes are killed by electromagnetic radiation below 300 nm. Gamma rays are generally used for this purpose.

Membrane filter: Heat sensitive materials like antibiotics, sera, hormones, growth media, enzymes, vitamins can be sterilized by using membrane filters. In hospitals some operation theaters and burn wards receive filtered air to lower the number of air borne microbes.

Pasteurization: This process was developed by Louis Pasteur to kill non-spore forming bacteria, e.g., milk is pasteurized by heating at $71^{\circ}C$ for 15 seconds and at $62^{\circ}C$ for 32 minutes to destroy Tuberculosis and Typhoid bacteria in milk. Pasteurization does not change the taste of milk.

Low temperature: Low temperature **(10-15°C)** can preserve food for several days, such as milk, egg, meat, cheese and vegetables.

Freezing: Meat and some vegetables can be prevented from microbial destruction by freezing at below **0°C (-10 to -18°C)** for several weeks to several months.

Drying: In this method water is removed from food like meat, milk, vegetables etc, thus bacteria can not grow because their enzymes need water for action.

Preservatives: Many preservatives stop the growth of microbes, e.g., **Acid** lowers the pH, salts and sugar decrease water in food, the reduced water checks the growth of bacteria.

Certain chemicals: Like potassium metabisulphate stops bacterial growth when added in pickles, candies, jams, bread and biscuits.

Chemical methods to control bacteria:

Following chemical methods are used to control microbes.

Antiseptics: There are certain chemical substances (such as iodine, Dettol) that stop the growth of microbes called antiseptics.

Disinfectants: Certain chemicals like halogens and phenols, H_2O_2, potassium permanganate, alcohol and formaldehyde etc., are oxidizing and reducing agents that inhibit the growth of vegetative cells and are used on non-living materials.

Chemotherapeutic agents: Certain chemicals and antibiotics destroy and stop the growth of microbes in cells, e.g., penicillin, tetracycline etc.

6.10 Cyanobacteria

Why cyanobacteria are considered as the most prominent of the photosynthetic bacteria?

Cyanobacteria played major role in the evolution of life. They were the first oxygen producing organisms. Their photosynthetic activity gradually oxygenated the atmosphere and the oceans about two billion years ago. The level of oxygen increased by cyanobacteria, i.e. to about 21%. The amount of **ozone** also increased in the upper layers of the atmosphere by cyanobacteria. Ozone acted as a screen to protect the nucleic acids and proteins from destruction by ultra violet radiations from the sun.

It encouraged other autotrophs to appear and survive on earth. Many of cyanobacteria (about one third) are involved in the **fixation of atmospheric nitrogen** to produce nitrates e.g., Anabaena and Nostoc are purposely cultivated to increase the soil fertility, because of nitrogen fixation ability of these organisms.

Characteristics of Cyanobacteria

Habitat: These are found in damp places, salt water, fresh water, in moist soil, hot springs (with temperature up to 85°C).

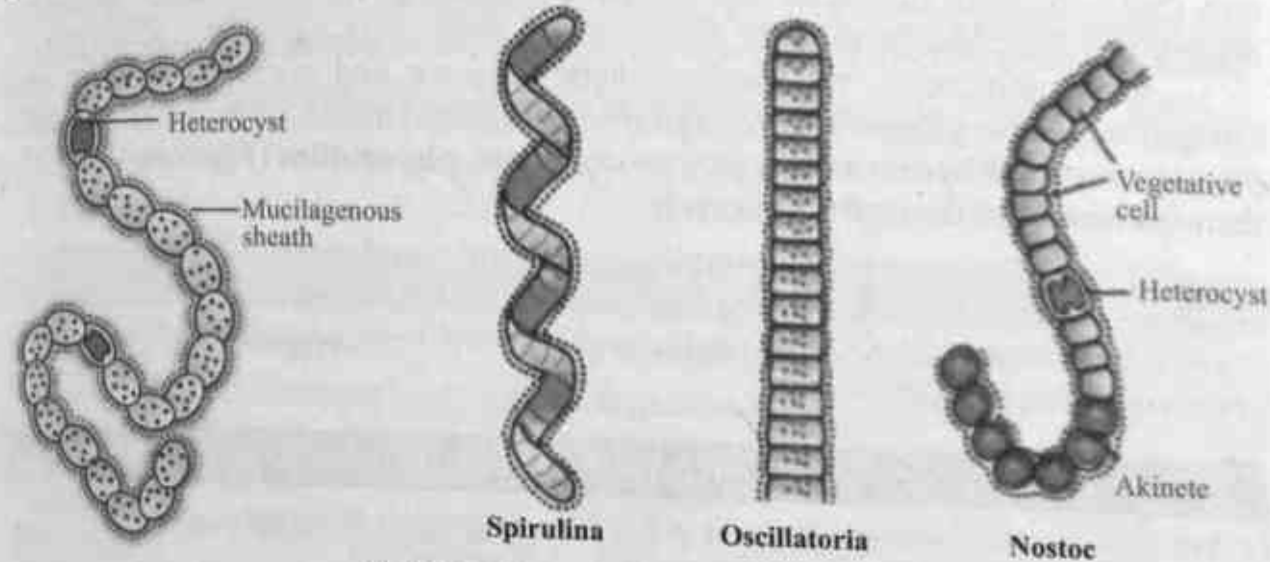


Fig.6.17 Examples of Cyanobacteria

Mode of life: May be epiphytic and symbiotic.

Form of life: May be unicellular and solitary, exist as colonies of many shapes, or form filaments consisting chains of cells (trichomes) surrounded by mucilaginous sheath.

> **Do you know?**
> *Bacterial cell membrane lacks cholesterol.*

Cell wall is Gram negative type (contains lipopolysaccharides, lipoproteins, peptidoglycan).

Photosynthetic System closely resembles to eukaryotes because cyanobacteria have chlorophyll *a* and photosystem II, use water as an electron donor and generate oxygen during photosynthesis. They have phycobilins as accessory pigments. Phycocyanin is their predominant pigment. The photosynthesis takes place in the extensive system of membrane, which is placed in the periphery of the cytoplasm.

6.10.1 Pigment Composition in Cyanobacteria

Cyanobacteria possess two accessory pigments, i.e., phycocyanin (blue pigment) and phycoerythrin (red pigment). In some species the mixture of chlorophyll and blue pigment, produces the blue green color, thus sometime known as blue green algae. But the other species contain red pigments, appear red, purple brown or even black.

6.10.2 Difference between the photosynthetic mechanisms in cyanobacteria and photosynthetic bacteria.

The photosynthetic bacteria release sulphur whereas cyanobacteria release oxygen during photosynthesis. The source of hydrogen in bacteria is hydrogen sulphide whereas cyanobacteria like plants obtain hydrogen from water.

The photosynthetic bacteria have photosystem I but lack photosystem II, thus only cyclic electrons flow is the sole means of generating ATP while cyanobacteria have chlorophyll *a* and photosystem II.

In cyanobacteria, the photosynthetic pigment and electron transport chain components are placed in thylakoid membrane linked with particles called phycobilisomes. **Phycocyanin** is their predominant **phycobilins** (Pigments) and CO_2 in them is assimilated through Calvin cycle.

Activity

Make a list of characteristics of Cyanobacteria and write some advantages of Cyanobacteria with respect to soil fertility.

Critical Thinking

1. Life is not possible without bacteria. Why? Give arguments to support this statement.
2. Why bacteria are widely used in biotechnological processes?

SUMMARY

- Bacteria are the oldest and simplest organisms, but they are metabolically much more diverse than all other life-forms combined.
- Bacteria differ from eukaryotes in many ways, the most important of which is the degree of internal organization within the cell.
- Most bacteria have cell walls that consist of a network of polysaccharide molecules connected by polypeptide cross-links.
- A bacterial cell does not possess specialized compartments or a membrane bounded nucleus, but it may exhibit a nucleoid region where the bacterial DNA is located.
- The two bacterial kingdoms, Archaebacteria and Eubacteria, are made up of prokaryotes, with about 30,000 species have formally been named so far.

- The Archaebacteria differ markedly from Eubacteria and from eukaryotes in their ribosomal sequences and in other respects.
- Mutation and genetic recombination are important sources of variability in bacteria.
- Many bacteria are autotrophic and make major contributions to the world in maintaining carbon balance. Others are heterotrophic and play a key role in ecosystem by breaking down organic compounds.
- Some heterotrophic bacteria cause major diseases in plants and animals.
- Human diseases caused by pathogenic bacteria include many fatal diseases that have had major impacts on human history, including tuberculosis, cholera, plague, and typhus.

EXERCISE

Section I: Objective Questions

Multiple Choice Questions

A. Choose the best correct answer.

1. Which of the following term describes most of the bacteria?
   (a) Anaerobic (c) Many-celled
   (b) Pathogens (d) Beneficial
2. What is the name for spherical-shaped bacteria?
   (a) Bacilli (c) Spirilla
   (b) Cocci (d) Colonies
3. What structure allows bacteria to stick to surfaces?
   (a) Pili (c) Chromosome
   (b) Flagella (d) Cell wall
4. Which of these organisms are recyclers in the environment?
   (a) Producers (c) Saprophytes
   (b) Carnivores (d) Pathogens
5. Which of the following is caused by a pathogenic bacterium?
   (a) AIDS (c) Nitrogen fixation
   (b) Cheese (d) Tetanus
6. Which of the following cannot be found in a bacterial cell?
   (a) Ribosomes (c) Chromosome
   (b) Nucleus (d) Cytoplasm
7. Which organism of the following can grow as blooms in ponds?
   (a) Archaebacteria (c) Cocci
   (b) Cyanobacteria (d) Viruses

8. A bacterium with a tuft of flagella at one side of the body.
(a) Lophotrichous (c) Peritrichous
(b) Amphiptrichous (d) Non of the above

9. Asexual reproduction in bacteria is called.
(a) Budding (c) Multiple fission
(b) Binary fission (d) Both A and B

B. Fill in the blanks.

1. Pili are made of protein called _______.
2. Flagella are made of a protein called _______.
3. The cell wall of bacteria is made of _______.
4. _______ are straight or rod shape bacteria.
5. Bacterium having single flagellum is called as _______.
6. The bacterium that gives the DNA during conjugation is called _______.
7. Typhoid is caused by _______.
8. Tuberculosis is caused by _______.

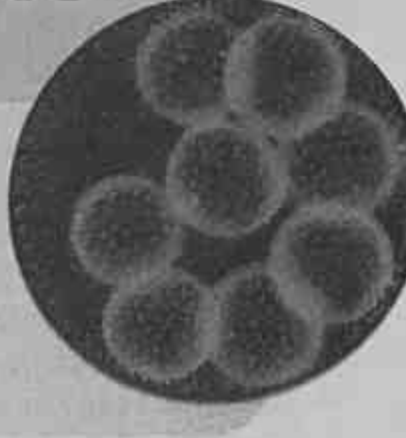
Section II: Short Questions.

1. How chemosynthetic bacteria differ from photosynthetic bacteria.
2. Explain one difference between photosynthesis of bacteria and cynobacteria with the help of equation.
3. Name any three bacteria which cause diseases in plants.
4. Differences between Bacteria and Archaea.
5. Write short note on peptidoglycan and slimy capsule.
6. How Gram positive bacteria differ from Gram negative bacteria.
7. Write harmful and useful effects of bacteria (three for each).
8. Write a brief note on cholera.
9. Describe briefly physical methods of control of bacteria.
10. Differentiate between following terms.
Lytic and lysogenic cycle, lysosome and mesosome, autotrophic and heterotrophic, plasmid and bacterial DNA, spherical and spiral bacteria, lag phase and log phase.

Section III: Extensive Questions.

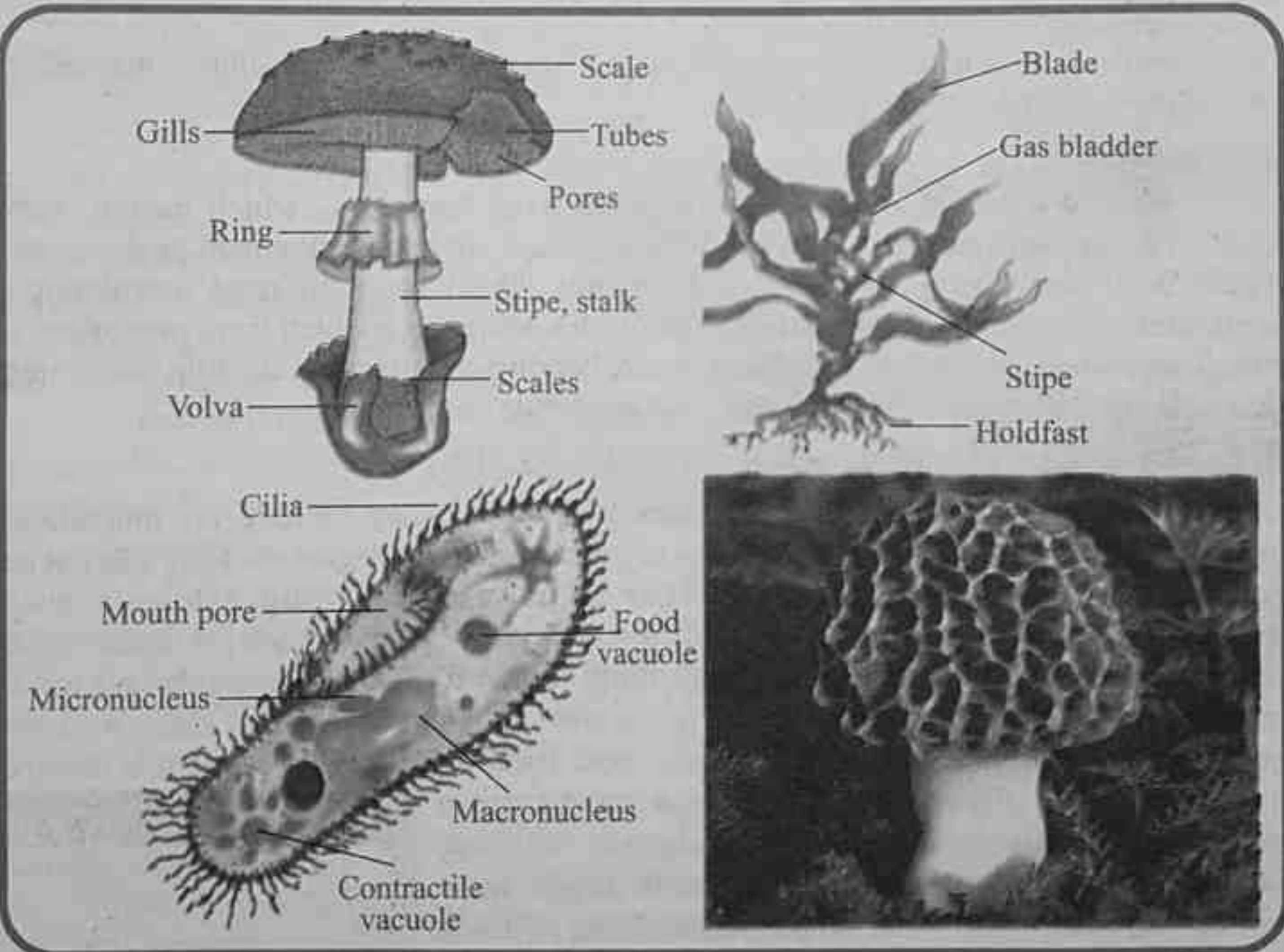
1. What characteristics can be used in naming eubacteria?
2. Most of the dairy products that you buy are pasteurized. What is pasteurization? How is it different from sterilization?
3. Describe mode of nutrition in bacteria.
4. Describe transduction and transformation in bacteria.
5. Write an essay on control of bacteria.

UNIT 7
PROTISTS AND FUNGI



Major Concepts

- 7.1 Protists: The Evolutionary Relationships
- 7.2 Major Groups of Protists
- 7.3 General Characteristics of Fungi
- 7.4 Diversity Among Fungi
- 7.5 Importance of Fungi



Students Learning Outcomes

On completion of this unit students will be able to:

- Explain protists as a diverse group of eukaryotes that have polyphyletic origin and defined only by exclusion from other groups.
- Describe the salient features with examples of protozoa, algae, Myxomycota and oomycota as the major groups of protists.
- Justify how protists are important to humans.
- List the characteristics that distinguish fungi from other groups and give reasons why fungi are classified in a separate kingdom.
- Classify fungi into Zygomycota, Ascomycota and Basidiomycota and give diagnostic features of each group.
- Explain yeast as unicellular fungi that are used for baking and brewing and are also becoming very important for genetic research.
- Name a few fungi from which antibiotics are obtained.
- Explain the mutualism established in mycorrhiza and lichen associations.
- Give examples of edible fungi.
- Describe the ecological impact of fungi causing decomposition and recycling of materials.
- Explain the pathogenic role of fungi.

Introduction

The word protist is derived from Greek word "*protistos*" which means "very first". **The protists are very first eukaryotes,** much more complex than prokaryotes. There is a vast variety of aquatic **eukaryotes** which have different morphology, reproductive system, types of nutrition, life styles and have evolved from prokaryotes. Fungi are non-motile, **achlorophyllous** , spore bearing organisms with chitin containing cell wall, live either parasitic, saprophytic or symbiotic mode of life.

7.1 Protists: The Evolutionary Relationship

Protists were very first eukaryotes to evolve. They include all unicellular eukaryotes and some simple multicellular organisms of diverse groups. They can not be considered as fungi, animals or plants. They are **polyphyletic group,** belong to many tribes. They exhibit similarities and differences with plants (such as autotrophic unicellular and multicellular algae), with fungi (heterotrophic slime molds and water molds) and heterotrophic animals like (protozoans). Thus they do not share a single common ancestor. Margulis and Schwartz have listed 27 phyla, to place this diverse assemblage of organisms. Their size varies from microscopic protozoans and unicellular algae to very large brown algae 'Kelps' more than 60 meters in length. Most protists are unicellular, some simple multicellular (without specialized tissues) and few are colonial (i.e., loose aggregation of cells). Some protists are **coenocytes** that is multinucleated cell but not multicellular.

Symbiosis

A mutually beneficial partnership between two different organisms (species) of different kinds, especially where one lives in or on another organism.

How do protists get their nutrients?

Some protists are plant-like **autotrophic** (photosynthetic algae), some are **ingestive heterotrophs** like animals (protozoans and slime molds) and some are fungi-like **absorptive heterotrophs** (water molds).

Different modes of life:

Some protists are **free living** (Amoeba, Paramecium), many are symbiotic either **mutualist** (Trichonympha and Colonympha) or parasitic (*Plasmodium*). Most are aquatic (either fresh water or marine algae). They also make up a part of the **plankton,** (can not resist water current, i.e., floating) none of these are **nekton** (which can resist water current, i.e, can swim against water current).

How do protists reproduce?

All protists exhibit asexual reproduction, many also reproduce sexually (exhibit **meiosis and syngamy**, i.e., the fusion of gametes). Most don't contain multicellular sex organs. There is no embryo or blastula stages in protists.

Types of locomotion:

Few are sessile while most are motile at some stage of their life, locomote either by **pseudopodia** (*Amoeba*) or **flagella** (Euglena) or **cilia** (*Paramecium*). Some have two or more means of locomotion (i.e. both flagella and pseudopodia).

Many protists (especially algae) are palatable thus they are most abundant source of food for animals and human.

Evolution of Protists:

All protists have evolved from prokaryotes (Monera) while fungi, plants and animals have evolved from protists. Some protists like euglena and slime mold exhibit characters of plants, animals and fungi.

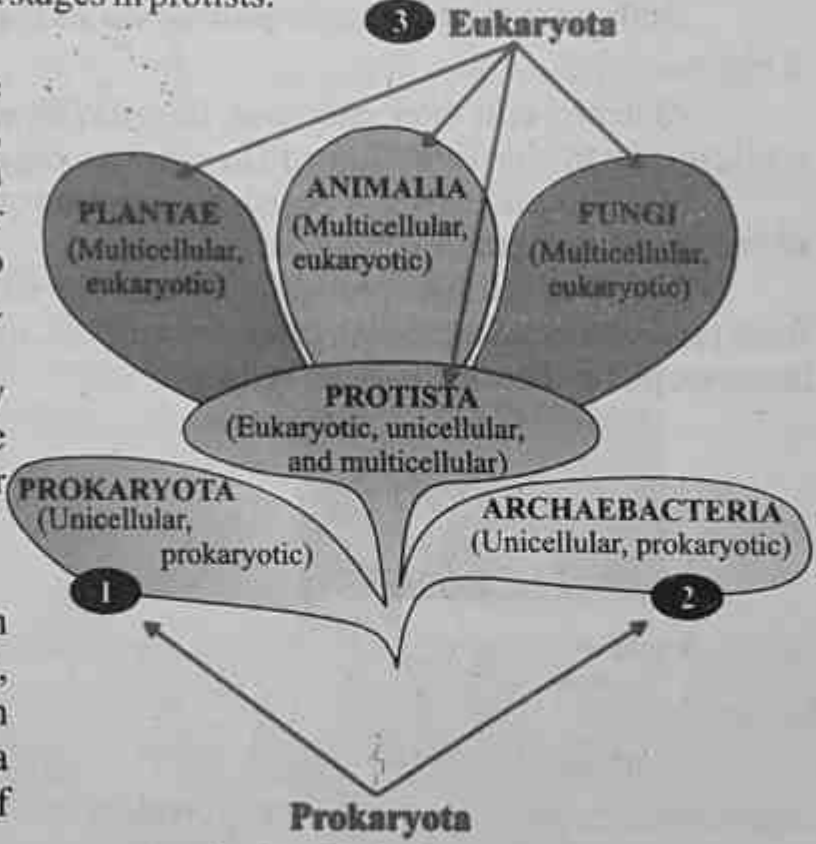


Fig. 7.1 Evolutionary Tree

7.2 Major Groups of Protists

The Protists are placed into following major groups **protozoans, algae, myxomycota** and **oomycota.** The salient features of these groups are given below.

> **Tit bits**
> *The term protozoa was introduced in 1818 by Germen Zoologist George August Goldfuss.*

7.2.1 Protozoa: The Animal-like protists

Protozoans are animal-like unicellular protists which ingest food and have no cell wall. The word protozoan is derived from two Latin words "*Proto*" means first "*Zoan*" means animal.

They are polyphyletic group with following salient features.

Habitat: Mostly aquatic (either fresh water or marine such as actinopods, foraminifera). Many are parasitic, e.g., *Trypanosoma, Plasmodium, Entamoeba* etc. Their **body** is single mass of protoplasm with almost all cellular structures of a typical cell, within which it performs all features of life such as nutrition, locomotion, reproduction, respiration, excretion, homeostasis etc.

Entamoeba histolytica

Intestinal parasite causes amoebic dysentery in human while Naegleria brain eating parasite causes meningoencephalitis, inhabit in warm fresh water.

The **vacuoles** in protozoans are either for ingestion, digestion and egestion (such as food vacuole) or in fresh water species **contractile vacuole** for excretion (removal of water and nitrogenous wastes).

Reproduction:

Both asexual and sexual reproduction takes place in protists.

Locomotion:

Either by cilia (*Paramecium*), flagella (*Trypanosoma*), or pseudopodia (*Amoeba*) while most parasitic forms have no locomotary organelles (*Plasmodium*).

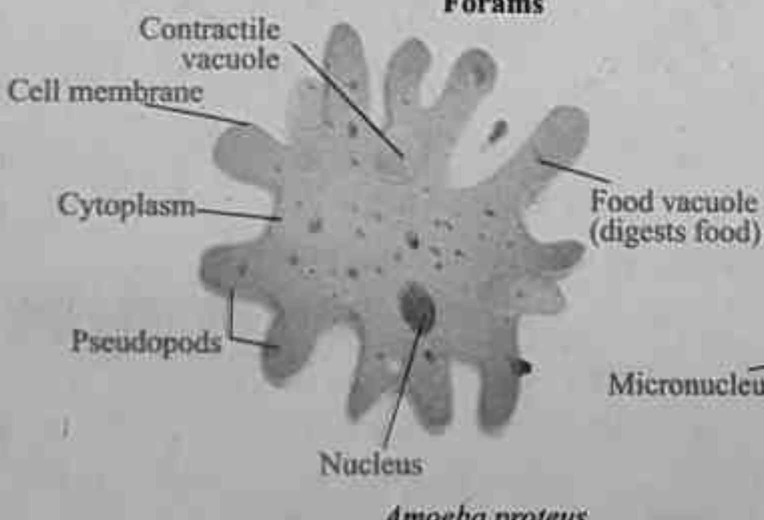
Many protozoans can **regenerate** and form **cyst** to overcome unfavourable conditions.

It is believed that probably animals have evolved from protozoans because both groups are motile, ingestive heterotrophs and do not possess cell wall.

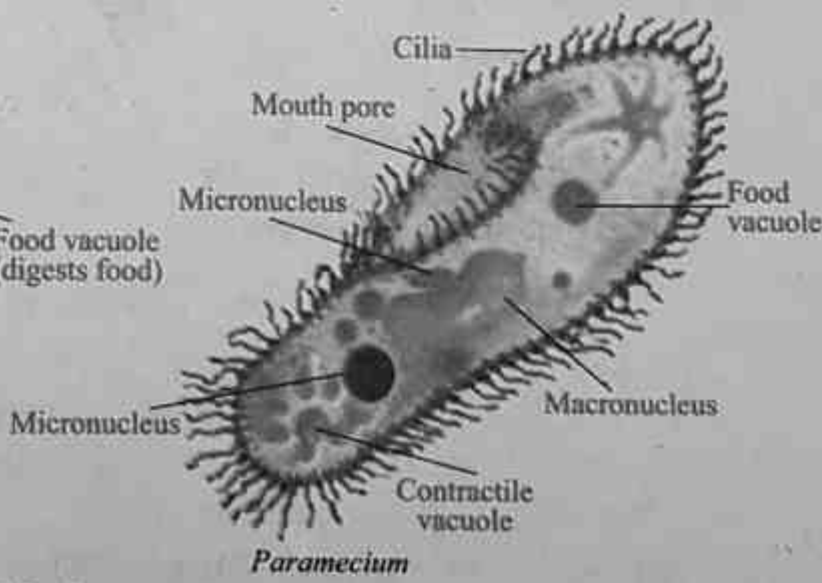
Tit bits

The shell of fossils of foraminifera, together with red algae and corals created vast lime stone in the ocean.

Forams



Amoeba proteus



Paramecium

Fig. 7.2 Some protozoans

Common groups of protozoans:

> **Thallus**
> *A plant or plant like body with no distinction between root, stem or leaves, and no vascular tissues, e.g., algae, fungi and bryophytes.*

1. **Amoebas** are mostly free living, locomote and feed with the help of pseudopodia, possess many food vacuoles and contractile vacuoles. e.g., *Amoeba proteus, Entamoeba histolytica and Naegleria fowleri.*

2. **Zooflagellates** (flagellum: whip) locomote by flagella, their body is covered with a proteinous pellicle, e.g. ***Trichonympha***, a complex mutualist flagellate, live in the gut of termites and other wood or cellulose eating insects, help in digestion of wood, it contains bacterium that produces cellulase.

   Trypanosoma, human flagellated parasite, causes a disease known as sleeping sickness. **Choanoflagellates;** (choano; collar) sessile stalk flagellate found both in marine and fresh water. Their flagellum is surrounded by delicate collar (like choanocyte cells in sponges).

3. **Ciliates** (cilium; eyelashes) are completely or partially surrounded by hair-like extensions known as cilia, e.g., *Paramecium.*

4. **Foraminifera** and **Actinopods** are marine protozoans, foraminifera (foramin; pore; ferrous: bearing) produce calcareous and porous shell, e.g., *Forams* while actinopods (actines: rays; podus: legs) produce siliceous shell.

5. **Apicomplexans** are a large group of parasitic protozoa. They are mostly pathogenic e.g., *Plasmodium* causes malaria, they are called apicomplexan because of unique arrangement of fibrils, microtubules, vacuoles and other cell organelles at one end of the cells. They have no locomotary organs and they move by flexing. They need two hosts to complete their life cycle.

7.2.2 Algae: The Plant-like Protists

Algae are mostly aquatic found in marine and fresh water ponds, lakes, moist soil, streams, hot springs, polar ice, moist rocks and trees. Their plant body may be unicellular or multicellular, some are filamentous. The filaments are either unicellular or multicellular.The multinucleated filaments lack cross walls (i.e. coenocytic) or distinct cells. Many multicellular algae possess leaf-like or branched body called thallus. The chlorophyll *a*, carotenoids, xanthophylls and phycoerythrin are their photosynthetic pigments. The life cycle of algae is extremely varied, many have isomorphic alternation of generation. All algae except red algae exhibit flagella in some stage of their life cycle.

How do algae differ from plants?

Their sex organs are mostly unicellular. There is no embryo formation in algae and having simple unorganized body.

Major groups of algae:

1. **Euglenoids** are unicellular fresh water organisms. Their body is covered by proteinous pellicle e.g., *Euglena*.
2. **Dinoflagellates** are also unicellular, vary in colour from yellow, green to brown.

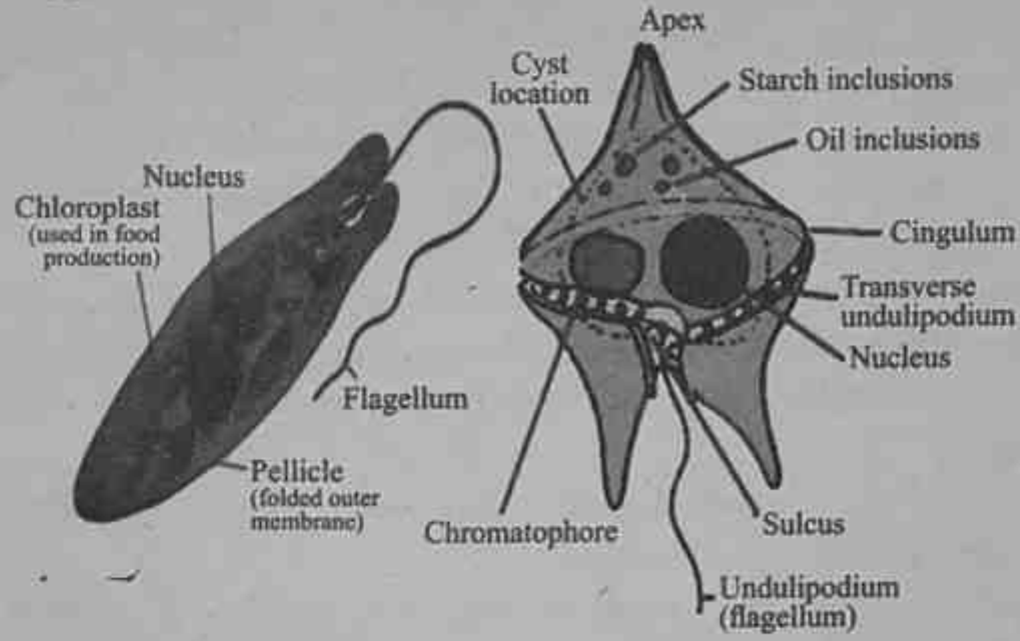


Fig. 7.3 Euglena and Dinoflagellate

3. **Diatoms**: Usually unicellular, found in fresh water and marine, and are most numerous algae found in oceans. They are called pastures of sea because they are important source of food in marine food webs. The body shape is like a box, because cell wall possess two halves, the larger half acts as lid for smaller half.
4. **Brown algae:** Multicellular plant-like algae live in colder marine water. They are largest of all algae, range from small form with simple filaments to giant "kelps" (upto 75 meters in length).

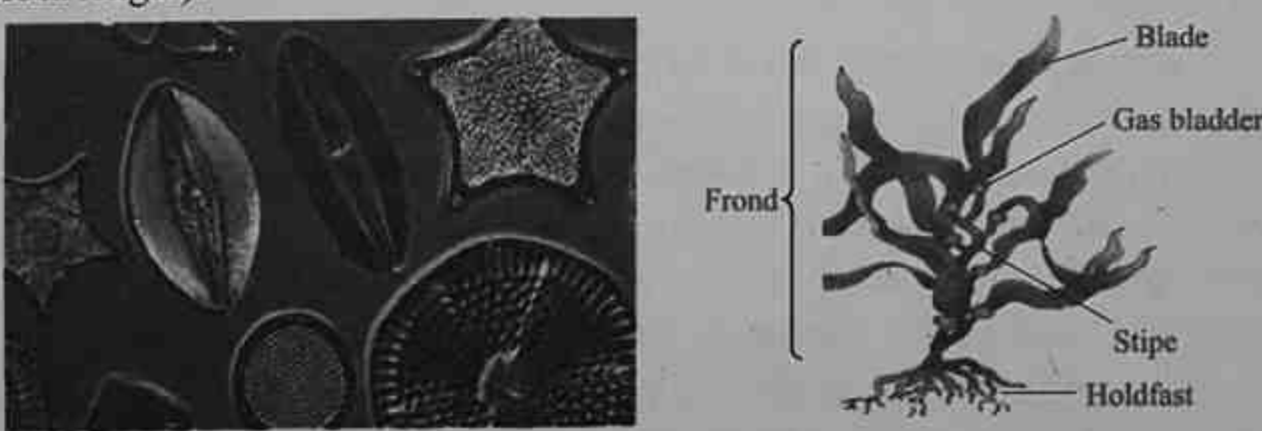


Fig. 7.4 Diatoms and Kelp

5. **Red algae:** Mostly multicellular some unicellular prefer warm sea water. In size they may be up to one meter long and attached to the rock or other submerged objects by a root-like basal hold fast.

6. **Green algae:** May be unicellular (such as *Chlorella and chlamydomonas*), Colonial (*Volvox*) or multicellular and filamentous (*Spirogyra* and *Ulva*). Mostly marine, some fresh water and few terrestrial. Mostly green, some may be orange, red or rust colour.

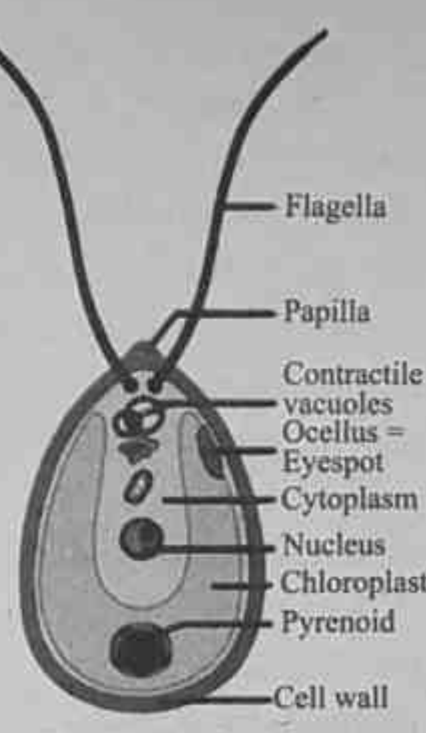


Fig. 7.5 Chlamydomonas

7.2.3 Fungi-like protists: Myxomycota and Oomycota

Myxomycota: Slime Molds:

The slime molds take many forms, during their life cycle and resemble other types of protists. They have mobile amoeba like feeding stage and stationary filamentous, saprotrophic fungi like reproductive stage produces spores. The acellular slime mold consists of a mass of cytoplasm *(Plasmodium)* containing thousands of diploid nuclei that is multinucleated and covered by slime sheath. Therefore, also called plasmodial slime mold. Sporangia are their reproductive structures which during unfavourable conditions produce spores by meiosis. In plasmodial slime mold, spores release a haploid flagellated cell or an amoeboid cell. Eventually two cells fuse to form a diploid zygote that feeds and grows, producing a multinucleated *Plasmodium* once again by mitosis. Slime molds differ from fungi due to the presence of motile stage in their life cycle e.g., *Physarum polycephalum* is an example of plasmodial slime molds.

Tit bits

Hyphae are filamentous thread like structures in fungi, which give the mycelium quite a large surface area per volume of cytoplasm. This facilitates absorption of nutrients.

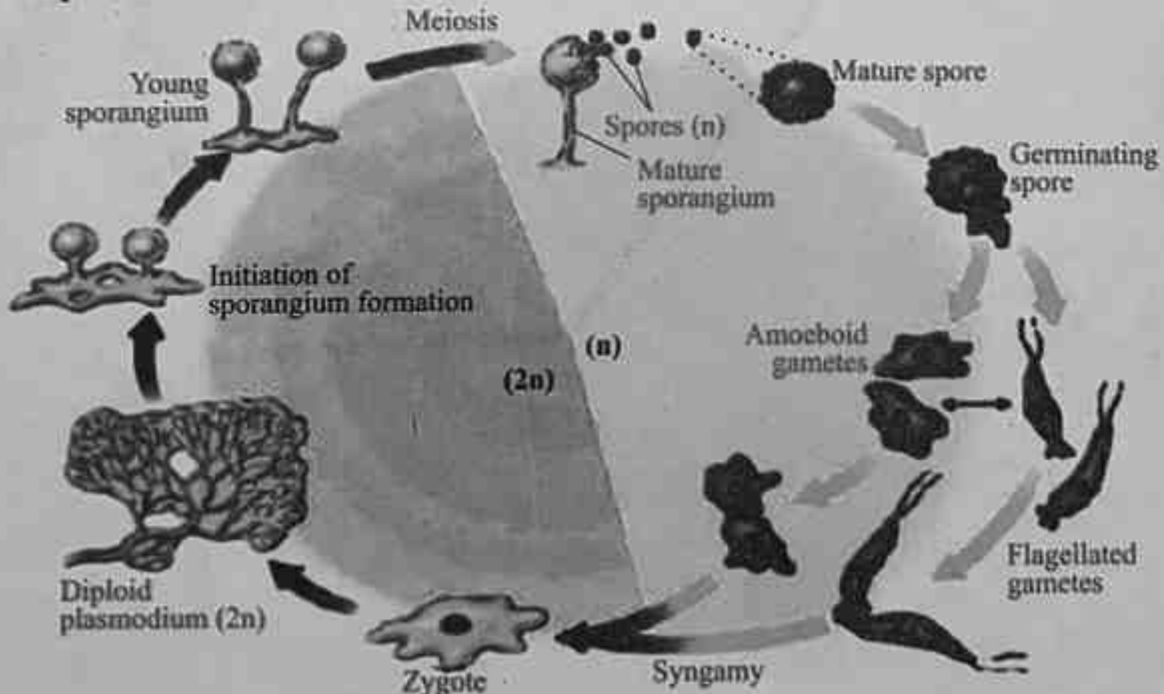


Fig. 7.6 Life cycle of Myxomycete (Plasmodial slime mold)

Oomycota: (The water molds):

Oomycetes are either parasites or saprotrophs which feed on humus. Their cell wall unlike fungi **contains cellulose** instead of chitin while like fungi possess filamentous structure called **hyphae**. The hyphae are **aseptate (coenocyte)** that is without intercellular septum or cell wall between nuclei. They asexually produce zoospores in their sporangium, which are biflagellates and motile. All oomycotes also exhibit sexual reproduction. There are two types of gametangia. The female gametangia is called **oogonium** while male gametangia is called an **antheridium**. The gametangia produce gametes by meiosis, thus show gametic meiosis. The male gametes flow from antheridium to oogonium lead to the fusion of one or more pairs of male nuclei with eggs to form zygotes (resulting in a diploid phase). The zygotes soon covered by a thick cell wall known as oospores. Due to this special kind of thick cell wall on **oospores** their phylum is named oomycota, e.g., water molds, white rust and downy mildews.

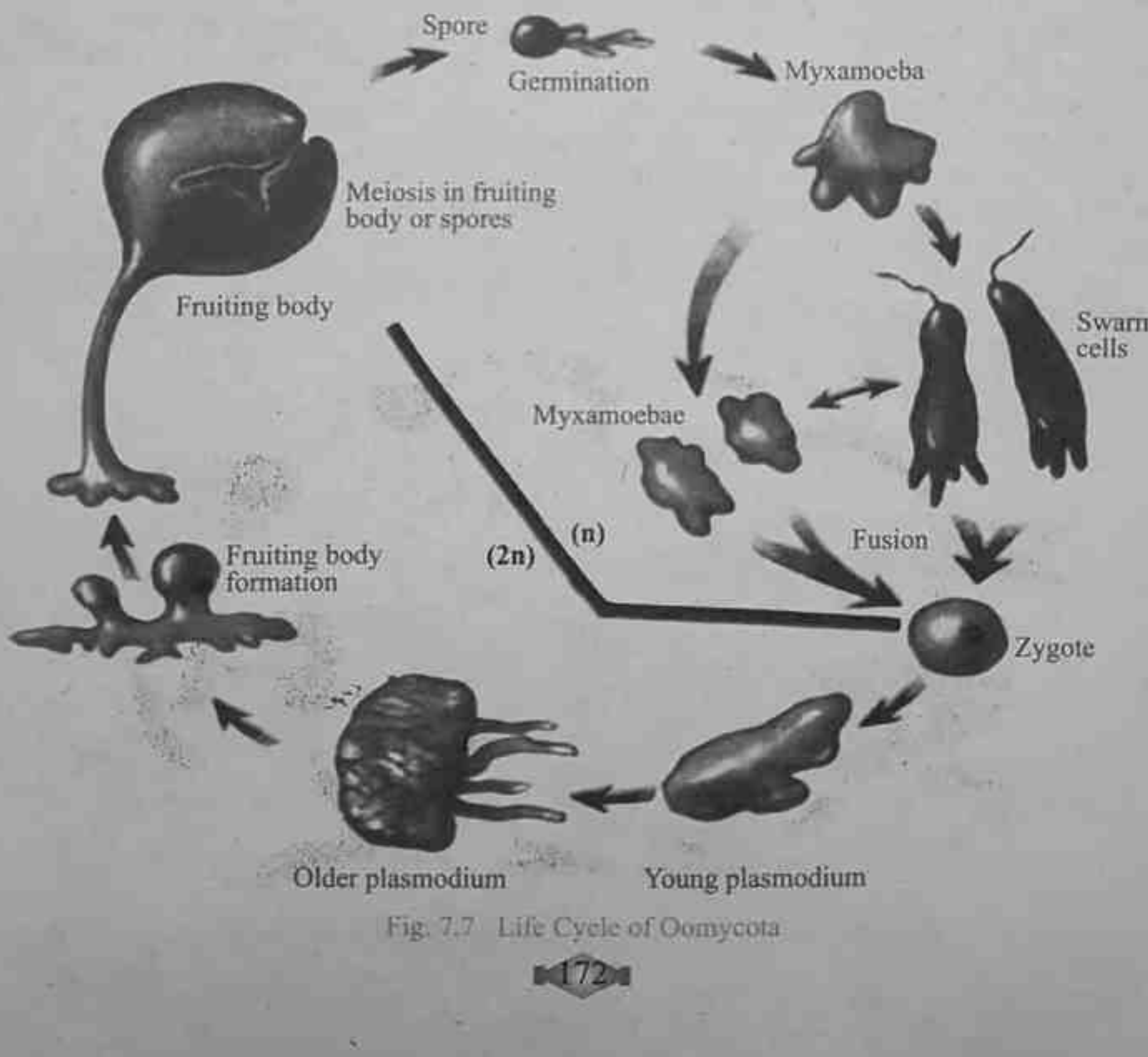


Fig. 7.7 Life Cycle of Oomycota

7.2.4 Importance of Protists to Humans

Protists are both useful and harmful to human.

Useful protists:

Dinoflagellates: They are great source of food for small marine and fresh water animals which are used as **palatable** food by humans.

Diatoms are also **source of oxygen** for aquatic animals. Brown algae is used as food and **fertilizer** in many countries, from it we also get **vitamin A,C,D and E.**

Red algae is used as source of **agar (algine)** which is produced from the mucilaginous cell wall. Agar is used to make capsules for vitamins and drugs, dental impressions, base for cosmetics and also used in laboratory as culture media for bacterial growth.

> **Do you know?**
>
> *Decomposers are mostly microbial heterotrophs that return constituents of organic substances to ecological cycles by feeding on and breaking down dead organisms and excreta.*

Antiseptic role: Algae is used in medicines, *Chlorella* is used for the synthesis of antibiotics, its agar is also used for stomach diseases. *Chlorella* has been used as an experimental organism in research for photosynthesis.

Green algae are important producers and is used as experimental organisms for photosynthesis in research laboratories (Such as *Chlorella*).

Algae are used as new food source; **single cell protein (SCP)** is derived from algae. *Chlorella* is sold as "health food" especially in Taiwan and Japan. Protists are used for **study of genetics** and other physiological processes.

In aquatic ecosystems **zooplanktons** (protozoans) feed on **phytoplanktons** are the most important primary consumers in a food chain.

Harmful effects of protists:

In some places protists act as **pollutants.** Sometimes they become the reason of closing of pipes. *Phytophthora* causes late **blight disease** in potatoes. Many protozoans cause diseases in human beings, such as **malaria** is caused by *Plasmodium*. According to World Health Organization about one to two million people die each year from this infectious disease. *Entamoeba histolytica* causes amoebic dysentery while ***Trypanosoma*** causes African **sleeping sickness.** Many protozoans also cause diarrhea. ***Acanthamoeba,*** a protozoan causes eye infections in contact lense users.

> **Tit bits**
>
> *Phytophthora infestans is an oomycote which is a plant pathogen. It causes late blight disease of potatoes. Plants show individual leaflets, with small brown dead and blighted areas.*

7.3 Kingdom Fungi

Fungi are eukaryotic spore-bearing **thallophytes** which lack chlorophyll. They are either saprotrophic or parasitic and possess **chitinous** cell wall. They live both in dark and light environment. The study of fungi is called

> **Tit bits**
>
> ***Dikaryotic or heterokaryotic*** *is a condition when two different haploid (+ and –) nuclei are present per cell, such as in Ascomycota and Basidiomycota.*

mycology and the person who studies fungi is called **mycologist**.

7.3.1 General characteristics of fungi

Fungi have wide range of habitat, may be aquatic or terrestrial, many are parasites of plants and animals. Fungi range in size from microscopic (such as yeast) to very large up to two meters (such as toadstool).

> **Do you know?**
> *In meiosis: diploid (2n) cell is reduced into four haploid (n) daughter cells while in mitosis (2n) diploid parent cell divides into two diploid (2n) daughter cells.*

Modes of life in fungi:

They live as saprotrophs, parasites or mutualists, few are predatory.

Fungi morphologically differ from other organisms:

Their plant body is **thallus** which is mostly multicellular structure known as mycelium (Gk. Filaments). **The mycelium** is an interwoven mass of thread-like filaments called **hyphae** (Gk. Web). There are two types of **hyphae, Non septate or aseptate** (coenocytic hyphae) are made of one cell with many nuclei that is no cross wall or septum between nuclei, e.g *Rhizopus*. **Septate hyphae** are made up of many cells separated by porous partition called septum, e.g., in *Penicillium*.

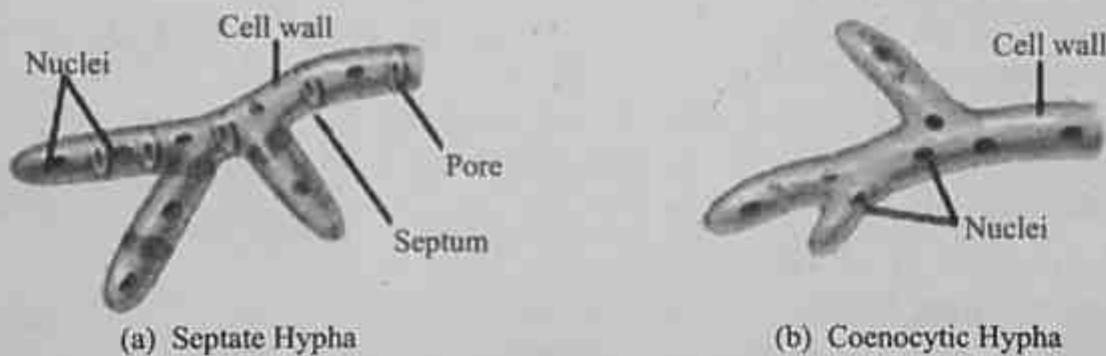


Fig. 7.8 Septate and Aseptate hyphae

Their **cell wall contains chitin**, which has high tensile strength and prevents osmotic bursting of cells. It has also more resistance to decay than cellulose and lignin (found in plants cell wall).

All fungi being **nutritionally absorptive heterotrophs,** digest organic food outside the body then absorb the digested food to body cells. Many are **decomposers.** They store carbohydrates in the form of glycogen. Fungi are non motile in all stages of their life i.e., lack flagella, move towards a food source by growing towards it. **Flagella** are also absent both in fungi and in red algae, thus most mycologists believe that fungi probably evolved from red algae. A fungus reproduces both asexually and sexually.

> **Tit bits**
> *Karyogamy is the fusion of nucleus while plasmogamy is fusion of cytoplasm. In some fungi karyogamy does not take place immediately after plasmogamy, e.g., Basidiomycota.*

Taxonomic status of fungi as a separate kingdom:

Fungi differ both from plants and animals in many characters.

Differences from plants: Fungi lack chlorophyll, they are absorptive heterotrophs rather than autotrophs, cell wall contains chitin instead of cellulose, glycogen is formed as stored form of carbohydrates instead of starch (in plants).

Fungi differ from animals having cell wall, absorptive heterotrophs rather than ingestive heterotrophs, non-motile, produce spores, no centrioles. Unlike plants and animals fungi show **"nuclear mitosis".**

Tit bits

In nuclear mitosis, nuclear membrane remains and mitotic spindles form within nucleus then nuclear membrane pinches between the two clusters of daughter chromosome. In some fungi it dismantles later.

Thus fungi are distinct from all other eukaryotes, therefore, they are placed in a separate kingdom that is kingdom fungi.

Diversity among Fungi:

The kingdom fungi contains more than 100,000 known species. Most of which are terrestrial, few are aquatic. Fungi are mostly multicellular, some are unicellular, varied in structure.

7.4 Classification of fungi

Classification of fungi is based on types of reproduction (either sexual or asexual), and types of hyphae. They are classified into three major groups i.e., Zygomycota, Ascomycota and Basidiomycota.

Activity

Make a list of common fungal diseases and their causes in our country by searching internet sources. Also share your knowledge with your class fellows.

Table 7.1 Phyla (Groups) of Fungi

Phylum	Common Names	Familiar Species	Number of species
Zygomycota	bread molds zygomycetes	*Mucor, Rhizopus, Pilobolus*	2,000
Ascomycota	sac fungi, truffles, morels, blue- green molds, powdery mildew, chestnut blight	*Penicillium, Saccharomyces, Morchella, Claviceps, Aspergillus*	32,000
Basidiomycota	basidiomycetes, mushrooms, rusts, smuts, puffballs, bracket fungi	*Agaricus, Puccinia, Ustilago, Polyporus, Boletus, Amanita*	22,300

7.4.1 Zygomycota (Conjugating Fungi)

Phylum Zygomycota includes fungi in which diploid zygospores are formed examples; ***Rhizopus*** (black bread mold) and ***Mucor.*** These are saprobs generally grow on remains of plants, bakery products, fruits and vegetables, some are parasites of land protists. Their hyphae are aseptate, possess branching mycelium. The hyphae are of three types, rhizoid hyphae, stolon hyphae and sporangiophore hyphae.

> **Do you know?**
> *Yeast is used to synthesize vitamin B complex on commercial scale. It is also utilized in medicine as a source of enzymes.*

Asexual reproduction: It takes place by conidia or spores.

Sexual reproduction:

In zygomycetes it takes place by conjugation. The haploid (n) cells from hyphae of different mating types fuse sexually to produce zygote, which develops into zygospore. The plus (+) and minus (-) strains hyphae produce hormones that stimulate the tip of hyphae to come together forming gametes producing structure called gametangia. The plus and minus nuclei fuse to form a diploid nucleus that is zygote. The zygote develops into a **zygospore.** The zygospore is thick walled and resistant to unfavourable conditions.

> **Tit bits**
> *Lichens act as original colonizers of new terrestrial environment.*

Germination:

At the return of favourable conditions, zygospore divides by meiosis. The wall of zygospore splits and hyphae grows upward. The tip of the hyphae develops into a sporangium which have many nuclei. The wall of the sporangium bursts and the spores are released. Each spore grows into new plus and minus strain of mycelium.

"Due to presence of conjugation and zygospore formation, they are called **conjugating Fungi or Zygomycota".**

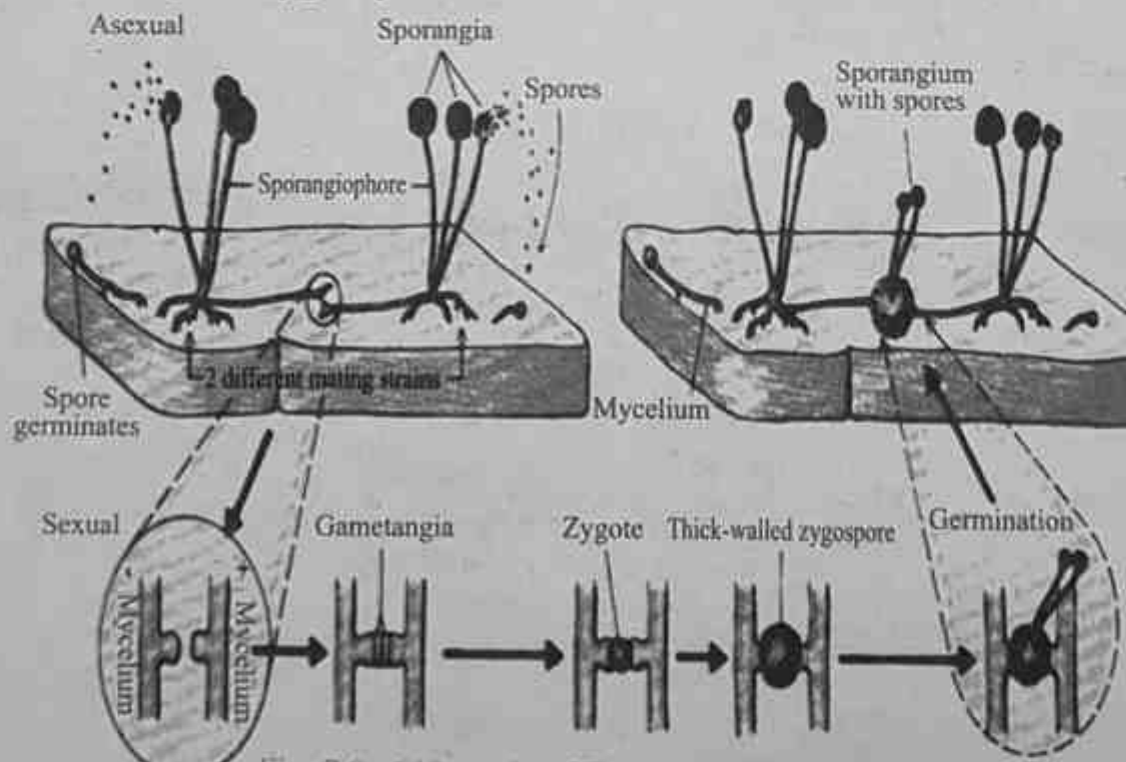


Fig. 7.9 Life cycle of Zygomycota (Rhizopus)

7.4.2 Ascomycota (Sac Fungi)

> **Do you know?**
> *Now most mycologists think that lichen is not a mutualist association rather than a control parasitism of algal cells by the fungus.*

The name Ascomycota or Sac fungi is given because their spores are produced within sacs called asci (ascus means sac).

Ascomycota is the **largest group** of fungi, containing about 30,000 species. Some examples are morels, truffles, yeasts and neurospora. Their hyphae are usually septate. The septa are porous so that cytoplasm can move between compartments. The sac fungi may be unicellular (Yeast) or multicellular (Truffles).

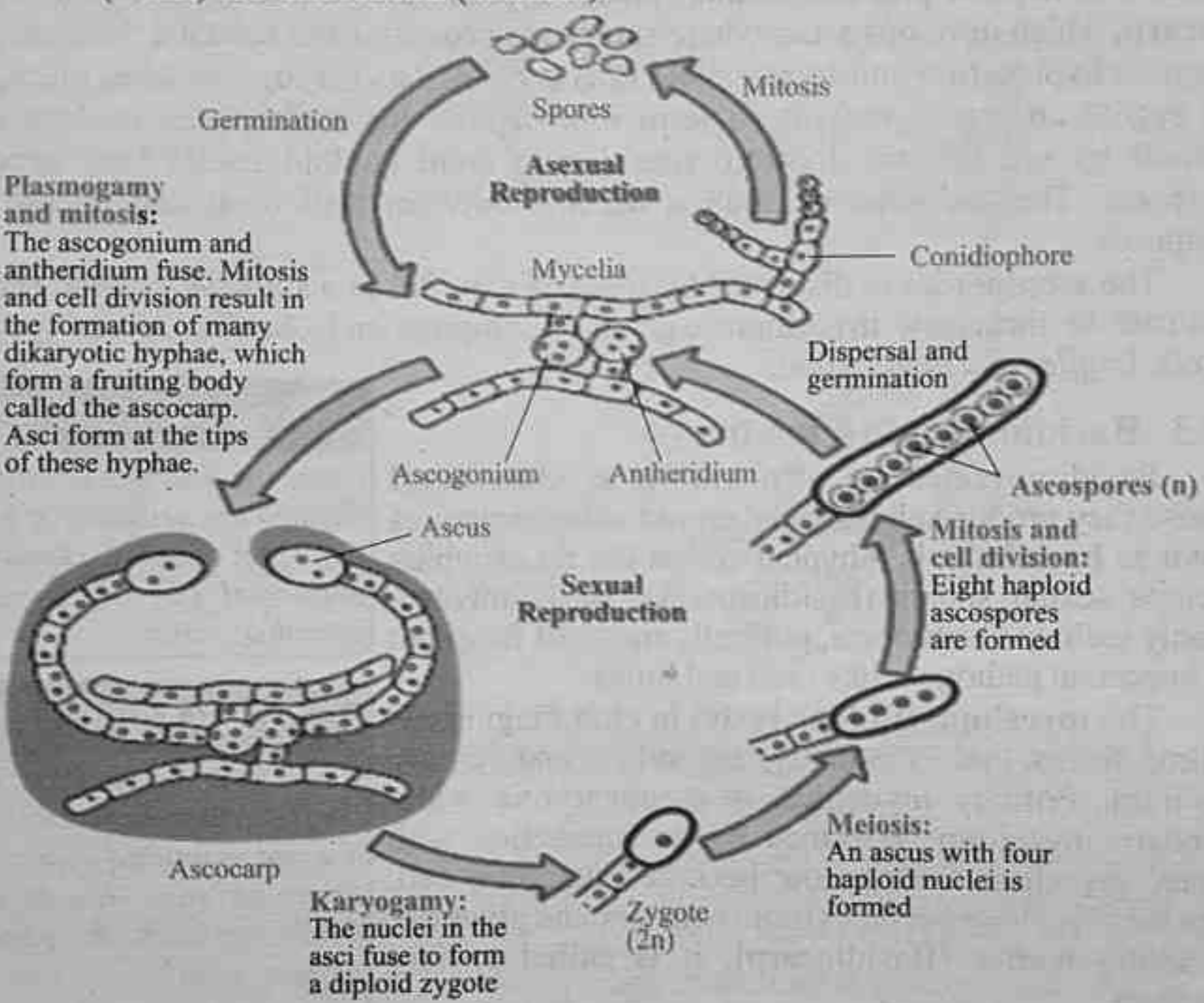


Fig. 7.10 Life cycle of Ascomycete

Reproduction:

Ascomycetes reproduce both asexually and sexually.

Asexual reproduction:

It takes place either by conidia or budding. The conidium; (Gk: dust) may be unicellular or multicellular, vary in shape and size, develop on the tips of erected modified hyphae called conidiophores. There are no sporangia in sac fungi. The colours of conidia vary in different species and it gives characteristic brown, blue, pink or other tint to many of these fungi. **Bud** is an outgrowth, separates from parent body and grows as independent fungi e.g. unicellular yeast (yeast also reproduces asexually by **fission**).

Sexual reproduction in Ascomycota:

Sexual reproduction occurs by ascospores in both multicellular and unicellular sac fungi.

In sac fungi sexual activities begin when plus and minus strains produce multinucleated sexual bodies. The sexual bodies meet forming a connecting bridge. The nuclei migrate from one body to the next, but do not fuse, forming a new **dikaryotic** hyphae. The haploid plus and minus nuclei hyphae form a fruiting body known as **ascocarp,** which develops ascus where spores are produced and released. In ascus, the dikaryotic hyphae fuse and form diploid (2n) nucleus, i.e., karyogamy takes place, the (2n) zygote undergoes meiosis to form four haploid (n) nuclei, each nucleus then followed by one mitotic division, resulting in eight haploid nuclei later become ascospores. The asci after maturation become swollen, then burst and release the ascospores.

The ascospores are dispersed by wind, if they fall in a suitable location (host), germinate to form new mycelium. e.g., in *Neurospora* and *Saccharomyces* (yeast). *Morels, Truffles and Penicillium.*

7.4.3 Basidiomycota (club fungi)

Basidiomycetes are also known as **club fungi** because they produce club shaped reproductive structures known as **basidia.** It is a hyphal cell at the tip of which develops sexual spores (basidiospores). Basidiomycota not only include mushrooms, puffballs and shelf fungi but also important pathogens like rusts and smuts.

> **Do you know?**
>
> *Humus in the soil is formed through the activities of both fungi and bacteria. Humus is essential for the proper growth of plants.*

The **mycelium** (fruiting body) in club fungi exists in three forms that is primary, secondary and tertiary mycelium. Primary mycelium is monokaryotic while secondary mycelium is formed by an interaction with primary mycelium which now become dikaryotic cell. When the mycelium becomes more complex and gives rise to fruiting bodies (Basidiocarp), it is called tertiary mycelium.

Mushroom *(Agaricus)* consists of mass of white branched, thread-like separate hyphae that occurs mostly below the ground.

> **Do you know?**
>
> **Rusts and smuts:** *Rusts are involved in many rusty and orange coloured diseases, Spots on stem, leaves etc. Smuts are black, dusty spore masses similar to soot in wheat, corn etc.*
>
> Rust is caused: *by Puccinia while smut by Ustilago species.*

Reproduction in club fungi (Basidiomycota):

Club fungi usually reproduce sexually, occasionally asexually by conidiophores. The mushroom itself is called fruiting body, consists of stalk and a cap. It is known as **basidiocarp.** The lower surface of the cap usually consists of many thin perpendicular plates called **gills**. They radiate from the stalk to the edges of cap. In the gills the haploid nuclei of dikaryotic cells fuse to form diploid zygote.

Zygote is only diploid structure in their life cycle. Each zygote immediately undergoes meiosis to produce four (+) and (–) haploid basidiospores in the gills.

The gills burst and spores are released from the fruiting body and carried by wind or animals to a suitable moist land. Each "+ve and –ve" mycelia grow towards each other and cytoplasms fuse (plasmogamy) but nuclei do not fuse. Thus each cell of secondary mycelium contains two haploid nuclei, grows and forms compact mass called **buttons,** along the mycelia. Each button grows into a fruiting body (tertiary mycelium). The dikaryotic stage ends and a new diploid stage begins when (n + n) cells fuse to form zygote in the basidium.

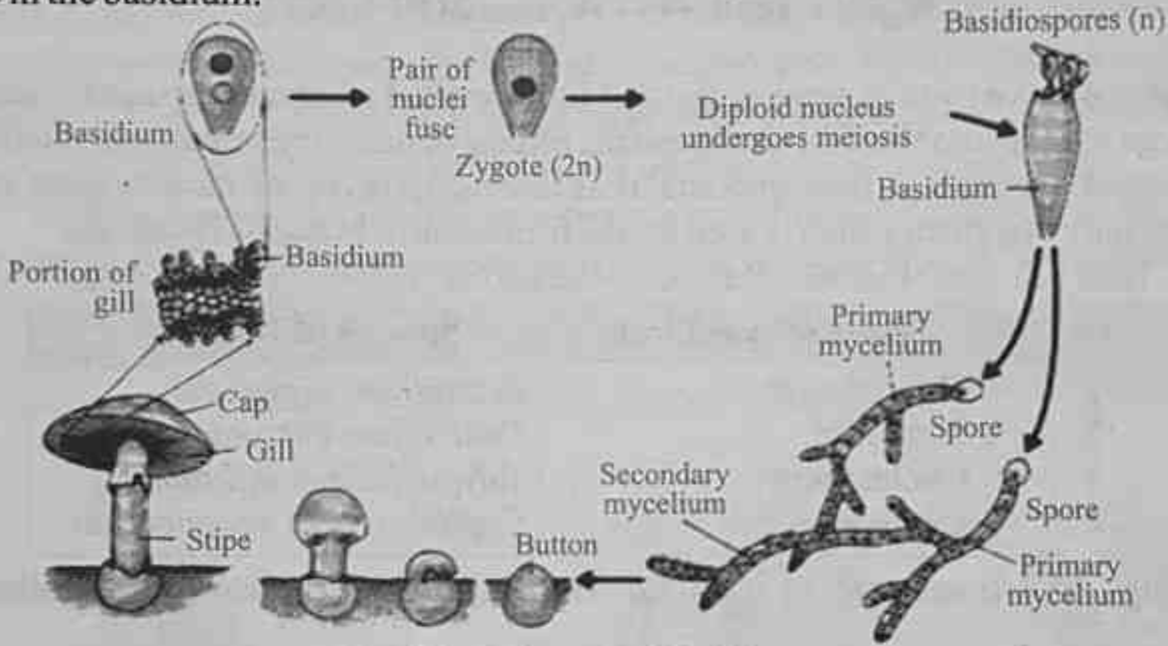


Fig. 7.11 Life cycle of Basidiomycota

Table 7.2 Comparison between Algae and Fungi

Algae	Fungi
They are autotrophic.	They are heterotrophic.
They are mostly aquatic .	They are mostly terrestrial.
Cell wall contains cellulose .	Cell wall is made up of chitin.
Their stored food is starch.	Their stored food is glycogen and oil.

7.5 Importance of Fungi

Fungi are both useful and harmful to human beings and other organisms. Many fungi are palatable, used as food, some help in making various chemicals. It also causes diseases in human beings and other living things. They spoil and decay our food and many other articles.

7.5.1 Importance of yeast

The *Saccharomyces cerevisiae* (yeast) have many benefits to mankind, such as

bread making.

For manufacturing bread yeast is mixed with white flour. The CO_2 produced by yeast become trapped in dough as bubbles, causing the dough to rise, this is what gives leaven bread its light texture. The CO_2 and alcohol produced by yeast is evaporated during baking. The flavour and quality of bread is attained by selecting different strains of yeast.

Brewing (Production of Alcohol) Ethyl alcohol (wine, beer) is prepared by the fermentation of cereals, potatoes, fruit, sugars etc.

$$C_6H_{12}O_6 + \text{yeast} \xrightarrow{\text{Enzymes}} \underset{\text{Ethanol}}{2C_2H_5OH} + 2CO_2$$

In genetic research: yeasts have been used in biological research; especially study of mutation, genetic recombination and to test the effects of many chemicals and medicines. Yeasts possess plasmids in their genome, thus like bacteria can be used as gene vector. Yeast is the only organism which is used for the formation of hepatitis B vaccine.

Table 7.3 Some important antibiotics obtained from different species of fungi

No.	Name of antibiotic	Species of fungus
1	Griseofulvin	*Penicillium nigricans*
2	Penicillin	*Penicillium chrysogenum*
3	Cyclosporins	*Tolypocladium inflatum*
4	Cephalosporin	*Cephalosporin acremonium*

Drugs like **lovastatin** is used for lowering blood cholesterol, **ergotine** for migraine.

7.5.2 Mutualist Role of Fungi (Lichens and Mycorrhizae)

Many fungi live in mutually beneficial relationship (Mutualism) with other organisms, in which both partners get benefit from each other. There are two types of mutualistic association in fungi, i.e., Lichens and Mycorrhizae.

Lichens and their types:

Lichens are associations of fungi (mostly sac fungi) with algae (often green algae and cyanobacteria), therefore, known as compound or **composite organisms.** The fungus provides support and prevent from desiccation, i.e., absorb water from air while in response, the algae partner provides food.

The body of lichen has three layers: the upper thin and tough layer which consists of fungal hyphae, the middle fungal hyphae interwoven with photosynthetic green algae and cyanobacteria while bottom layer consists of loosely packed fungal hyphae. There are three types of lichens.

1. **Crusticose Lichens:** Grow on damp rocks, bark of trees, these are compact lichens.
2. **Foliose Lichens:** These are leaf-like in shape.
3. **Fruticose Lichens:** These are shrub-like and branched, vary in colour, shape,

overall appearance and growth form.

Lichens prefer to grow in areas with low moisture and low temperature. They have great ability to absorb moisture and to get nutrients, therefore, they can survive in area with poor or no soil. Fruticose lichens absorb pollutants from air thus cannot grow where air is polluted. Thus their presence is a **bioindicator** that the air is healthy for humans to breath.

Mycorrhizae:

A mutualistic association between fungus and roots of the vascular plants (about 80%) in a mutual beneficial relationship is called mycorrhizae. The fungus gets sugar from plants and in response gives greater surface area for absorption of water and inorganic salts (P, Zn, Cu, etc.). Mycorrhizae help in better growth of plants, (95% of plants families have this relationship). There are two types of mycorrhizae.

1. **Endomycorrhizae:** In this type hyphae enters into the cell wall of outer cells of plant root forming coils, swelling and minute branches also extend out into surrounding soil.
2. **Ectomycorrhizae:** In this type of association, hyphae surround and extend between the cell wall (do not enter) of roots. They occur mostly with pines, firs etc.

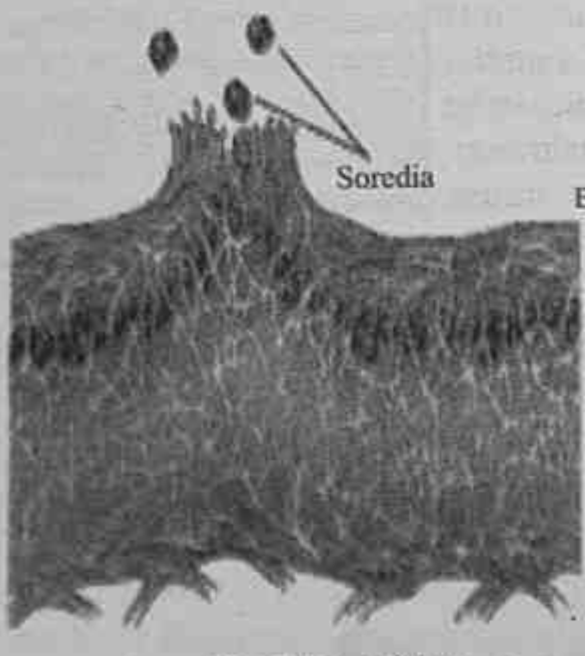


Fig. 7.12 Lichen

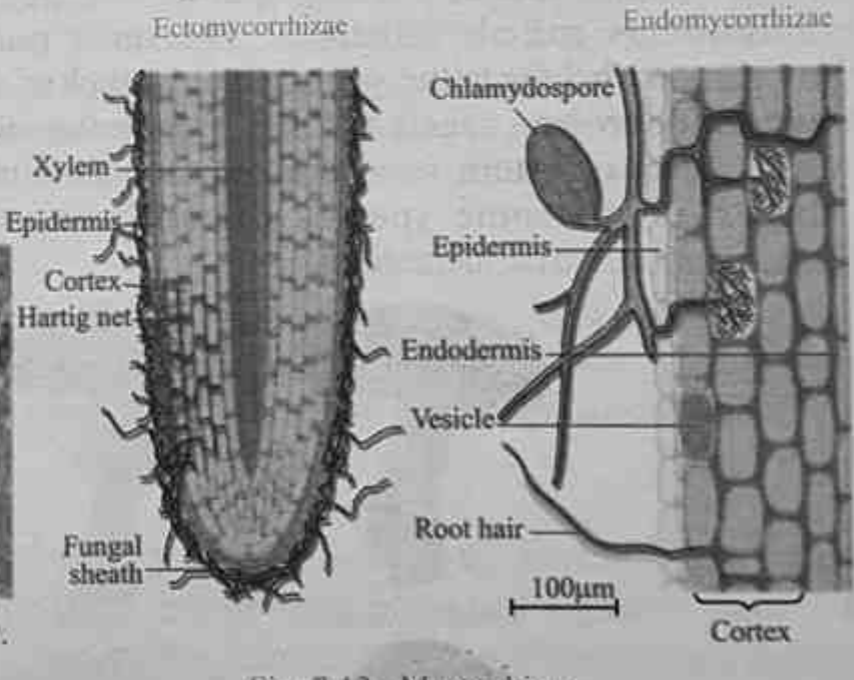
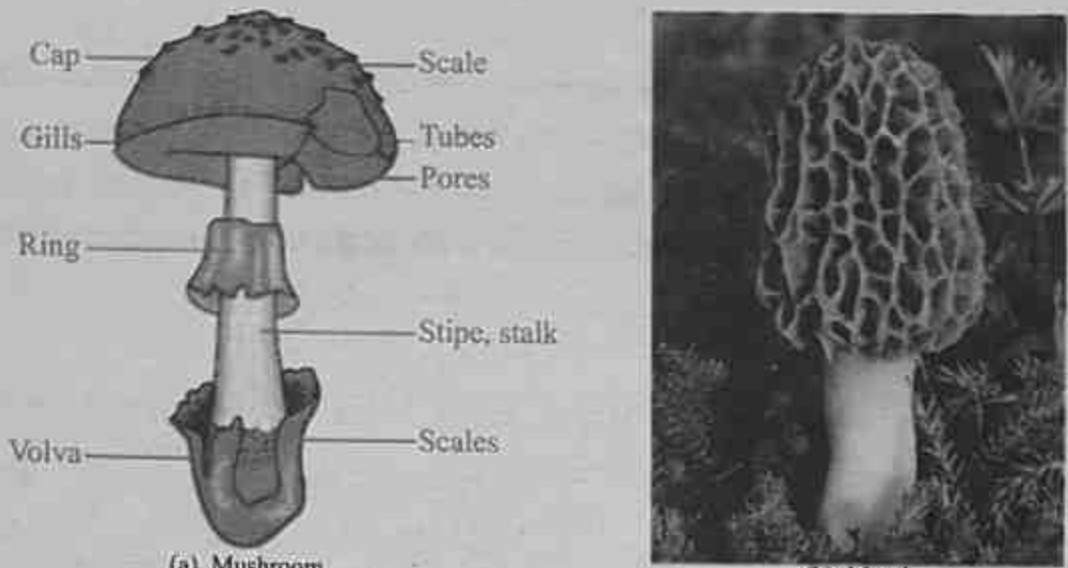


Fig. 7.13 Mycorrhizae

7.5.3 Edible Fungi

Mushrooms are considered popular food throughout world. Mushroom pizzas are famous for their taste. It also gives peculiar flavour and taste to certain types of cheese. About more than 200 species of mushrooms are edible.

Aspergillus tamarii is an example of edible mushrooms. The ascocarp of



(a) Mushroom (b) Morel

Fig. 7.14 Edible fungi

Morchella esculenta (a morel) and *Tuber melanosporum* (a truffle) are commercially cultivated and highly prized for their complex flavour.

Yeast is also used as nutritional supplement because it contains high level of vitamin B and about 50% of yeast is comprising of protein.

There are about 70 species of poisonous mushrooms called toadstools. The most poisonous mushrooms belong to the genus *Amanita* such as *Amanita virosa* (destroying angel) and *Amanita phalloides* can be fatal. Jack-o-lantern is also a poisonous mushroom. Ingestion of some species of mushrooms cause intoxication and hallucinations.

Do you know?

A pathogenic fungi named "Armillaria" may be considered as the largest organism. A single mycelium may produce one kilometer hyphae per day. It has been measured up to 15 hectares which belongs to group basidiomycota.

Fig. 7.15 Common Poisonous Mushrooms

7.5.4 Ecological impacts of Fungi

Decomposition and recycling of materials

Fungi and bacteria are the basic decomposers in biosphere. Both make significant contribution to the ecological balance of our world. They decompose organic matter and release the substances locked in dead bodies of animals and plants for circulation in the ecosystem.

Fungi possess **potent enzyme system** which helps in splitting tough organic compounds that can not be digested by most other living things, e.g., lignin (in wood). The released substances become available to the next generation of organisms. They also release large amount of CO_2 in the air by decomposition, which is used for the synthesis of organic food by green living things (plants, algae and cyanobacteria).

Thus fungi **recycle** nutrients in nature and are called recyclers. The fungi clean the earth by removing the organic matter and because of this characteristic they have earned the name "scavengers".

7.5.5 Pathogenic Role of Fungi

The pathogens are disease causing organisms. Many fungi are also pathogenic and cause diseases in plants, animals and human beings.

Plant diseases:

Fungi cause many plant diseases, some of which are very important. All plants are susceptible to many fungal infections. Most common fungal diseases of cereals are rusts and smuts caused by *Puccinia* and *Ustilago* respectively which belong to group basidiomycota. Sac fungi cause diseases like powdery mildews, apple scab, chest-nut blight, Dutch elm disease, red rot of sugar cane and brown rot which attack plums, peaches, apricots and cherries.

Fungal diseases of animals:

Fungi cause many diseases in animals, some of which are: Ring worms in dogs and horses are caused by the species of *Trichophyton rubrum* and *Microsporum audouinii*. *Aspergillus sp*. causes abortion in many animals. *Saprolegnia parasitica* is the parasite of carp and salmon fish.

Fungal diseases of human:

Fungi infect all parts of human body especially the skin. *Rhizopus* and *Mucor* species cause the infection of lungs (**Histoplasmosis**), brain and digestive tract. The cause of **dandruff** is *Microsporum furfur*. *Candida* species causes candidiasis (causes infection in the mucus membrane of the throat, mouth, vagina etc.). *Neurospora* and *Fusarium* cause infection of corneal tissues of eyes. *Aspergillus fumigatus* causes aspergillosis which like AIDS destroys immune system. *Aspergillus flavus* produces aflatoxin, a cancer causing mycotoxin in improperly stored grains of peanut, corn etc. Purple ergot rye causes **ergotism,** which causes nervous spasm, convulsion, psychotic delusion and even gangrene. Athlete's foot is caused by *Tinea pedis*.

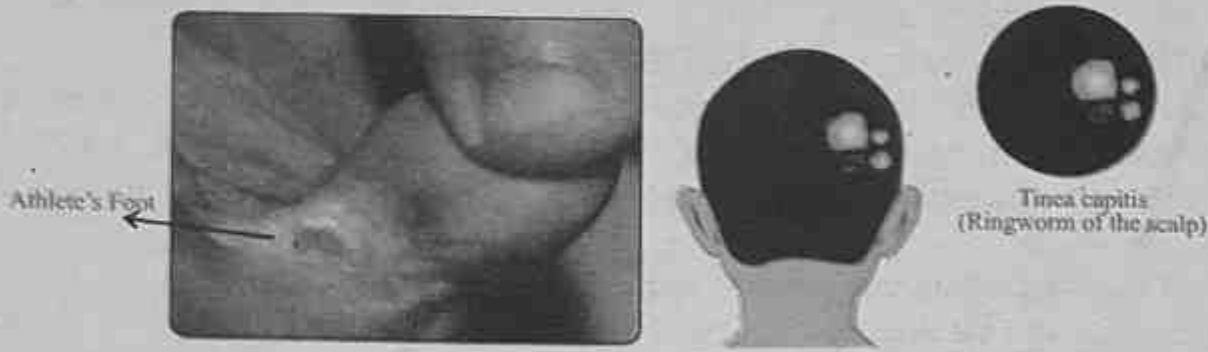


Fig. 7.16 Athlete's Foot and Ring worm

Critical Thinking

Protists are ancestors of plants, animals and fungi. what evidences you can provide to support this belief?

SUMMARY

- The kingdom protista is a polyphyletic group of organisims that do not share a single common ancestor.
- Kingdom Protista includes organisms that are animal-like, plant-like, and fungus-like.
- Protists may be unicellular or multicellular, and may be microscopic or very large.
- Most plantlike protists can make their own food through photosynthesis.
- Protozoa, animal-like protists have various structures that help them to move, such as flagella, pseudopodia, or cilia.
- Some animal-like protists can cause disease such as malaria.
- Fungus-like protists decompose organic matter. These protists have an important role in recycling nutrients through ecosystems. Unlike fungi, fungus-like protists can move during part of their life cycle. Fungus-like protists include slime molds and water molds.
- Fungi are eukaryotic organisms that appeared on land over 450 million years ago. They are heterotrophs and contain neither photosynthetic pigments such as chlorophylls nor organelles such as chloroplasts. Since they feed on decaying and dead matter, they are saprobes.
- Fungi are important decomposers and release essential elements into the environment. External enzymes digest nutrients that are absorbed by the body of the fungus called thallus.
- A thick cell wall made of chitin surrounds the fungal cell.
- Fungi can be unicellular as yeasts or develop a network of filaments called a mycelium, often described as mold.
- Most species of fungi multiply by asexual and sexual reproductive cycles, and display an alternation of generations.

- The divisions of fungi are the Zygomycota, Ascomycota and Basidiomycota.
- Fungi establish parasitic relationships with plants and animals. Fungal diseases can decimate crops and spoil food during storage.
- Fungi have colonized all environments on Earth but are most often found in cool, dark, moist places with a supply of decaying material.
- Many successful mutualistic relationships involve a fungus and another organism. They establish complex mycorrhizal associations with the roots of plants. Lichens are a symbiotic relationship between a fungus and a photosynthetic organism, usually an alga or cyanobacterium.

EXERCISE

Section I: Objective Questions

Multiple Choice Questions

A. Choose the best correct answer.

1. All members of which of the following group are single-celled.
   (a) Algae (b) Protozoa
   (c) Fungi (d) Helminths
2. Protists which absorb nutrients from dead organisms are called.
   (a) Photoautotrophs (b) Autotrophs
   (c) Saprobes (d) Heterotrophs
3. Phycoerythrin is found in which of the following algae.
   (a) Red (b) Green
   (c) Brown (d) All
4. Parasitic Protozoans that form spores at some stage in their life belong to:
   (a) Apicomplexans (b) Ciliates
   (c) Actinopods (d) Diatoms
5. Oomycetes show close relation with fungi and their cell wall contains:
   (a) Chitin (b) Muramic acid
   (c) Silica (d) Cellulose
6. Algae in which the body is differentiated into blade, stipe and hold fast belong to:
   (a) Kelps (b) Euglenoids
   (c) Golden algae (d) Green algae
7. In basidomycetes, fruiting body is made up of mycelium which is:
   (a) Polykaryotic (b) Monokaryotic
   (c) Trikaryotic (d) Dikaryotic

8. Zygomycetes have
   (a) Septate hyphae (b) Imperfect fungi
   (c) Coenocytic hyphae (d) Perfect fungi
9. Lichens are ecologically important as?
   (a) Decomposers (b) Bioindicators
   (c) Oxidizers (d) Pollutants

B. Fill in the blanks.

1. The feeding stage of a slime mold is called ____________.
2. Both Fungi and animals mode of nutrition resemble because both are ________.
3. Spore bearing structures are called _________.
4. The basidiomycetes are also called _________.
5. Histoplasmosis is a serious infection of human ________.
6. The largest algae is called giant _______.
7. Plasmodium causes a disease called _________.

Section II : Short answers.

1. Give one characteristic of each type of protist that explains why it is animal-like, plant-like, or fungus-like.
2. What are three types of structures that help some protists move?
3. Name two animal-like protists that cause disease.
4. Explain how do hyphae help a fungus to absorb food?
5. Why are yeasts useful to scientific research?
6. Explain how does the decomposing activity of fungi carry both beneficial and harmful effects?

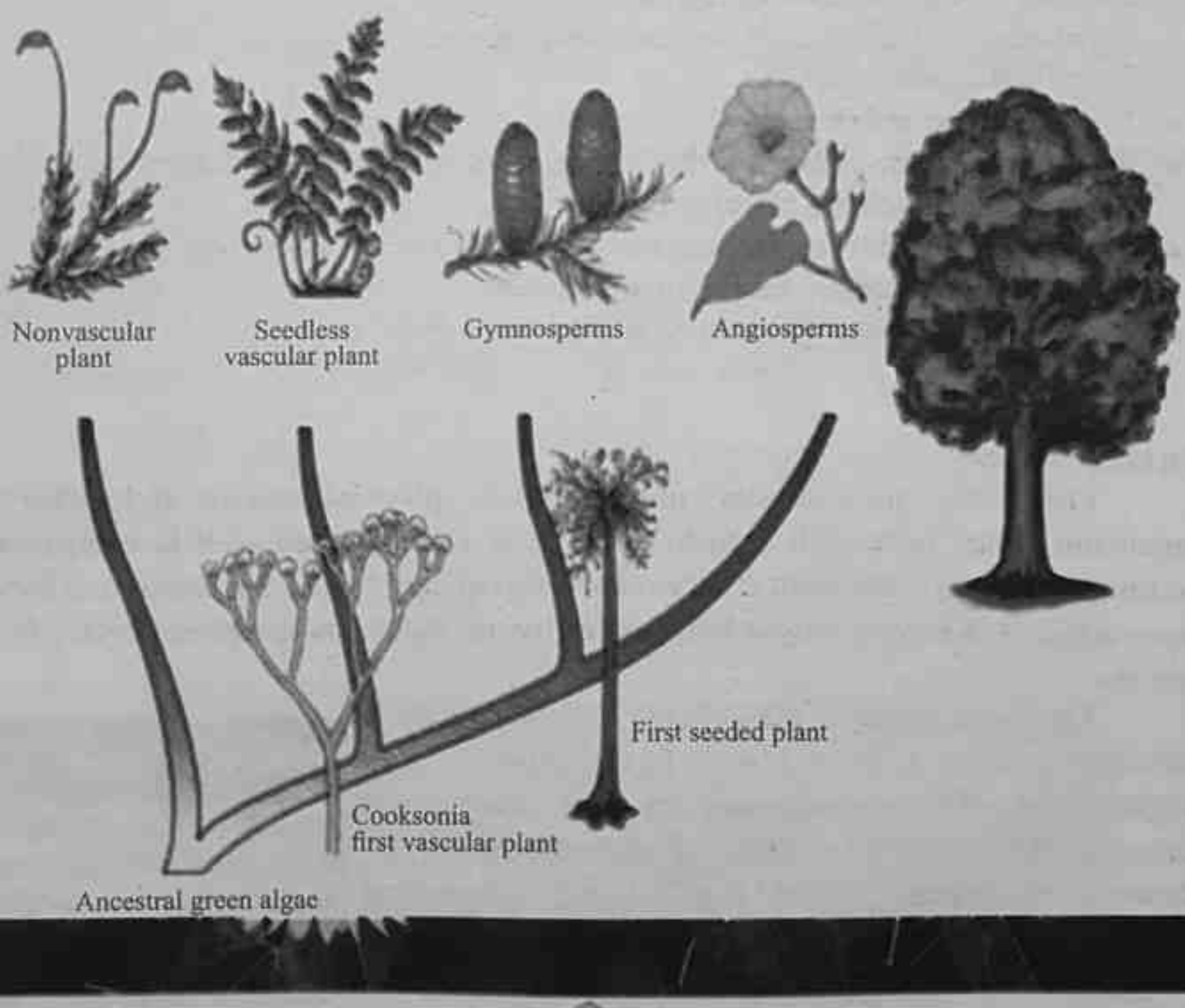
Section III: Extensive Questions

1. Describe how algae differs from all the other eukaryotic organisms.
2. Describe the economic importance of yeast.
3. Explain the structure and reproduction of Ascomycota.
4. Explain the structure and reproduction of Zygomycota.
5. Write note on mycorhizae and lichens.
6. Describe Asexual and Sexual reproduction in Rhizopus.

UNIT 8 DIVERSITY AMONG PLANTS

Major Concepts

8.1 The Evolutionary Origin of Plants
8.2 Non-Vascular Plants
8.3 Seedless Vascular Plants
8.4 Seeded Plants



Students Learning Outcomes

On completion of this unit students will be able to:

- Outline the evolutionary origin of plants.
- List the diagnostic features shared by all plants, with emphasis on the alternation of generations.
- Describe the general characteristics of bryophytes.
- Outline the life cycle of a moss.
- Explain the land adaptations of bryophytes.
- List the advantages/uses of bryophytes.
- Describe the general characteristics of vascular plants.
- List the characters of seedless vascular plants with examples of whisk ferns, club mosses, horsetails and ferns.
- Explain the evolution of leaf in vascular plants.
- Outline the life cycle of ferns.
- Describe vascular plants as successful land plants.
- Summarize the importance of seedless vascular plants.
- Describe the evolution of seed.
- Describe the general characteristics and uses of gymnosperms.
- Define angiosperms and explain the difference between monocots and dicots.
- Explain the life cycle of a flowering plant.
- Explain how this life cycle demonstrates an adaptation of angiosperms on land.
- Define inflorescence and describe its major types.
- Describe the significance/benefits of angiosperms for humans.

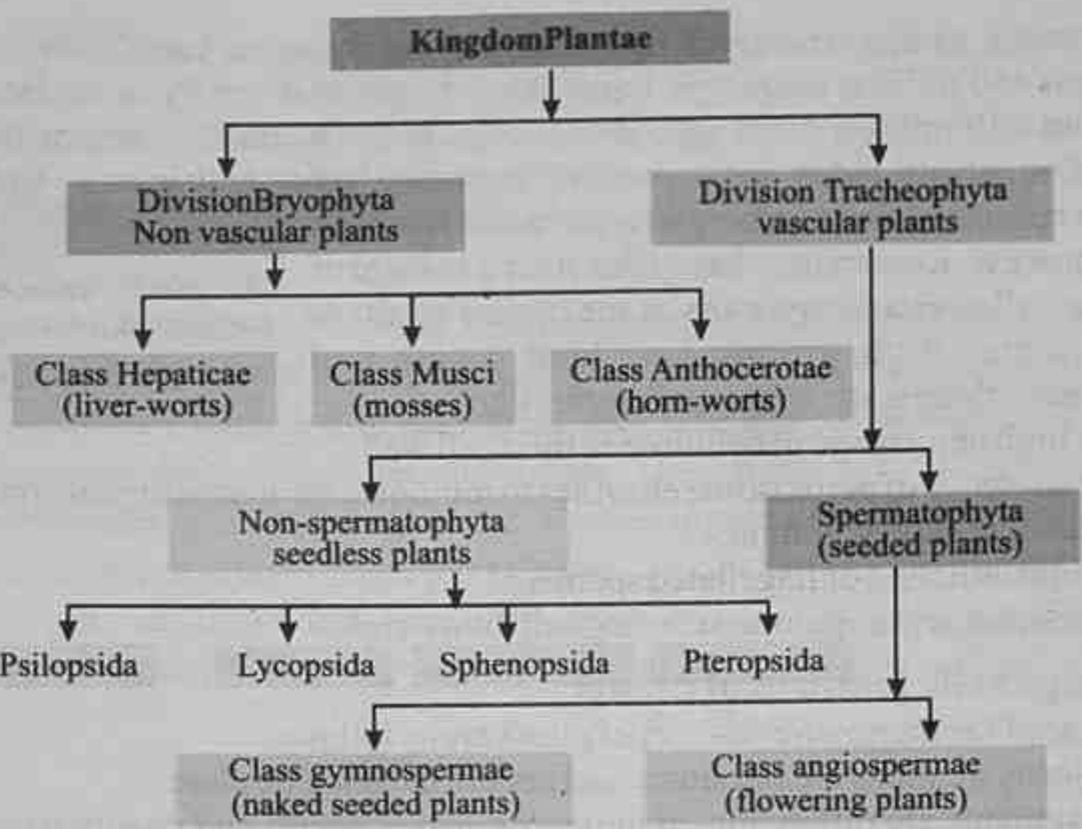
Introduction

Plants are multicellular, predominantly **photosynthetic** and eukaryotic organisms. They have well defined body parts and their **cell wall is composed of cellulose.** They develop from embryo. Their stored carbohydrate is starch and they are non-motile. It is second largest kingdom of living organisms comprises over 3,60,000 species.

The major groups of plants are bryophytes, seedless vascular plants, seeded plants (gymnosperms and angiosperms). The **angiosperms** are very diverse and largest group. Plants live in almost all sorts of habitats. i.e., deserts, mountains, tundra, tropical and subtropical regions as well as in water. The outline of classification of kingdom Plantae is given below.

Do you know?

Plants protect themselves from frost and dehydration stress with the antifreeze proteins, heat shock proteins and sugar.



8.1 The evolutionary origin of plants

The evolution of plants has resulted in widely varying levels of complexity, started from green algae through bryophytes, lycopods and ferns to the complex gymnosperms and angiosperms .

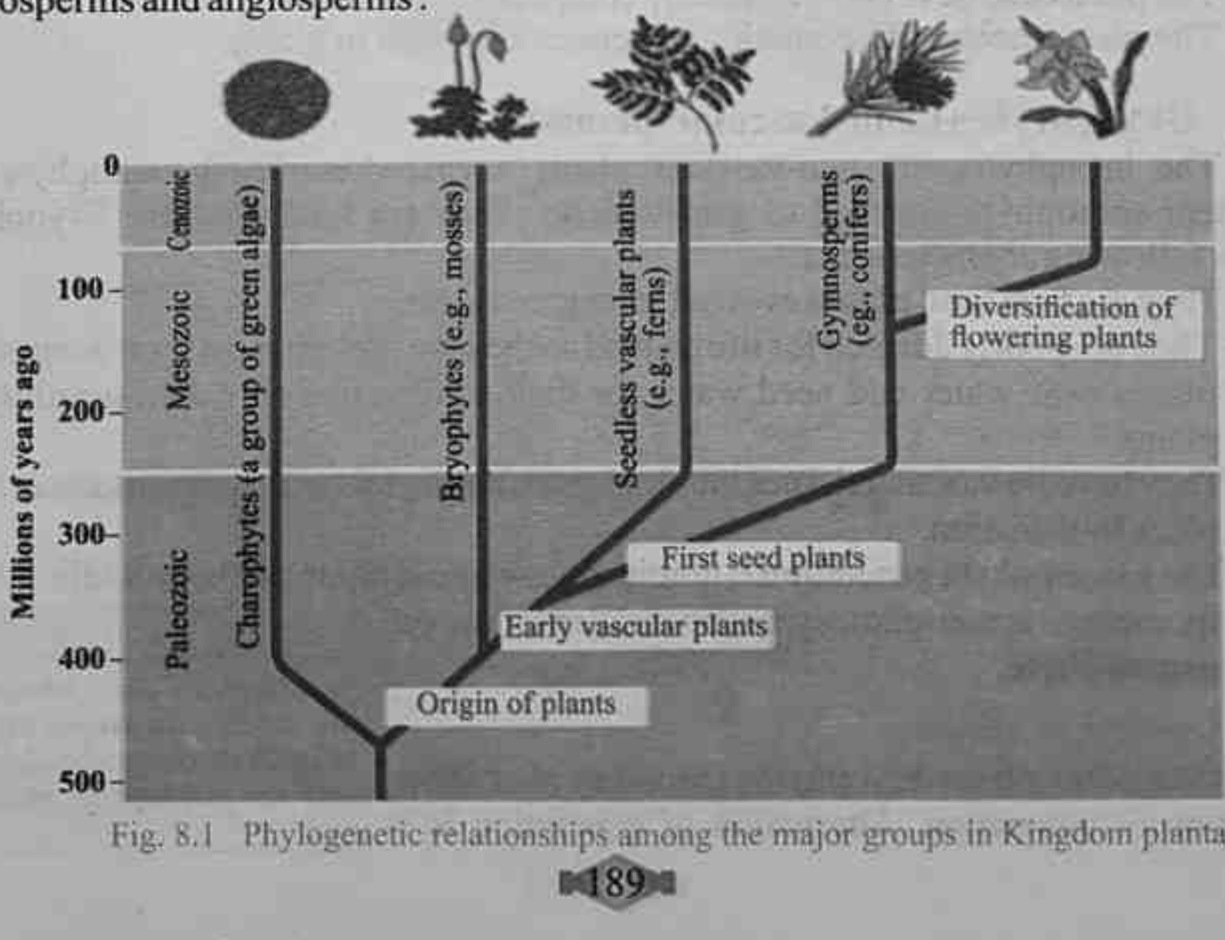


Fig. 8.1 Phylogenetic relationships among the major groups in Kingdom plantae

Evidence of appearance of **first land plants** is traced back in the ordovician period about 450 million years ago. Land plants began to diversify in the late **Silurian** period about 430 million years ago. By the middle of Devonian many of the features recognized in plants today were present, including roots and leaves. Evolutionary innovation continued from carboniferous era and is still an ongoing process. Researchers have identified a lineage of green algae called **charophyceans** as the closest relatives of land plants. Both groups i.e., land plants and charophyceans share some common features like:

> **Tit bits**
>
> *The plant science is called botany. (Botany, Gk. botane means pasture or plant.*

1. The high percentage of cellulose in their cell wall.
2. The presence of peroxisome enzymes to minimize the loss of organic products as a result of photorespiration.
3. Similar structure of flagellated sperms.
4. Formation of phragmoplast during cell division etc.

8.1.1 Diagnostic features of plants

Some of the diagnostic features of plants are as follows.

- Majority of plants are stationary and remain fixed to one place.
- Most plants are differentiated into roots, leaves, stems and mostly have vascular tissues, (except bryophytes).
- Plants possess chlorophyll hence have the ability of photosynthesis.
- Plants possess cuticle to prevent water loss by transpiration.
- The plant cells have cell wall chiefly composed of cellulose.
- The phenomenon of alternation of generation exists in plants.

8.2 Bryophytes (Non-Vascular plants)

The bryophytes are non-vascular plants having dominant gametophyte and dependent sporophyte attached to gametophyte. They are homosporous. Bryophytes possess following characteristics.

- They are **first land plants** evolved from green algae.
- They are poorly adapted for life on land so they are present mostly on damp shady places near water and need water for their fertilization so called **amphibious** plants.
- They have no vascular tissues thus transport of minerals and food substances takes place by diffusion.
- The gametophyte generation is dominant, green and photosynthetic while sporophyte is non-photosynthetic and dependant on gametophyte.

> **Tit bits**
>
> *Bryophytes are important for soil conditioning as bioindicators, pesticides, fuel and as packaging material etc.*

8.2.1 Life cycle of Moss

Like other plants bryophytes (Mosses) also show alternation of generation. Alternation of generation is a phenomenon in which gametophyte and sporophyte generations regularly alternate with each other.

The bryophytes differ from other groups of plants in their life cycle. In bryophytes gametophyte generation is dominant, photosynthetic and independent while sporophyte is dependant and non-photosynthetic.

Gametophyte Generation:

The gamete producing generation is called gametophyte generation. It is haploid generation. The gametes are produced by mitosis. The male and female gametophyte generations are usually separated in case of mosses. The male gametophyte produces sperms while female gametophyte produces eggs. The gamete producing organs (sex organs) are **antheridium** and **archegonium.** The sex organs are intermixed with some multicellular hair-like structures called **paraphyses.** The sperm is motile and needs water for reaching to egg in archegonium. Thus fertilization occurs in archegonium. The egg is large and non-motile, containing large amount of food for nourishment of early stage of embryo.

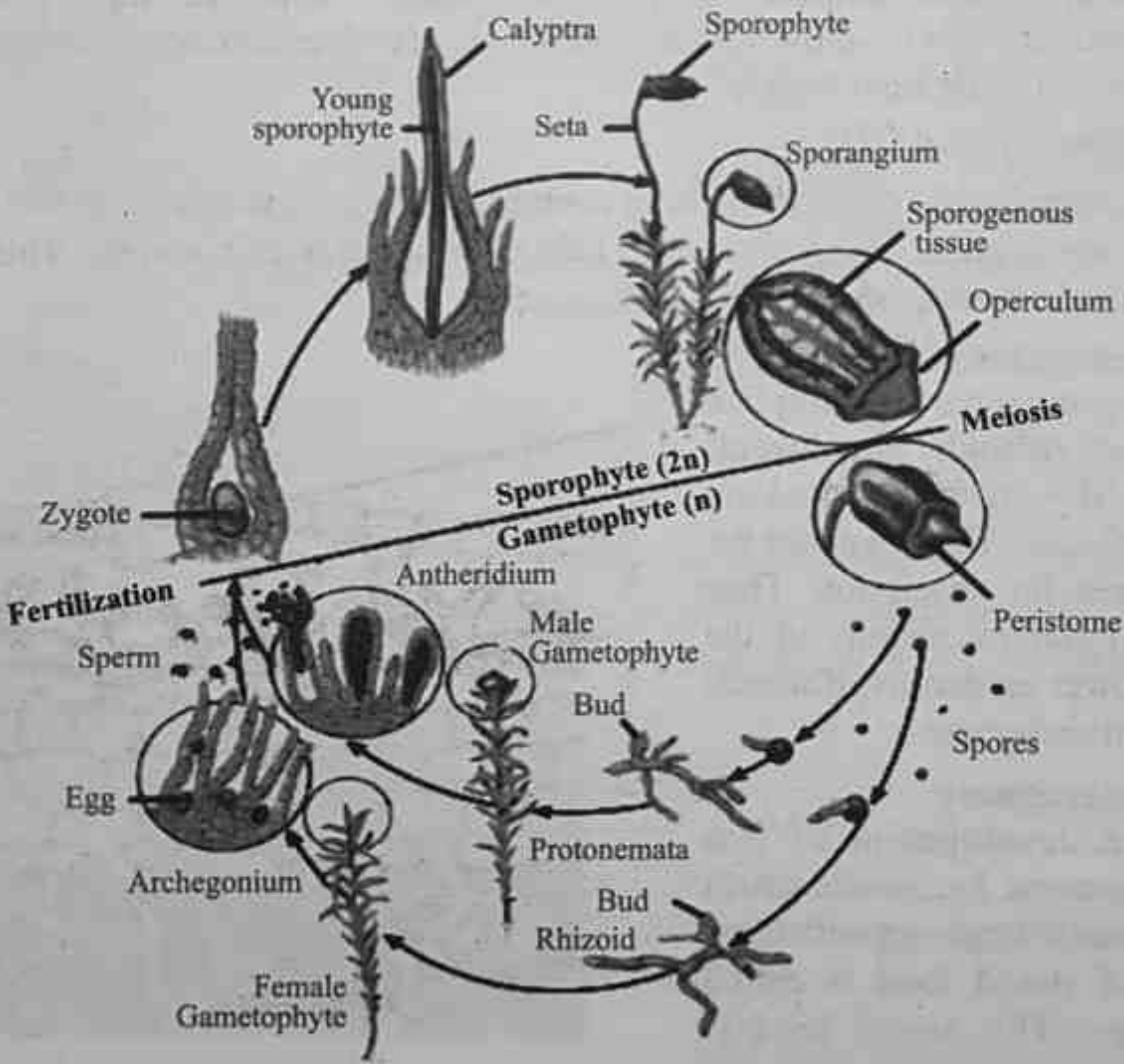


Fig. 8.2 Life Cycle of Moss

Sporophyte Generation:

It produces spores so called sporophyte. The fertilized egg in archegonium develops into sporophyte. The sporophyte remains attached on gametophyte. The sporophyte consists of three parts, i.e., **a foot** which is embedded in the tissue of gametophyte, **a stalk** (seta) and a **capsule** or sporangium.

> **Do you know?**
>
> *Bryophytes are known as amphibious plants because they need water for their reproduction.*

The sporophyte generation is diploid and spores are produced in sporangium by meiosis. These spores on availability of suitable conditions give rise to gametophytes.

8.2.2 Adaptation of Bryophytes for Life on Land

The bryophytes are called the first invaders of the land among the plants. They show the following adaptations for life on land.

1. Multicellular plant body and conservation of water

A multicellular compact plant body of bryophytes conserves water and reduce surface exposed to dry conditions. Moreover, a layer of cuticle develops to further reduce transpiration of water from surface.

2. Absorption of CO_2

Bryophytes like Marchantia have evolved elaborate structure to absorb CO_2. In epidermis many pores are present which help in diffusion of CO_2 and O_2. This CO_2 is absorbed by the wet surface of photosynthetic cells.

3. Absorption of water

The structures for absorption of water are **rhizoids.** The rhizoids are root-like structures lacking vascular tissues. They increase the surface area for absorption. They are unicellular extensions of the cells of lower epidermis. Rhizoids also help in anchorage.

4. Heterogamy

The development of two types of gametes, i.e., motile sperm and non motile large egg with large amount of stored food is called heterogamy. This stored food is used in early stages of development of embryo.

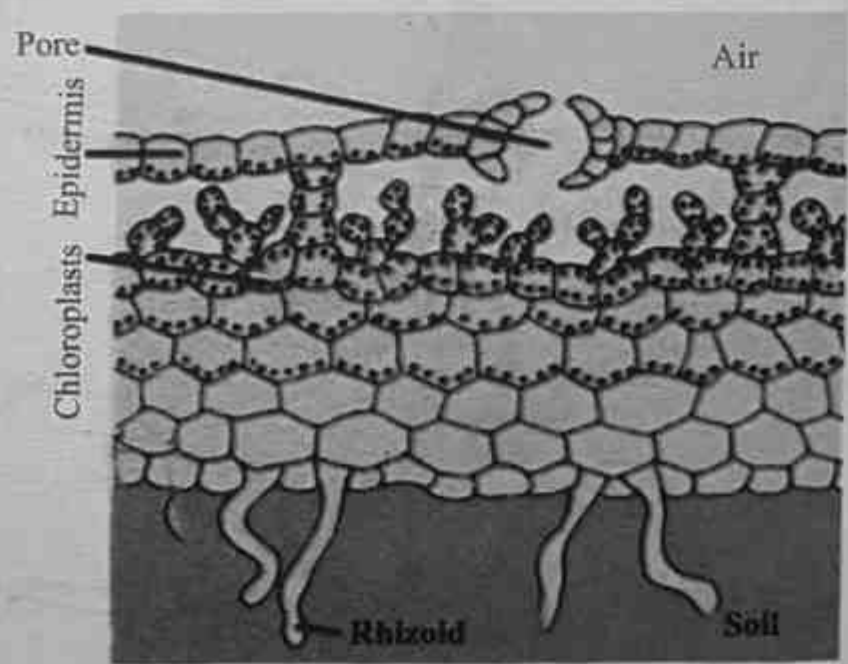


Fig. 8.3 T.S of Marchantia Thallus

5. Protection of Reproductive Cells

The male gametes, (sperms) are produced in antheridium and female gametes (eggs) are produced in archegonium. The sex organs are prevented from drying by leaf-like structures and sterile hairs. Spores are protected by sporangium.

Classification of Bryophytes

Bryophytes are divided into three classes or phylum.
1. Hepaticae (liver-worts).
2. Musci (mosses)
3. Anthocerotae (horn-worts).

6. Embryo formation

The developing zygote is called embryo. In bryophytes embryo remain protected in female sex organ, i.e., archegonium. Thus the embryo is protected from drying and mechanical injury, and it increases the chances of survival.

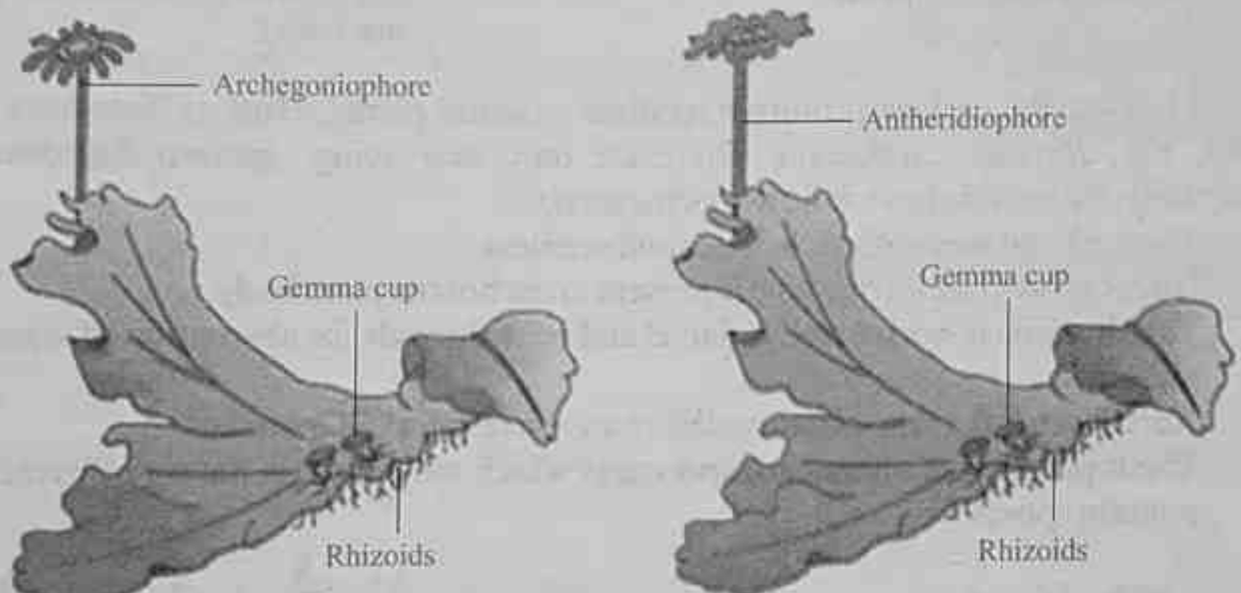


Fig. 8.4 Male and female thallus of Marchantia

7. Alternation of Generation

In all land plants there are two types of generations, i.e. sporophyte and gametophyte which alternate with each other. This phenomenon is called alternation of generation. This ensures the diversity and variation in characters and increases the chances of survival of plants on land.

8.2.3 Importance or Advantages of Bryophytes

Some of the uses of bryophytes are as under.

i) They prevent soil erosion by holding soil in place.
ii) The rocks are broken down into soil by their physical and chemical action.
iii) They increase soil fertility as they decay into soil.
iv) They also provide food for herbivores.
v) They retain soil moisture.
vi) Some bryophytes have medicinal value as well.

8.3 Seedless Vascular Plants

The seedless vascular plants are a sub group of tracheophytes. **The tracheophytes** have vascular tissue, i.e., **xylem** for conduction of water and minerals **phloem** for conduction of organic food. All vascular plants have **tracheids** in their xylem and thus called tracheophytes. They are successful land plants with dominant sporophyte and reduced gametophyte generation. The tracheophytes can be sub divided into following groups.

(i) Sub division Psilopsida
(ii) Sub division Lycopsida
(iii) Sub division Sphenopsida
(iv) Sub division Pteropsida

> **Critical Thinking**
>
> *Bryophytes do not have true roots and leaves. Guess how do they absorb water and nutrients?*

8.3.1 Sub division Psilopsida: (whisk ferns)

They are the earliest primitive seedless vascular plants. Most of them have been extinct, e.g., *Rhynia, Cooksonia.* There are only two living *genera Psilotum and Tmesipteris*. Psilopsida have following characters.

- These plants are rootless, leafless and seedless.
- Under ground stem, rhizome is present to anchor the plant body.
- The rhizome is horizontally placed and bear rhizoids for absorption of water and minerals.
- Aerial stem is green, photosynthetic and having forked branches.
- The reproductive organs are sporangia which are borne on the tip of branch and contain spores.

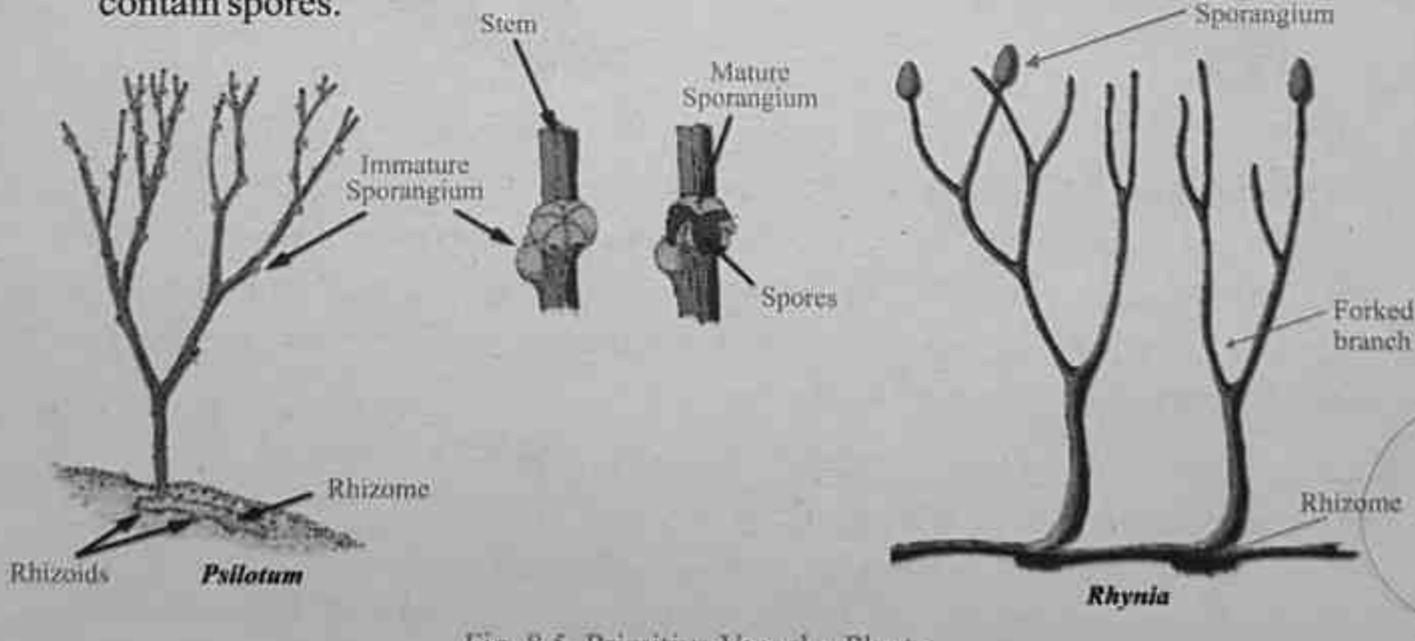


Fig. 8.5 Primitive Vascular Plants

8.3.2 Lycopsida (Club mosses)

It includes plants like *Lycopodium* and *Selaginella.* These plants are also called club mosses or spike mosses due to their club/spike shaped cones or ***strobilli*** and small moss like leaves. These plants have following characteristics.

- The plant body is sporophyte which is differentiated into roots, stems and leaves. Their leaves are called microphylls.
- Leaves may be spirally arranged or opposite.
- Sporangia develop singly on upper side of leaf such leaf is called sporophyll.
- Sporophylls may be grouped together to form cone or strobilus.
- These plants may be homosporous (*Lycopodium*) or heterosporus (*Selaginella*).
- Gametophyte of lycopsida is underground and has fungal association called mycorrhiza.

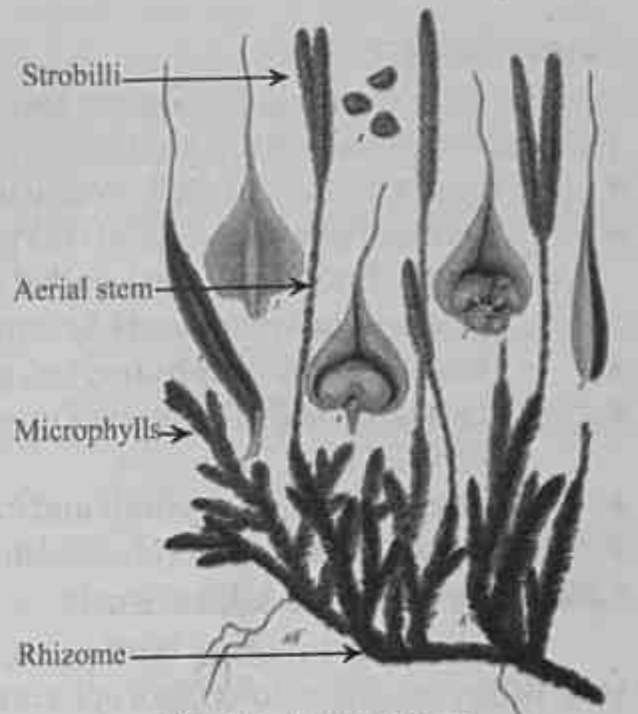


Fig. 8.6 Lycopodium

Do you know?

Lycopodium herb has been used in the traditional Austrian medicine internally as tea or externally to treat, skin, liver, bile, kidney and urinary tract infections.

8.3.3 Sphenopsida (Horsetail)

The plants of this group are called **arthrophytes** because whole plant consists of large number of joints. These plants are found in humus and wet places round the world. There is only one surviving genus *Equisetum.* They have following characteristics.

- The plant body is sporophyte differentiated into root, stem and leaves.
- Leaves may be broad or scale-like and are always arranged in whorls.
- Main stem is jointed and have ridges and furrows. From each node there is given out whorls of branches.
- The sporangia develop on sporangiophore. The sporangiophores group together to form cones.
- The gametophyte is thalloid and grows on clay soil or mud.

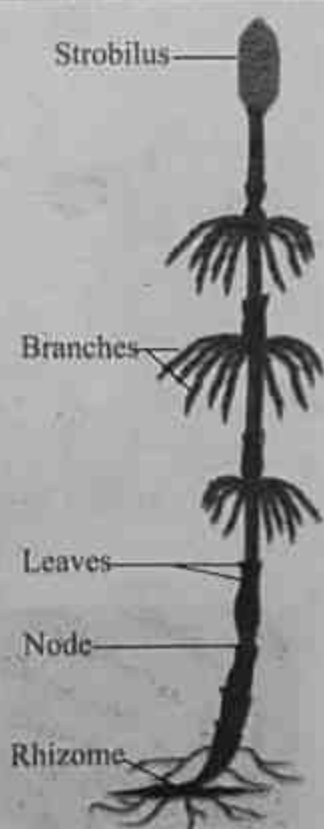


Fig. 8.7 Horsetail

8.3.4 Pteropsida

The Pteropsida is a heterogenous group of seedless vascular plants which consist of sub group or class Filicinae. These are found in moist and warm tropical areas.

Class Filicinae:

This class includes ferns which are the largest group of seedless vascular plants. These plants possess following important characteristics.

- These plants are usually found in moist and shady places.
- An important character of this group is that sporangia are attached on underside of leaves. Such leaves are called **fronds.** The immature or young frond has coiled pattern of development like watch spring and it is called **circinate Vernation**.
- Some ferns are **epiphytes**, i.e., grow on the bark of trees.
- Plant body is differentiated into leaves, stems and roots. Plants range in size from 1cm –24 m.
- Leaves are megaphyllous and may grow upto 5 meters (in a tree fern).
- Sex organs are antheridia and archegonia, for example: *Adiantum, Pteris* etc.

Life cycle of Fern (Adiantum):

Adiantum involves both asexual and sexual reproduction, i.e., morphologically two different generations (sporophyte and gametophyte) exist.

Sporophyte: The plant body is diploid sporophyte bearing groups of sporangia or **sori** on underside of margins of leaflets. Mature sori become black. The leaves bearing sporangia are called **sporophylls.** The sporangium is flattened, biconvex capsule born on the multicellular stalk. These capsules contain spores. Each spore is a simple cell consisting of cytoplasm and nucleus surrounded by two layers of cell wall. When the spores fall on suitable soil, it is germinated into a haploid gametophyte called **prothallus.**

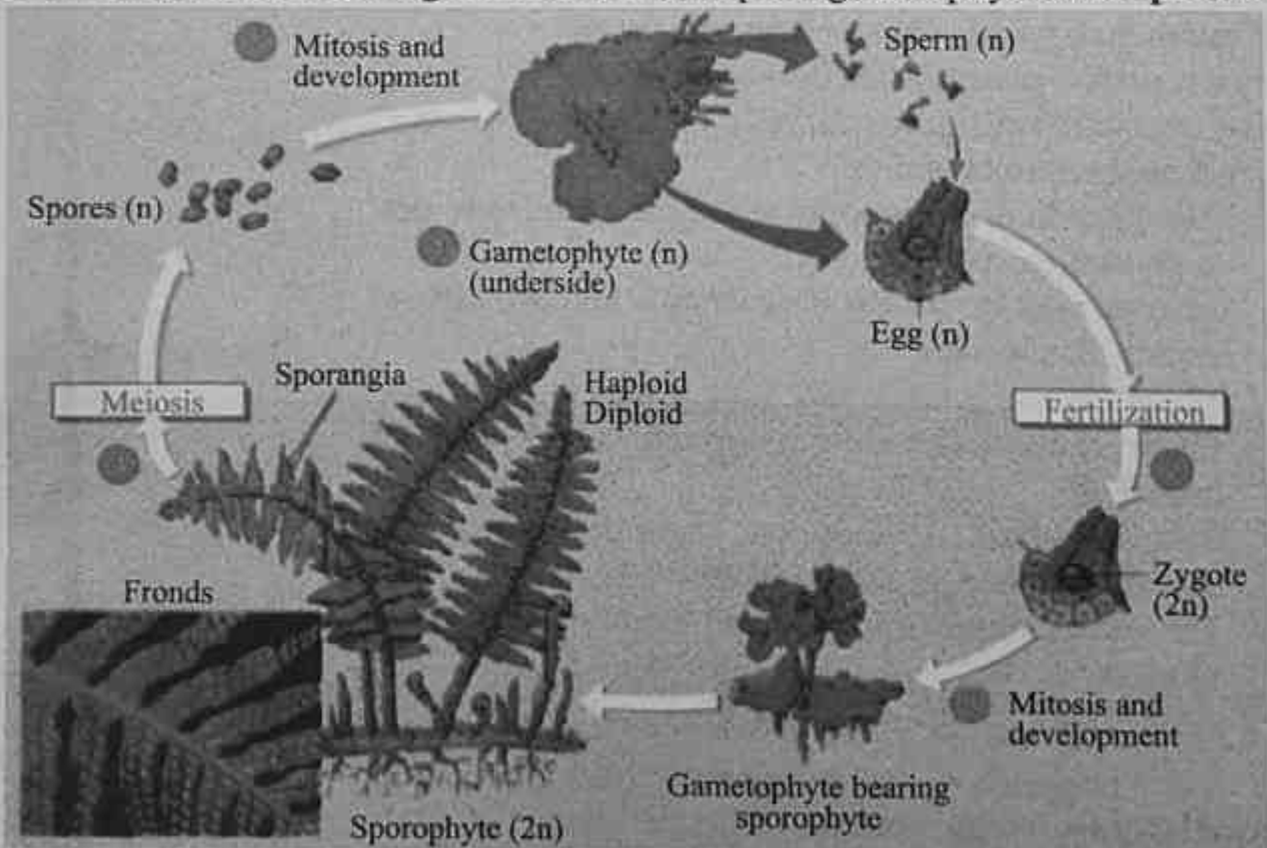


Fig. 8.8 Life cycle Adiantum

Gametophyte: The gametophyte generation is called prothallus which is a heart shaped structure and underground. From it`s posterior, under surface rhizoids are given out which fix the prothallus and absorb water. The prothallus is **monoecious**, i.e., both male and female sex organs develop on the same prothallus.

Antheridium: It is male sex organ in which large number of coiled multiciliated spermatozoids are produced.

Archegonium: These are flask shaped having broader part **ventre** and elongated part **neck**. Ventre contains egg or oospore.

Fertilization: The spermatozoids (sperms) reach the neck of archegonium by water pass through neck and unite with egg to form zygote or oospore.

Formation of sporophyte: The diploid zygote divides by mitosis to form the embryo and develops into sporophyte which is attached to gametophyte but later on becomes independent.

8.3.5 Evolution of Leaf

Lycopsida were the first group of plants that formed true leaves. There are two types of leaves.

1. **Microphylls:** These are small single veined leaves found in lycopods.
2. **Megaphylls:** These leaves have large blade or lamina, with large number of parallel or divided veins. These leaves are found in ferns and spermatophytes.

Evolution of one veined leaf (Microphyll):

There is no fossil record showing the evolution of one veined leaf. However, two hypothesis have been proposed to explain the evolution of one veined leaf.

a. Outgrowth hypothesis
b. Reduction hypothesis

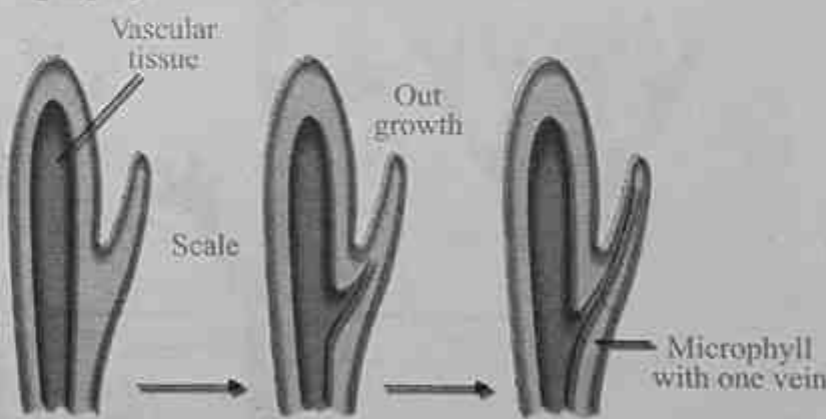


Fig. 8.9 Outgrowth Hypothesis

Out growth hypothesis:

This hypothesis states that one veined leaf originated as a result of outgrowth from the naked branches of primitive vascular plants. Due to increase in size of these outgrowth vascular tissues were needed for transport of food and water. Thus vascular

Tit bits

Evolution of leaf was a slow process and it took about 15–20 million years.

bundles extended to these outgrowths which gave rise to one veined leaf.

Reduction hypothesis:

This hypothesis states that one veined leaf originated as a result of reduction in size and flattening of leafless branches.

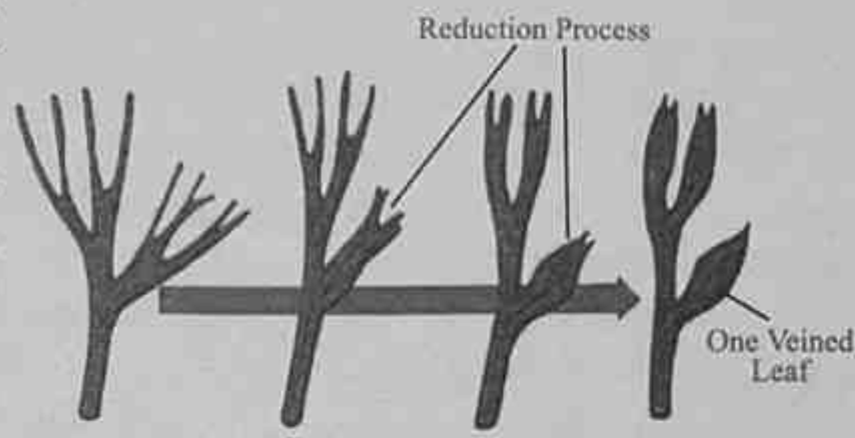


Fig. 8.10 Reduction Process of One Vein Leaf

Evolution of many veined leaf:

The evolution of many veined (Megaphylls) leaf took place in following steps.

a. **Overtopping:** It is unequal development of various branches. In primitive Rhynia and fern like plants the aerial portions of stem showed unequal branching, i.e., some branches were small while others were long.

b. **Plannation and flattening:** The unequal branches become arranged in one plane and became flat called plannation.

c. **Fusion or webbing:** The space between overtopped branches were filled by photosynthetic tissues that connected these branches. Thus a flat leaf **blade** was formed which superficially resembles to the webbed foot of duck and thus many veined leaf evolved.

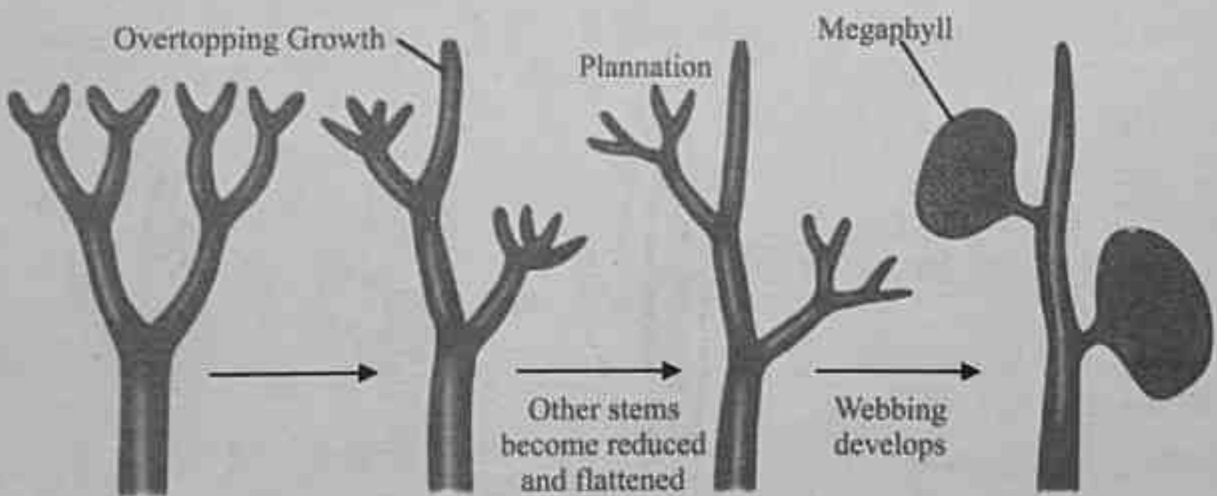


Fig. 8.11 Evolutaion of many veined leaf

8.4 Evolution of seed

Seed forming plants are called spermatophytes among vascular plants seeded plants are more successful land plants.

The development of seed habit occurred approximately 390 million years ago but complete seed forming plants appeared in late Devonian period about 365 million years ago. Seed can be defined as fertilized ovule, integumented in indehiscent megasporangium. Integument is a specialized protective covering around megasporangium.

Following steps were involved in the evolution of seed:

1. Evolution of heterospory.
2. Retention and germination of megaspore within megasporangium.
3. Development of integument, a protective layer around megasporangium.
4. Reduction to a single functional megaspore per megasporangium.
5. Development of embryo sac within megasporangium.
6. Modification of distal end for megasporangium to capture pollen.

Spermatophyta (Seeded plants):

There are two groups of seeded plants, gymnosperms and angiosperms.

8.4.1 Gymnosperms: (Latin, Gymno: naked, Greek, Sperma: seed)

These plants produce naked seeds, i.e. seed is not enclosed in fruit. It is wide spread group of plants and consists of one third of world forests. The gymnosperms are woody plants either shrubs, trees or rarely vines (in some gnetophytes). They differ from

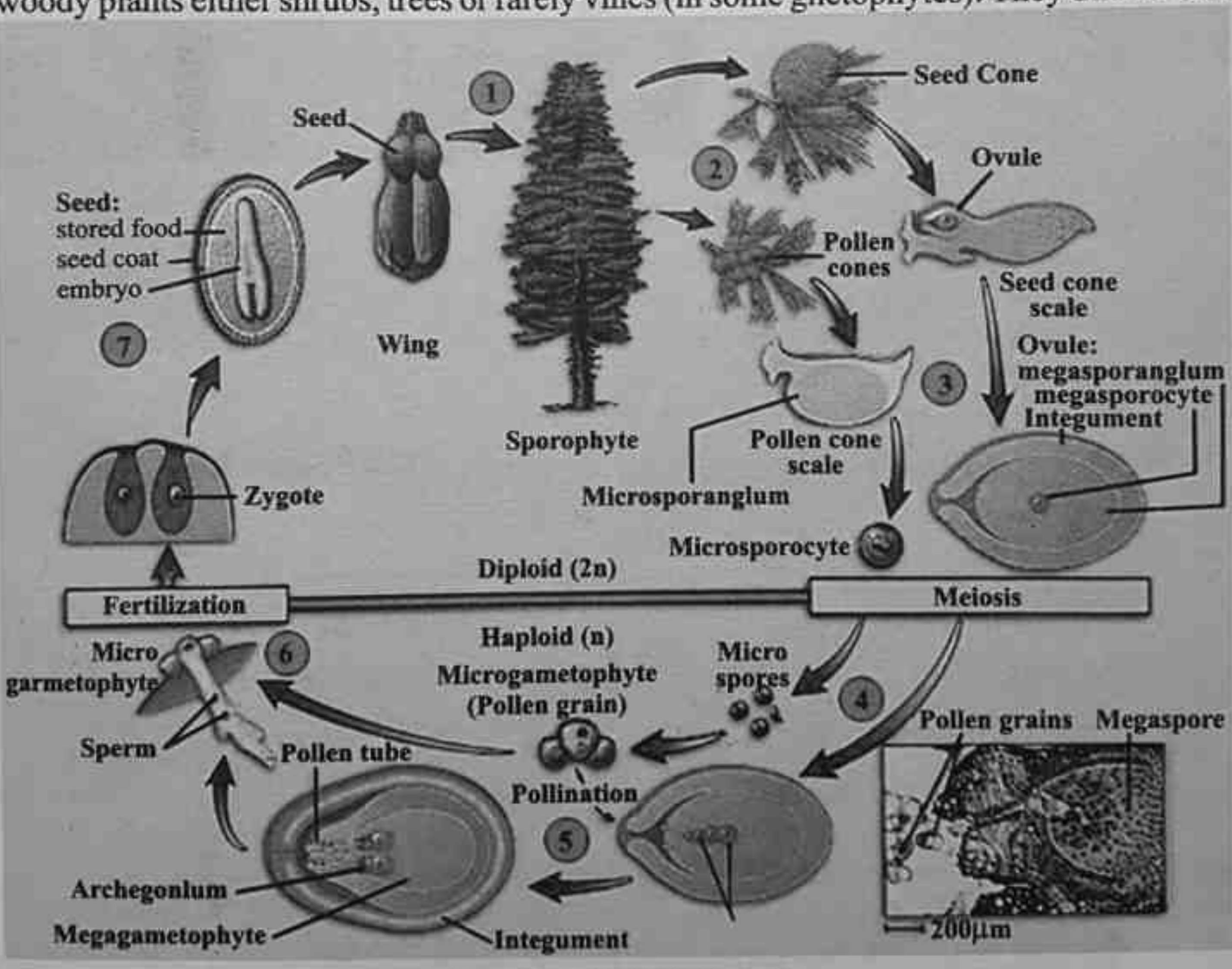


Fig. 8.12 Life cycle of *Pinus*

flowering plants in that the seeds are not enclosed in an ovary but are exposed within any of the variety of structure, the most familiar being cones. The plants show heteromorphic alternation of generation with independent dominant sporophyte and dependent reduced gametophyte. The female gametophyte is retained in the ovule permanently. The microspore develops on microsporophyll and megaspores develop on megasporophyll.

There are two types of leaves, i.e. **foliage and scale.** The leaves are evergreen and exhibit xerophytic features like thick and tough cuticle, sunken stomata etc. The xylem consists of tracheids and xylem parenchyma. **Polyembryony** is common but usually single embryo gets mature.

The important genera of gymnosperms are:

1. Cycas (Cycad)
2. Pinus (pines)
3. Picea (hemlock)
4. Cedrus (deodar)
5. Ginkgo
6. Ephedra


Ginkgo


Cycad

Fig. 8.13 Gymnosperms

Activity

Search the pictures of gymnosperms like Ephedra, Cedrus(deodar) and Picea(hemlock) from internet sources.

Table 8.1 Differences between male and female cones

Female cone	Male cone
• It is woody.	• It is herbaceous.
• It is large in size.	• It is small in size.
• It grows singly.	• It grows in groups.
• Borne on higher branches.	• Borne in lower branches.
• It is long lasting.	• It is short lived.

Importance of Gymnosperms:

The gymnosperms are used by man for following purposes.

- Their seeds may be used as food, e.g. pine, chilghoza.
- To obtain drugs, e.g., ephedrine which is obtained from *Ephedra.*
- Wood is used for making paper, construction, packing etc.
- Grown as ornamental plants like cycads.

Many commercial products, e.g., resins, turpentine's, tar and many oils, soap, varnish, nail polish, gum, perfumes etc., are obtained from gymnosperms.

8.4.2 Angiosperms (Greek: Angio means enclosed, sperm means seed)

All flowering plants belong to angiosperms. Like gymnosperms, angiosperms are seed producing plants. It is most diverse group of plants. They are distinguished from gymnosperms by characteristics including, flower, endosperm within seeds, and production of fruits that contain seeds. It is believed that angiosperms diverged from gymnosperms in Triassic period about 245 million years ago. There are 3,60,000 known species of plants out of these 2,35,000 species are angiosperms. All angiosperms are divided into two sub classes, i.e. monocot and dicot.

Life cycle of the flowering plants (Angiosperms):

Like other plant groups, angiosperms also show alternation of generation, i.e. both sporophyte and gametophyte generations are present which alternate with each other.

Sporophyte generation:

The adult flowering plant is diploid sporophyte consisting of root, stem, leaves and flowers. **Flower** is the reproductive part and is modified shoot. Each flower consists of pedicel, thalamus and floral leaves, i.e. sepals, petals, stamens and carpel. The **thalamus** is a modified stem while floral leaves are essential parts of flower. The sepals and petals are not essential for reproduction, however, sepals and petals are protective parts of flower and also attract insects for pollination. **Stamen** is the male reproductive part of flower and consisting of long filament having bilobed anther at its tip. In anther haploid microspores are produced by meiosis inside the pollen sacs. **Carpel** is a female reproductive part of flower. The basal broader part of the carpel is ovary, elongated part is style and terminal broad part of carpel is stigma. Inside ovary one or more ovules are present which are covered by integument. The embryo sac is surrounded by a tissue called nucellus.

Pollination:

The transfer of pollen grains from anther of stamen to the stigma of carpel is called pollination. The pollination may takes place either by insects, wind or water.

Gametophyte Generation:

The gametophyte generation is inconspicuous and haploid (n). There are separate male and female gametophytes.

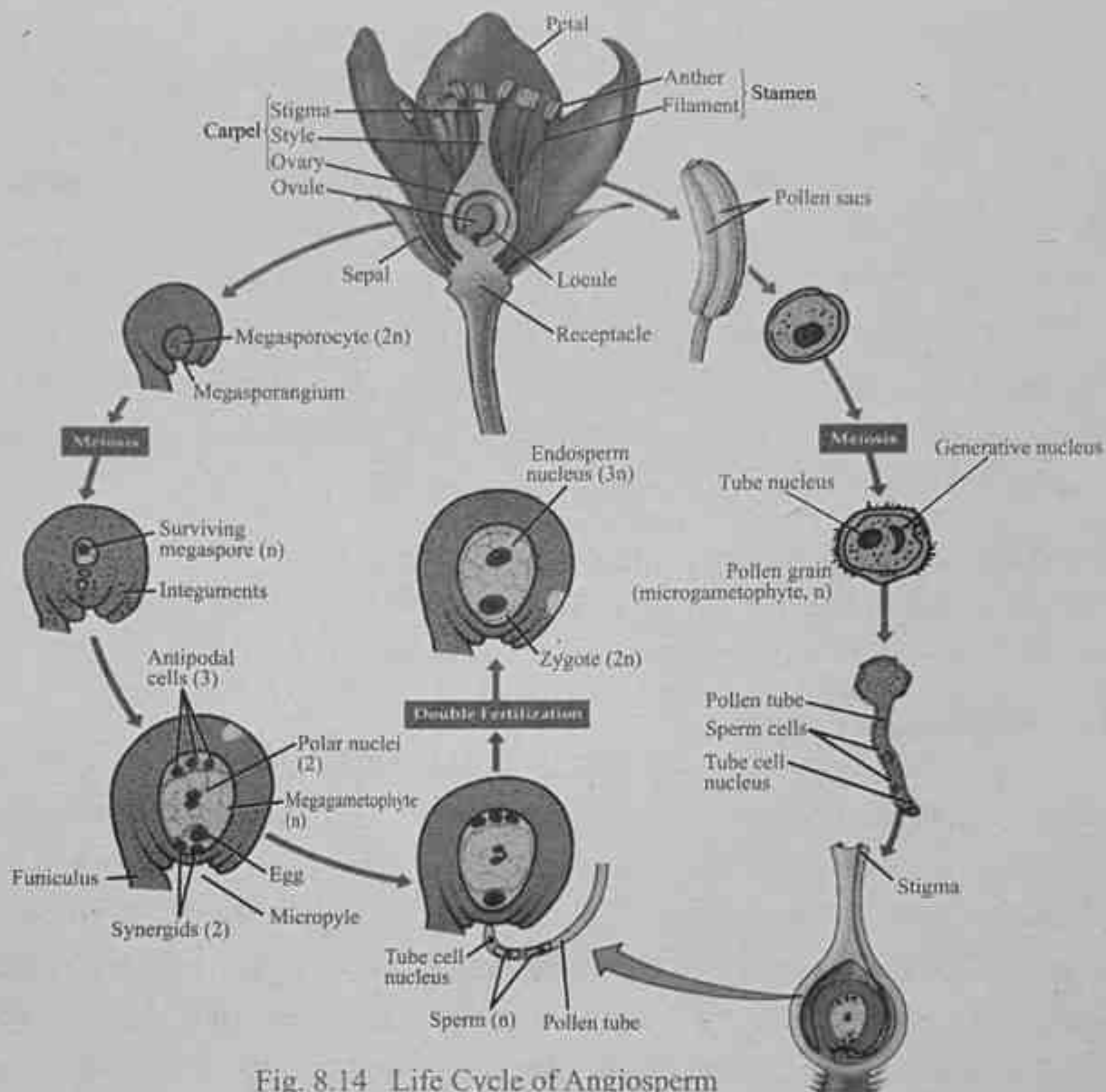


Fig. 8.14 Life Cycle of Angiosperm

Male gametophyte: After pollination, the pollen grain is transferred to stigma. Here it germinates to form pollen tube. The nucleus of the pollen grain divides by mitosis into two nuclei, one generative and other tube nucleus. The generative nucleus again divides into two sperm nuclei. The part of pollen tube with tube nucleus and two sperm nuclei is called male gametophyte.

Female gametophyte: Inside the ovule a single functional megaspore divides by mitosis to form female gametophyte or embryo sac. Embryo sac contains eight cells out of which one cell is egg or oospore.

Double fertilization: The pollen tube brings two sperms into ovule. One sperm fuses with egg to form zygote, while other sperm fuses with diploid nucleus to form endosperm. So it is called double fertilization which is unique characteristic of angiosperms.

Significance of double fertilization:

It is an important evolutionary advancement. The stored food is made after fertilization. This stored food is utilized at the time of germination.

Seed and fruit formation:

After formation of endosperm and embryo the ovule increases in size to form seed. Its integument becomes hard and dry to form seed coat or testa and tegmen. The wall of the embryo grows rapidly around the seed and matures to form fruits.

8.4.3 Inflorescence

An inflorescence is a group of flowers arranged on a stem that is composed of a main branch or a complicated arrangement of branches on stem. There are three main types of inflorescence.

1. Racemose
2. Cymose
3. Compound

Racemose Inflorescence:

In this type of inflorescence, the main axis does not end in a flower but it continues to grow and flowers arise laterally.

Cymose inflorescence:

The determinate simple inflorescence is generally called cymose. In cymose the primary axis terminates in a flower but the growth continues through the lateral buds. These buds give rise to lateral branches which bear flowers. The outer flowers are younger and upper flowers are older.

Compound inflorescence: In this type of inflorescence, the main axis branches once or twice repeatedly in racemose or cymose manner and these repeated branches bear flowers. The oldest flower are at the tip while the younger ones are away from it e.g., amaltas, wheat, rice etc.

Critical thinking

What are unisexual and bisexual flowers? Why are the stamens and carpels called the reproductive parts of flowers?

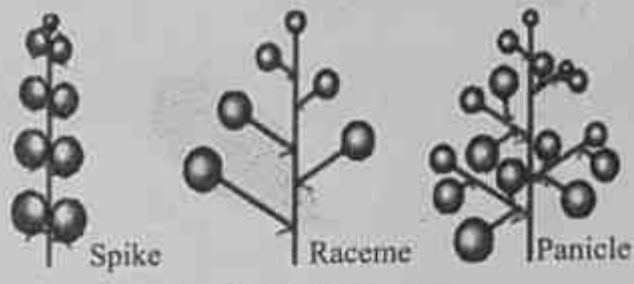


Fig. 8.15 Racemose

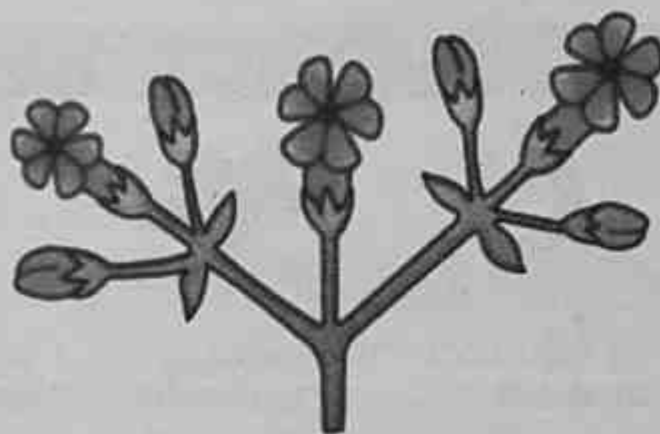


Fig. 8.16 Cymose

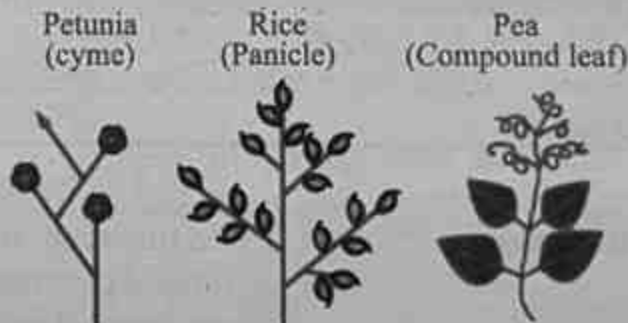


Fig. 8.17 Compound inflorescence

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Angiospermae consists of 416 families 13164 genera and 2,95,383 known species.

Table 8.2 Differences Between Monocot and Dicot.

Dicot	Monocot
1. Embryo has two cotyledons.	1. Embryo has one cotyledon.
2. Petals in multiple of 4 or 5.	2. Petals in multiple of three.
3. Leaf venation is reticulate, i.e. veins form network in lamina.	3. Leaf venation run parallel in the lamina.
4. Secondary growth often present.	4. Secondary growth absent.
5. Tap root system is found in them.	5. Fibrous root system is found in them.
6. Examples: peas, beans, roses, lilies, mints, tomatoes etc.	6. Examples: corn, wheat, rice, banana, bamboo, sugar cane, onion, grasses etc.

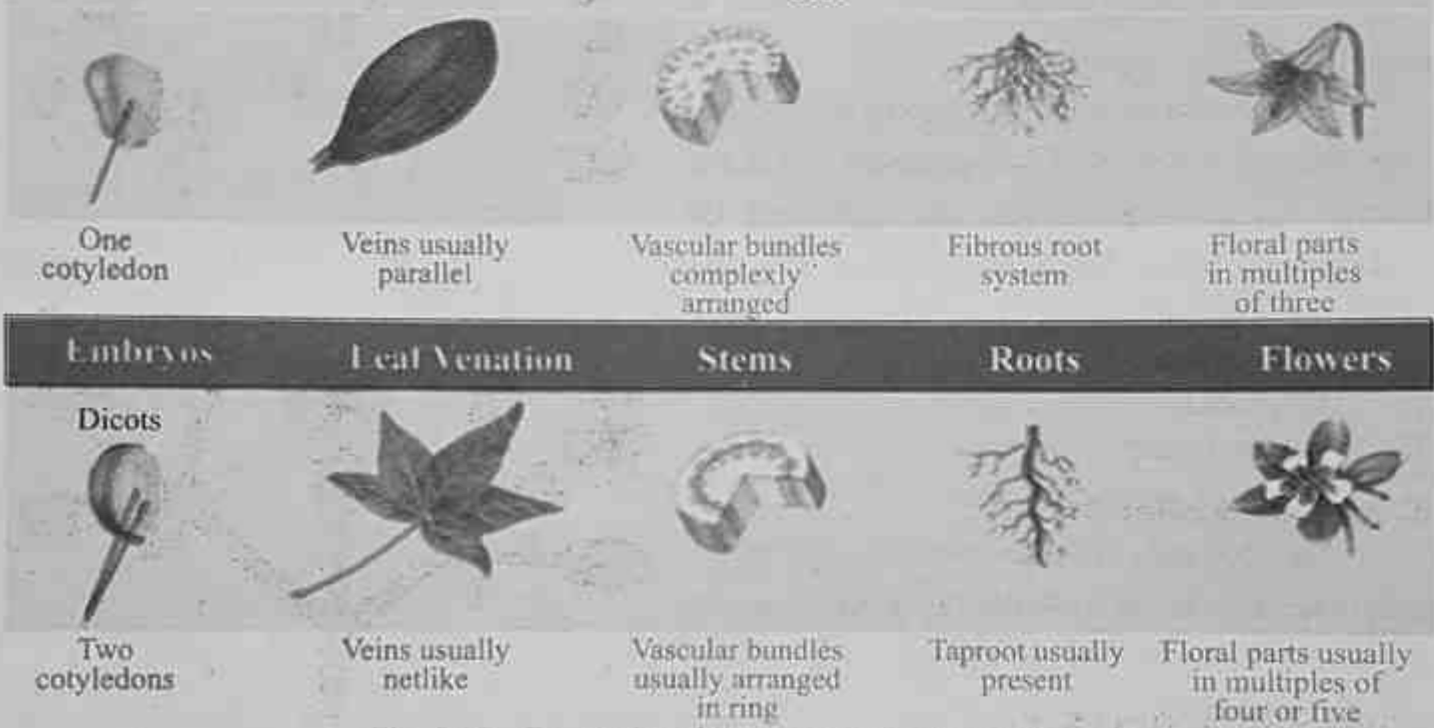


Fig. 8.18 Comparison between monocot and dicot plants

Do you know?

The earth has more than 80,000 species of edible plants. 90% of human food comes from just 30 plants. 70,000 plant species are utilized for medicine. Only 1% of rain forest plants have been studied.

Table 8.3 Comparison of Major Plant Groups

Bryophytes	Fertilization occurs in water, haploid generation is dominant, diploid generation is reduced, cuticle, stomata present in some. They are found in moist habitats.
Pteridophytes	Fertilization occurs in water, diploid generation is dominant in them.
Spermatomhyta **(a) Gymnosperms** **(b) Angiosperms**	Seed is present, fertilization mostly does not need Water. Vascular plants with naked seeds, no fruit or flower. Vascular plants with flowers and protected seeds.

Significance of angiosperms to humans: Angiosperms virtually provide all plant based food, i.e., Wheat, rice, sugar cane, maize, barley, rye, oats, etc. They provide a significant amount of livestock feed, provide all important vegetables like potato, tomato, peppers, cabbage, carrot, raddish, turnip, mustard. Great deal of fleshy fruits like cherries, mangoes, oranges, apples, water melon, peach, apricot, grapes, pears, plums and host of others. They are source of oils, like soybean, sunflower, mustard, coconut and olive. They are good source of dry fruits like almond, walnut, pistachio. Flowering plants also provide economic resources in the form of wood, paper, fiber (cotton, flex and hemp), medicines (digitalis, camphor) ornamental landscaping plants and many other uses.

Do you know?

A sunflower looks like one large flower, but each head is composed of hundreds of tiny flowers called florets, which ripen to become the seeds.

In one year, the average tree gives off enough oxygen to allow four people to breathe for a year.

SUMMARY

- The kingdom Plantae contains land plants, which manufacture their own food through photosynthesis and retain a multicellular embryo within the female gametangium. All plants have an alternation of generations.
- Plant kingdom includes bryophytes, pteridophytes, gymnosperms and angiosperms.
- Bryophytes are plants which can live in soil but are dependent on water for sexual reproduction. They possess root-like, leaf-like and stem-like structures.
- The bryophytes are divided into liverworts and mosses.
- The main plant body of a bryophyte is gamete-producing and is called a gametophyte. It bears the male sex organs called antheridia and female sex organs called archegonia.
- In pteridophytes the main plant is a sporophyte which is differentiated into true root, stem and leaves. These organs possess well-differentiated vascular tissues.
- The gymnosperms are the plants in which ovules are not enclosed by any ovary wall. After fertilization the seeds remain exposed and, therefore, these plants are called naked-seeded plants.
- In angiosperms, the male sex organs (stamen) and female sex organs (pistil) are borne in a flower.

- The angiosperms are divided into two classes – the dicotyledons and the monocotyledons.
- During the life cycle of any sexually reproducing plant, there is alternation of generations between gamete producing haploid gametophyte and spore producing diploid sporophyte.

EXERCISE

Section I: Objective Questions

Multiple Choice Questions

A. Choose the best correct answer.

1. Which of the following is the amphibian of the plant kingdom?
   (a) Pteridophytes (b) Bryophytes
   (c) Gymnosperms (d) Angiosperms
2. Liverworts are closely related to
   (a) Algae (b) Fungi
   (c) Lichens (d) Mosses
3. The only positive evidence of aquatic ancestry of bryophytes is
   (a) Thread like protonema (b) Green colour
   (c) Some forms are still aquatic (d) Ciliated sperms
4. If the chromosome number in the leaf of Funaria is 20, what will be the chromosome number in the spores
   (a) 20 (b) 40
   (c) 10 (d) 5
5. Most primitive living vascular plants are
   (a) Brown algae (b) Sphagnum
   (c) Ferns (d) Cycads
6. A fern differs from moss in having
   (a) An independent gametophyte (b) An independent sporophyte
   (c) Presence of archegonia (d) Swimming antherozoids
7. Spore baring leaf is called
   (a) Sorus (b) Indusium
   (c) Ramentum (d) Sporophyll
8. Circinate vernation is found in
   (a) Cycas (b) Fern
   (c) Both a and b (d) None of these

9. Megasporophyll is the term used in gymnosperm to denote
   (a) Carpels (b) Stamens
   (c) Leaves (d) Female cone
10. In which of the following feature angiosperm resemble gymnosperm.
   (a) Presence of ovules (b) Presence of vessels
   (c) Nature of endosperm (d) Mode of fertilization

A. Fill in the blanks.

1. The gametophytes of bryophytes possess______ number of chrmosomes.
2. The highly developed plants group is____________.
3. Liver worts are placed in the class__________.
4. The female sex organs of amphibious plants are called________.
5. Double Fertilization is the unique characteristics of ________.
6. Xylem tissues of angiosperms contain xylem vessels and also_________.
7. Adiantum belongs to group__________.
8. Gametophyte generation is dominant in_________ plants.

Section II : Short Questions.

1. What are sporangia and what do they do?
2. Define antheridia and archegonia and also write their functions.
3. Define alternation of generation.
4. Define sporangium, sporophyte and gametophyte.
5. Briefly discuss the economic and ecological value of the gymnosperms.
6. What changes have taken place to the gametophyte generations in seed plants?
7. How would you distinguish between following?
   monocots and dicots, microphyllous and megaphyllous leaves, xylem and phloem, male gametophyte and female gametophyte.

Section III: Extensive Questions.

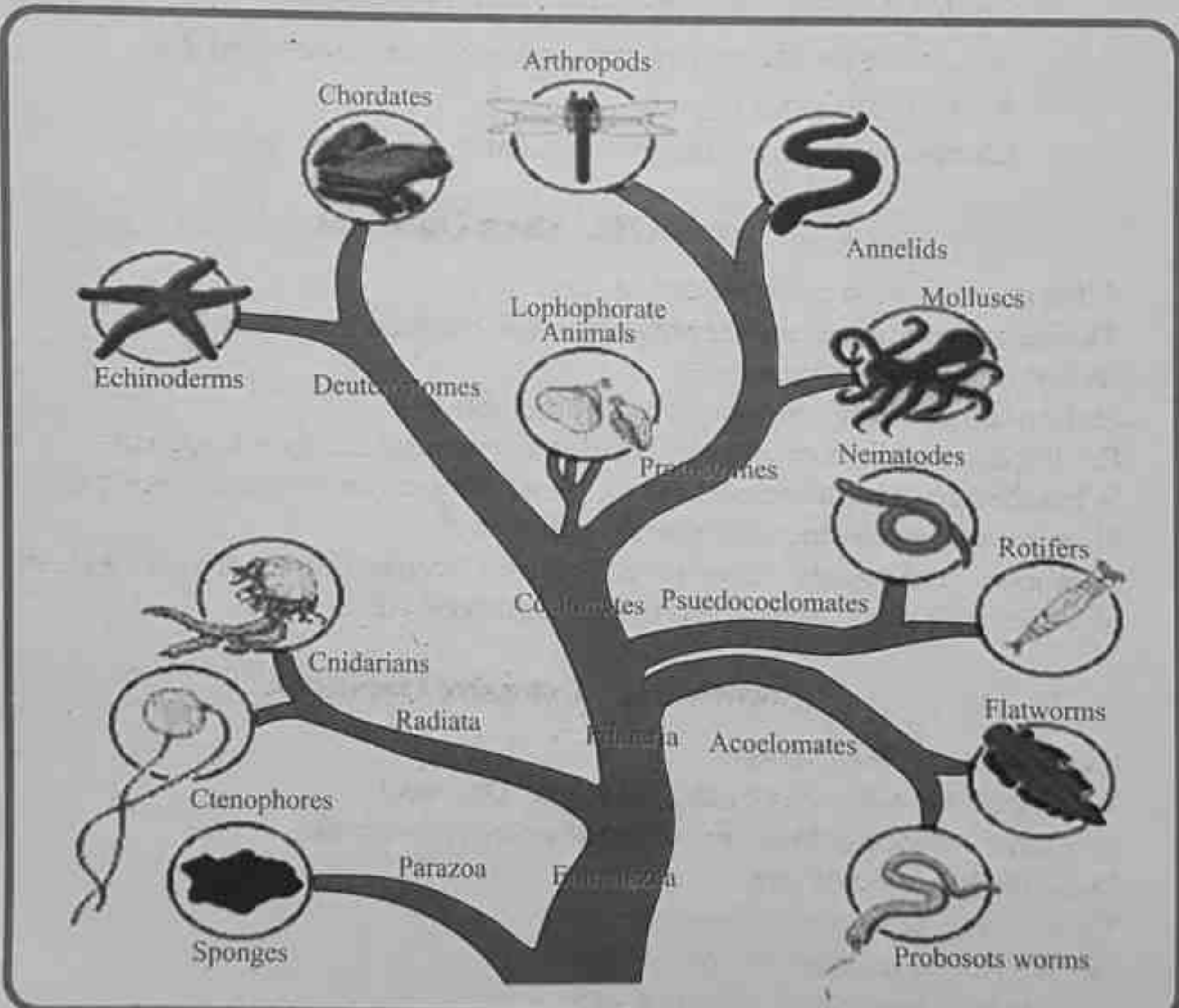
1. Explain life cycle of Moss.
2. How Sphenopsida differ from Lycopsida? Discuss.
3. Explain evolution of both one vein and many vein leaves.
4. Describe life cycle of fern.
5. Explain life cycle of angiosperm.
6. What is inflorescence? Explain its types.
7. Explain land adaptation of bryophytes.

UNIT 9

DIVERSITY AMONG ANIMALS

Major Concepts

9.1 Characteristics of Animals.
9.2 Criteria for Animals Classification.
9.3 Invertebrates.
9.4 Vertebrates.(Chordates).



Students Learning Outcomes

On completion of this unit students will be able to:

- Describe the general characteristics of animals.
- Classify animals on the basis of presence or absence of tissues.
- Differentiate the diploblastic and triploblastic levels of organization.
- Describe the types of symmetry found in animals.
- Differentiate pseudocoelomates, acoelomates and coelomates.
- Classify coelomates into protostomes and deuterostomes.
- Describe the general characteristics, importance and examples of sponges, cnidarians, platyhelminthes, aschelminthes (nematodes), molluscs, annelids, arthropods and echinodermates.
- Describe the evolutionary adaptations in the concerned phyla for digestion, gas exchange, transport, excretion and coordination.
- Describe the characteristics of invertebrate chordates and vertebrates.
- List the diagnostic characteristics of jawless fishes, cartilaginous fishes and bony fishes.
- Describe the general characteristics of amphibians, reptiles, birds and mammals.
- Differentiate among monotremes, marsupials and placentals.
- Describe the evolutionary adaptations in concerned groups for gas exchange, transport and coordination.

Introduction

The kingdom Animalia includes all animals. The word animal is derived from Latin word **anima** which means breath or soul. Animals are multicellular ingestive heterotrophic organisms which are developed by fusion of haploid "n" non motile eggs and haploid "n" motile sperms. They were originated from animal-like protists. The branch of biology which deals with the study of animals is called Zoology.

9.1 Characteristics of Animals

All animals are eukaryotic multicellular heterotrophic organisms, found almost in all types of habitat (such as terrestrial, aquatic, aerial, arboreal etc). Most animals are **motile**, some are **sessile** but their larval stage is motile, few are parasite and size ranges from microscopic (worms) to very large in size (Blue whale) almost 150 tons. **Locomotion**, mostly by means of muscle fibers. Most animals contain two sets of chromosomes in their body cell. They **respire** both aerobically and anaerobically. The body of animals may be from soft to hard, diploblastic or triploblastic, either radially symmetrical or bilaterally symmetrical, few are asymmetrical. Their body is mostly covered with shell, chitin, bony plates, scales, furs, feathers etc. Bilateral symmetrical animals may be either **acoelomates** (Platyhelminthes) or **pseudocoelomates** (Nematodes) or **coelomates** (from Annelida to chordate). They possess only **ingestive heterotrophic** nutrition. Animals have either incomplete digestive system (single opening) or complete **digestive system** i.e., tube like digestive system with mouth and anus at opposite ends. **Excretory system** is well developed in most animals while it is absent in poriferans and coelenterates. **Nervous system** in poriferans is absent while in coelenterates neuron net is present. It is well developed in most animals, sensory cells or sense organs are also present. **Respiratory system** is mostly present i.e., from arthropods to chordates, while lower non chordates respire only by diffusion from surrounding water.

> **Tit bits**
>
> *Currently there are 66 thousand types of vertebrates, about 5% of total 1.3 million animal species.*

Skeletal system is recorded in all animals, which is spicules or spongin fibers like in poriferans. In most invertebrates hydrostatic skeleton is present. While endoskeleton is recorded in few molluscs (cuttlefish), echinoderms and in all vertebrates. Exoskeleton is also present in many invertebrates (Arthropods, molluscs). It is also present in most chordates. The circulatory or **blood vascular system** is well developed from Annelida to Chordata, while in other invertebrates transportation occurs by diffusion.

All animals **reproduce** either asexually or sexually. Asexual by mitosis and sexual by meiosis and syngamy, embryo is present in all animals, they give birth to their young ones, or lay eggs.

Regeneration is present in poriferans, coelenterates, Platyhelminthes etc.

All animals lack cell wall, no plastids in their cells but **centrioles** are present.

9.2 Criteria for animal classification

Kingdom Animalia is divided into two subkingdoms i.e., parazoa and eumetazoa. (Table 9.1). The two subkingdoms are formed on the basis of presence or absence of cellular organization. The **parazoa** (para: beside: zoon; animal) are an ancestral sub kingdom of animals. They are simplest multicellular animals believed to be evolved from protozoans, their body is just collection of cells which are not differentiated into tissues or organs, there is some division of labour among cells but are not strongly associated to perform a specific collective function.

> **Do you know?**
>
> *The geometrical view of an organism is called symmetry. The asymmetrical animals do not exhibit symmetry.*

The only surviving parazoans are sponges belong to phylum **porifera.** Mostly asymmetrical animals, however, few are radially symmetrical.

Sub kingdom eumetazoa includes animals, in which body cells are arranged into tissues, the tissues organized into organs and organs into **organ systems** . The cells or tissues of eumetazoans are arranged into layers, either diploblastic (two germinal layers) or triploblastics (Three germinal layers). Germinal layers are present during development of an embryo.

Table 9.1 Broad classification of Kingdom Animalia based on common fundamental features

Kingdom	Levels of Organisation	Symmetry and Germinal Layers	Body Cavity or Coelom	Phylum

- **Animalia (Multicelluar)**
  - Cellular Level (Parazoa) — **Porifera**
  - Tissue / Organ / Organ System (Eumetazoa)
    - Radial (Diploblastic) — **Coelentrata**
    - Bilateral (Triploblastic)
      - **Without body Cavity - Platyhelminthes (Acoelomates)**
      - **With false coelom - Aschelminthes (Pseudocoelomates)**
      - **With true Coelom (Coelomates)**
        - Annelids
        - Arthropoda
        - Mollusca
        - Echinodrmata
        - Hemichordata
        - Chordata

Echinodermata exhibits radial or bilateral symmetry depending on the stage.

9.2.1 The sub kingdom eumetazoa can be classified on the basis of body symmetry into grade radiata and grade bilatera.

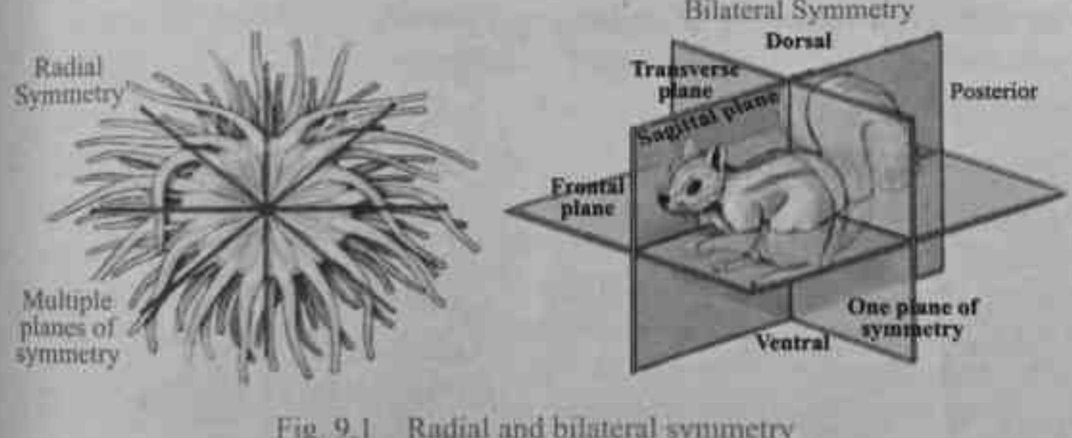


Fig. 9.1 Radial and bilateral symmetry

Table 9.2 Differences between Radiata and Bilatera

Grade Radiata	Grade Bilatera
1. This grade includes radially symmetrical animals e.g., coelenterates and adult of echinoderms.	1. This grade includes bilaterally symmetrical animals e.g., from phylum Platyhelminthes to Chordata.
2. The arrangement of body organ around a central axis and can be cut into two identical halves from any plane that pass through the central axis.	2. Their body can be cut into two identical halves from a single longitudinal plane running down the middle line.
3. No right and left side.	3. Right and left side, anterior and posterior ends, dorsal and ventral surface.
4. Mostly sessile animals thus considered an adaptation for a sessile life.	4. Mostly motile animals thus considered an adaptation to motility.

Table 9.3 Classification on the basis of arrangement of tissue layers. Either Diploblastic or Triploblastic

Diploblastic animals	Triploblastic animals
1. Two germ layers animals that is ectoderm and endoderm, in between these layers jelly like mesoglea is present which is mostly non cellular.	1. Three germ layers animals, the ectroderm, mesoderm and endoderm. These layers are visible only during embryonic development, later transformed into various organs.
2. Mostly devoid of specialized organs and organ systems.	2. Mostly specialized organs and organ systems are present.
3. They have no specialized nervous system rather have net work of neurons (nerve cells) with few ganglia. (aggregation of neurons).	3. They have specialized nervous system, having ganglia or brain.
4. Radially symmetrical animals.	4. Bilaterally symmetrical animals.
5. They have gastrovascular cavity with single opening, which act both as mouth and anus, example: phylum Coelenterata or Cnidarian.	5. They have well developed digestive system, which is tubular having anterior mouth and posterior anus or cloaca. Example: all phyla except coelenterata i.e. from Platyhelminthes to Chordata

9.2.2 Classification of animals according to coelom (Body cavity).

Coelom is a fluid filled cavity between outer body wall and the alimentary canal which is lined by mesodermal membranes.

The grade Bilatera is divided into three groups on the basis of kind of coelom.
1. Acoelomate 2. Psuedocoelomate 3. Coelomate

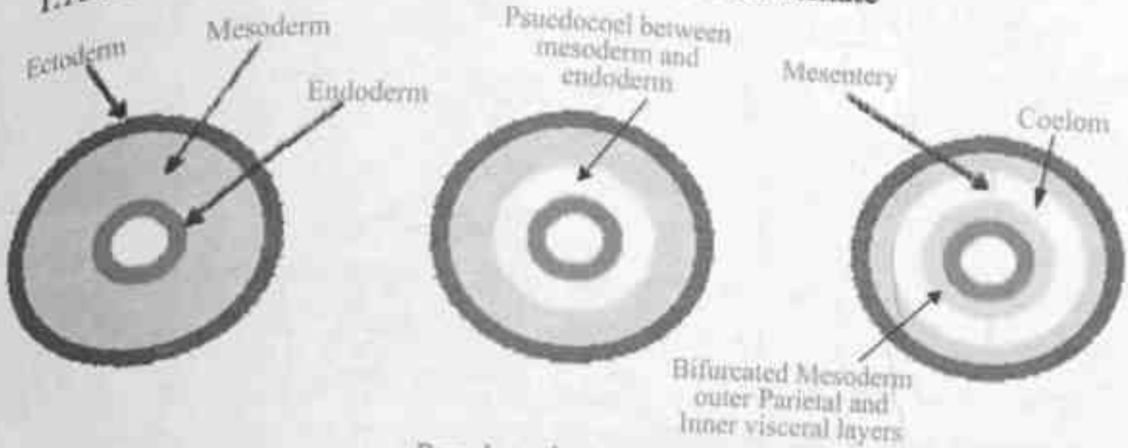


Fig. 9.2 Acoelomate Pseudocoelomate Coelomate

Table 9.4 Differences between Acoelomates, Psuedocoelomates and Coelomates

Acoelomates	Psuedocoelomates	Coelomates
1. No body cavity or coelom and recorded only in Platyhelminthes.	1. Possess false coelom thus called psuedocoelom and recorded only in nematodes (Aschelminthes).	1. Possess true body cavity or coelom and recorded from annelids to chordates.
2. No body cavity between digestive tract and outer body Wall, mesoderm form a loose, cellular tissue called parenchyma or mesenchyma.	2. Coelom is present between mesoderm and endoderm thus not covered by coelomic epithelium and is the remnant of blastocoel.	2. The mesoderm splits into outer parietal layer and inner visceral layer and filled with coelomic fluid.

9.2.3 Coelomates

Coelomates can be classified into two groups on the basis of early development.

1. Protostomes
2. Deuterostomes

The differences between Protostomes and deuterostomes are explained in table 9.5.

Tit bits

Cleavage is the division of zygote in which number of cells increase but size of cell hardly increase, cleavage is either radial or spiral.

Do you know?

*The **blastopore** is the first opening of the embryo while **archenteron** is the primitive gut.*

Critical Thinking

Bilateral symmetry is more successful body plane than radial symmetry. Can you guess why?

Table 9.5 Differences between Protostomes and Deuterostomes

Protostomes	Deuterostomes
1. Cleavage of zygote is spiral and determinate.	1. Cleavage of zygote is radial and indeterminate.
2. Blastopore or its anterior margin becomes mouth and anus is formed later on during development.	2. Blastopore become anus and mouth is formed afterwards during development.
3. **Schizocoelous** (that is coelom is formed by mesodermal splitting).	3. **Enterocoelous** (coelom is formed by out pouching of endoderm (archenteron).
4. The lips of blastopore produces mesoderm. **Examples:** Nematoda, Annelids, Molluscs and Arthropods.	4. The wall of archenteron produces mesoderm. **Examples**: Echinodermata, Hemichordata and chordata

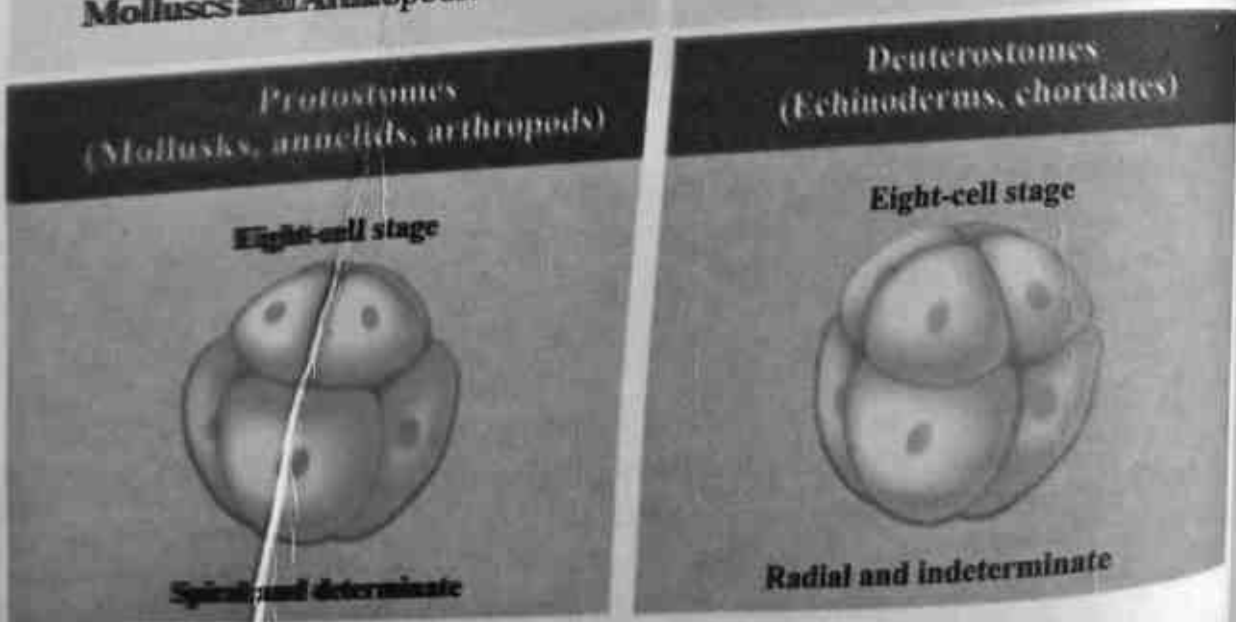


Fig. 9.3 Comparison between Protostomes and Deuterostomes

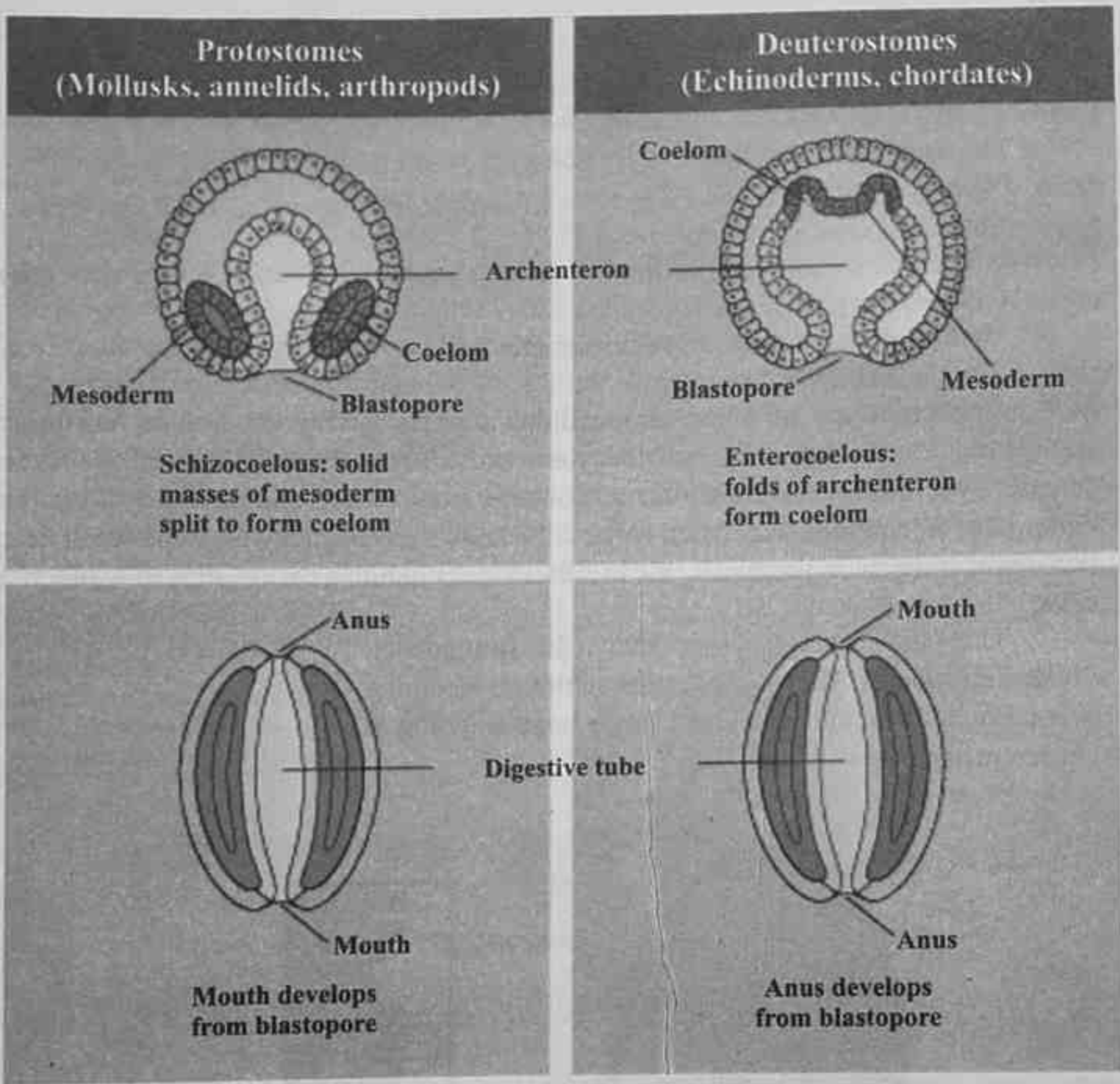


Fig. 9.3 Comparison between Protostomes and Deuterostomes

9.3 Invertebrates

Most biologists have divided the animals into two groups on the basis of presence or absence of vertebral column (back bone).

The group invertebrates lack vertebral column while group vertebrate possess vertebral column. Invertebrates account for 95% of known animal species, invertebrates are divided into eight major phyla, which are Porifera, Coelenterata, Platyhelminthes nematodes, annelids, Mollusca, Arthropoda and Echinodermata.

9.3.1 Phylum Porifera

(Greek: Poros means channels, Latin: Ferre means bear)

The name Porifera was given by Robert E. Grant in 1836. Phylum Porifera is also known as sponges and possess following characteristics.

> **Tit bits**
>
> *The mesenchyma of sponges contain amoeboid cell, store food give color while scleroblasts are spicules and spongin fibers forming cell.*

Habitat: Their larval stage is motile while adult is sessile (attached to submerged rock), about 10,000 species have been recorded.

Their **size** range from a few millimeter wide to more than a meter long (e.g., *scolymastra joubini* from Antarctica).

Body: Poriferans are simplest multicellular animals having no tissues and organ organization. Asymmetrical or radially symmetrical. The body wall is formed of an outer dermal layer known as **pinacoderm**, contains pinacocytes and an inner layer, the **choanoderm**, contains flagellated collar cells known as choanocytes. In between these two derms is a gelatinous matrix, the mesenchyma containing many kinds of wondering cells.

They have single body cavity, the **spongocoel**, divided into canals. The body contains numerous incoming or incurrent pores, the **ostia** and a single large outgoing or excurrent pore, the osculum.

> **Activity**
>
> *Draw the evolutionary tree diagram of coelomates. You may take help from the figure on title page of this chapter.*

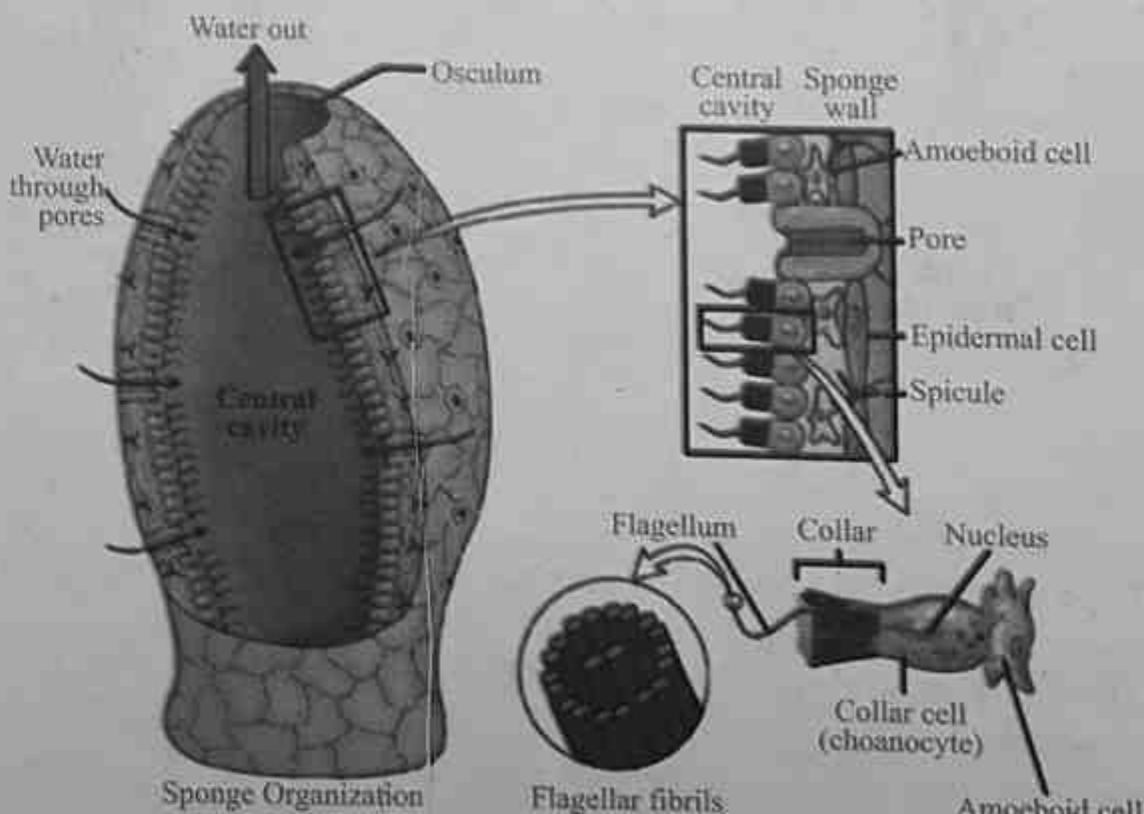


Fig. 9.4 Anatomy of sponges

Nutrition: Sponges are heterotrophic depend on food coming to their body with water current through ostia and moved in by flagella of choanocytes, where intracellular digestion takes place, the digested foods are transported by mesenchymal cells. The waste material either diffuse out of the sponges directly through the body wall or through osculum.

Nervous system is absent, but neuron and neurosensory cells help to coordinate water flow. The **skeleton** is formed of needle like structures the **spicules (either calcareous or silicious)** while some sponges, like **bath sponge possess sponging fibers**, osculum and ostia also contain spicules. The sponges possess both asexual and sexual reproduction. **Asexual**, either by external budding or internal budding (**gemmule** formation), **regeneration** is also common. Sponges are mostly **hermaphrodite** (Bisexual) and **protandrous** (male gametes develop before the female). **Fertilization** is internal, occur in mesenchyma. The sponges have probably evolved from flagellated protists known as **choanoflagellates.** Examples: sycon (marine sponge), *Leucosolenia* (erect tube shaped), *Euplectella* (glassy frame work), *Spongilla* (fresh water sponge).

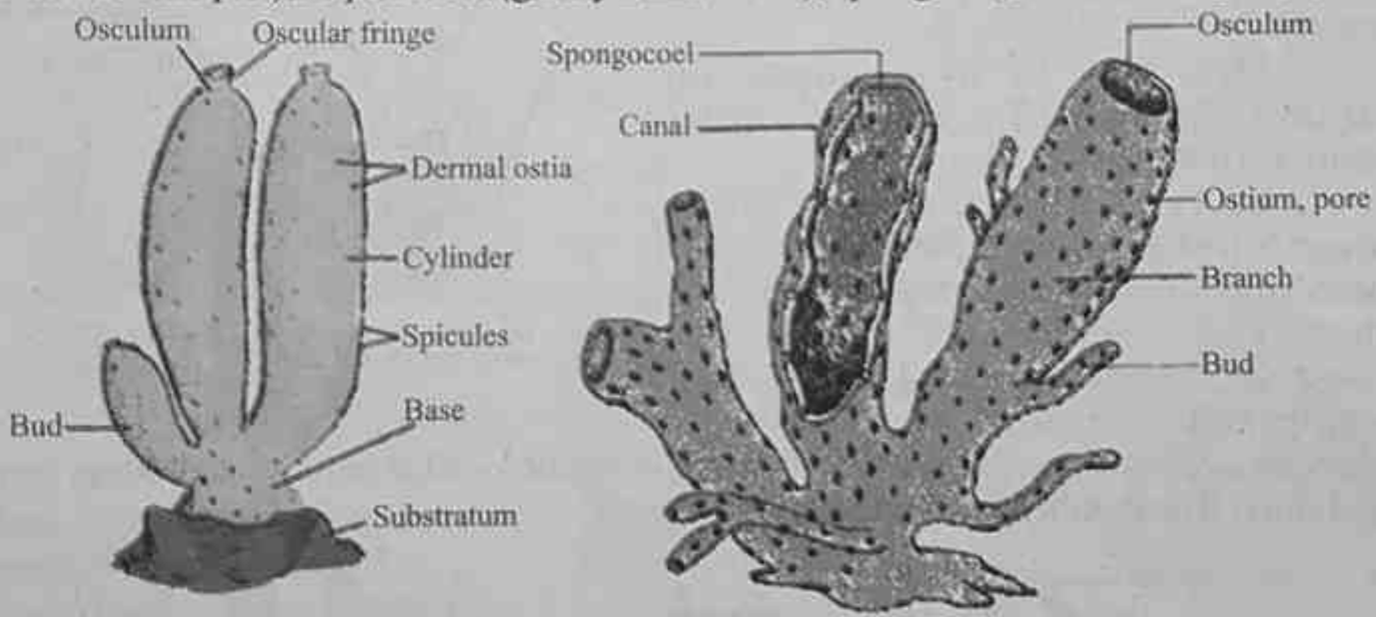


Fig.9.5 Scypha and Leucosolenia

Evolutionary adaptation in Porifera:

Sponges having intracellular digestion, which is facilitated by flagellated collar cells. The respiration occurs by diffusion, because almost each body cell is in contact with water.

> **Tit bits**
>
> *The food of sponges is 20% Zooplankton and phytoplankton, 80% detritus.* ***Detritus*** *is dead and decaying organic matter.*

Transportation of substances (food, excretory products) either by diffusion or by water current through canal systems. "Water enters through ostia into spongocoel and goes out of body through the osculum." They have weak coordination, only some neurosensory cells and neurons coordinate water flow.

Importance of sponges:

The **bath sponges** are used for washing and bathing by human. Sponges can greatly **absorb water** thus are used in surgical operation for absorbing fluid and blood. In large buildings, sponges are used for sound absorption, to **prevent echo.** They are also used as **decorative** purpose and used in shoe or **vehicle polishing.**

9.3.2 Phylum Cnidaria (Gk. Kindle, nettle, + L. aria connected with)

The name Cnidaria is given to this phylum due to the presence of specialized stinging cells called cnidocytes all over the body which give rise to nematocysts. The **nematocyst** is a capsule with paralizing venom which acts as offensive and defensive organ. Phylum Cnidaria exhibit following characteristics.

Habit and Habitat: Cnidarian are either sessile e.g., hydra or free living motile e.g., jellyfish). Many are colonial (e.g., *Obelia*). Most of them are carnivores. All cnidarians are aquatic (both marine and fresh water).

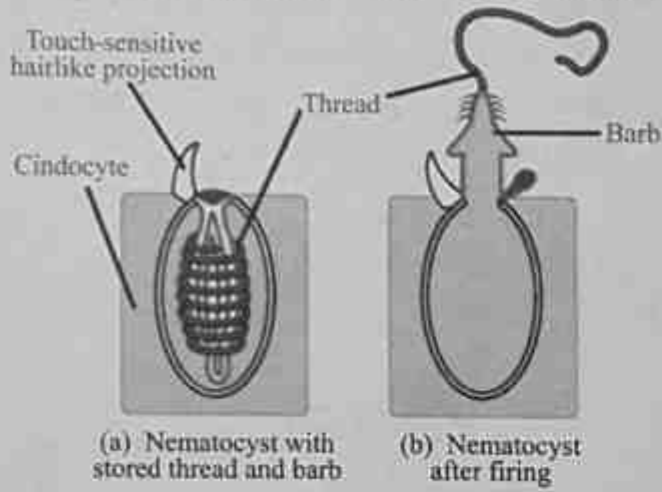


Fig.9.6 Structure of Cnidocyte

Size: may be from microscopic (*Hydra*) to very large (e.g., *Brachioceranthus*, up to two meter (in length.)

Body: Cnidarian are radially symmetrical, most are diploblastic i.e., have outer ectoderm and inner endoderm between these two layers, there is gelatinous cementing substance, called mesogolea. A single hollow internal cavity known as **enteron** or gastrovascular cavity with a single opening called mouth (act both as mouth and anus). The mouth is surrounded by **tentacles.**

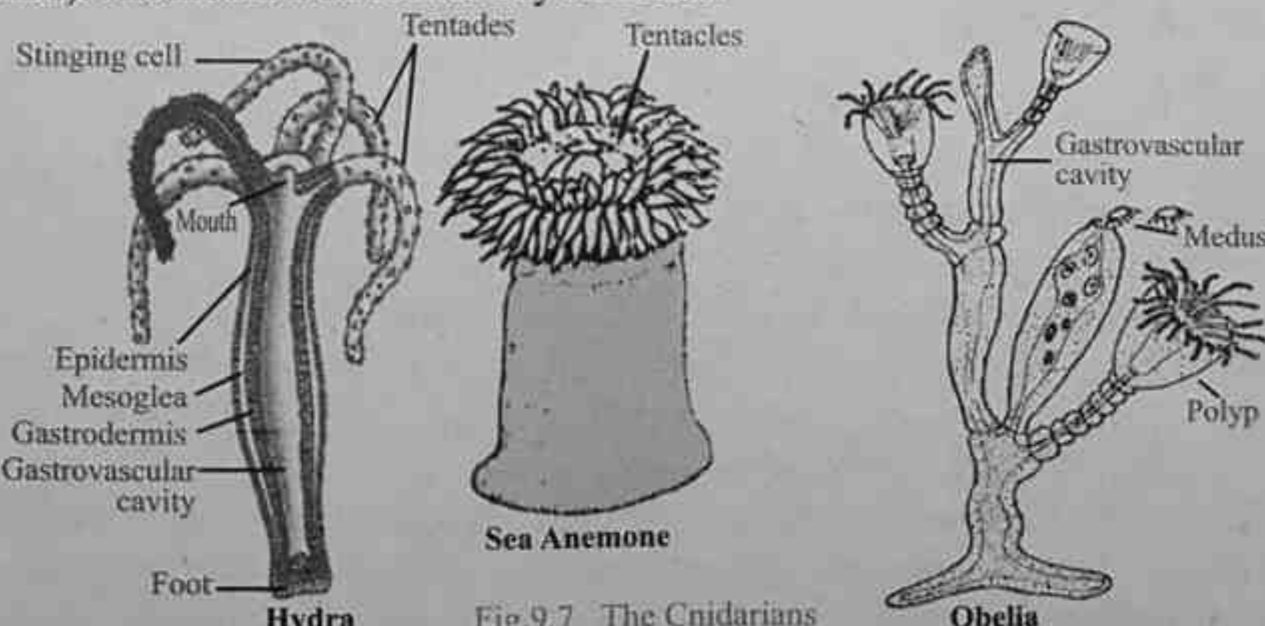


Fig.9.7 The Cnidarians

Nervous system consists of irregularly placed net work of neurons with few ganglia. Some colonial cnidarians exhibit **Polymorphism**.
They can reproduce both asexually and sexually. Asexual by means of budding and regeneration (such as in hydra), in sexual reproduction gametes are formed.

Do you know?

Class anthozoa of cnidarians is triploblastic.

Tit bits

*Polymorphism is a condition, in which a species has two or more very different structural forms there is division of labour among different group of cells, which are formed in units known as zooids, mainly they are of two types: **polyps or hydrozoids;** cylindrical feeding zooids, mouth is up wards and **Medusa** are umbrella shaped reproductive zooid. Their mouth is down ward.*

Evolutionary Adaptation in Cnidarians:

In cnidarian colonial forms exhibit **polymorphism** and **alternation of generation**, both polyp and medusa are diploid and diploblastic. Some colonies (like corals) grow to a great size, living in their own secreted skeleton, made of Calcium carbonate (lime) which they get from sea water by ectodermal cells. These skeletons form **coral reef** (under water ridge or rock) and even an island. Mostly found in Florida, West Indies, Austria, east coast of Africa. In cnidarian most systems are still not appeared such as transport, excretory, respiratory, thus only diffusion help in respiration and excretion. Although a sac like gastrovascular cavity is present.

Importance of Cnidarians:

Cnidarians are both beneficial and harmful such as coral reefs protect the shores from **erosion** by tidal waves. Many jewellery items are made by corals. Used as decoration in aquarium and rock garden. Some Cnidarians **sting human** (Jelly fish and sea anemone). In Pakistan, they are common at sea shores of Mekran and Karachi. Many people are affected by poisonous cnidarians while they swim.

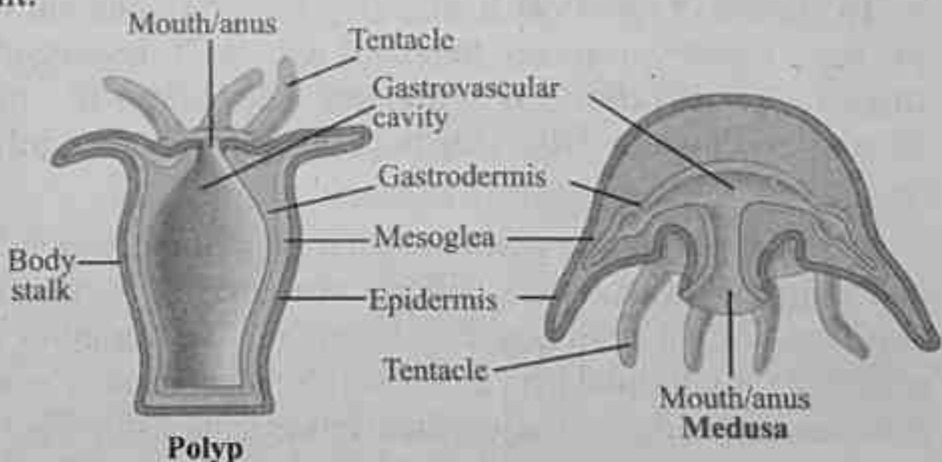


Fig.9.8 Polyp and Medusa

9.3.3 Phylum Platyhelminthes (Gk.Platy: flat , helminth: worm)

Platyhelminthes are also called flat worms or **acoelomate** worms. The characteristics of phylum Platyhelminthes are:

Habit and Habitat: Platyhelminthes are either free living (e.g., planaria) or parasitic (e.g., tapeworm). These worms are recorded both in fresh water and marine, while parasitic worms are also found in the liver and gut of humans beings.

Body: Flat worms are triploblastic, bilaterally symmetrical and soft bodied animals. Their body is dorsoventrally flattened and acoelomate. Free living forms possess

incomplete digestive system i.e., with a single opening known as mouth while less developed or absent in parasitic forms. **Excretory system** is well developed protonephiridial system containing flame cells. **Nervous system** consists of network of nerves, with two longitudinal nerves and anterior cerebral ganglion. Locomotion occurs by means of underside cilia.

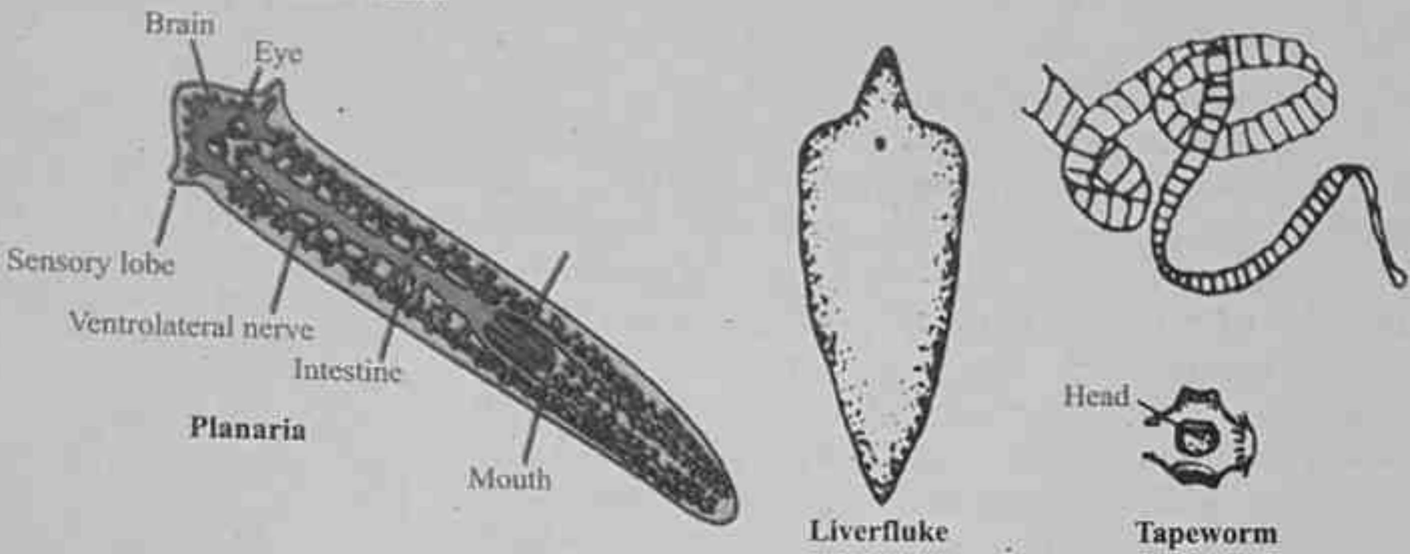


Fig.9.9 Platyhelminthes

Reproductive system: Asexual by fission (regeneration) sexual reproduction is also present. These worms are **bisexual** with well developed gonads, ducts and accessory organs, **fertilization is internal,** development may be direct or indirect. Examples: Planaria (*Dugesia*), liver fluke (*Fasciolla*) and Tapeworm (*Taenia*).

Evolutionary Adaptation in Platyhelminthes:

There is simple gastrovascular type of incomplete digestive system. Respiratory and transport systems are still not appeared, it occurs by diffusion. Excretory organs appeared, called protonephridial system. The initiation of centralized nervous system with two longitudinal nerves and cerebral ganglion. The parasitic form developed many parasitic adaptations to adjust themselves in parasitic life.

Importance of Platyhelminthes:

The parasitic flat worms cause many serious diseases. In human, such as liver fluke infect liver, tape worm to human intestine, and the blood fluke to cattle etc.

9.3.4 Phylum Aschelminthes (Greek: Askos means Sac, Helminths means worms) Nematodes or The round worms

Habit: Mostly parasitic, some are free living.

Habitat: Muscular and intestinal parasites of human and other animals, some are free living (in soil, roots of plants).

Body: Triploblastic and bilaterally symmetrical. Segmentation absent, body cylindrical and pointed at both ends. The body cavity is psuedocoel, which is remnant of blastocoel (not formed by mesoderm).

Digestive system:

It is complete, consists of a single tube with a mouth at the anterior end and anus at the posterior end.

Muscular layer: It is not continuous: divided into four longitudinal quadrants, (two dorsolateral and two ventrolateral). **nervous system** consist of nerve ring from which nerve cord and fibers extend in various directions.

Senses: Sensory papillae are present in front part of the body, especially on lips. **Sexes** are mostly separated. Dioecious some are monoecious, fertilization is internal. **Circulatory and respiratory systems** are absent.

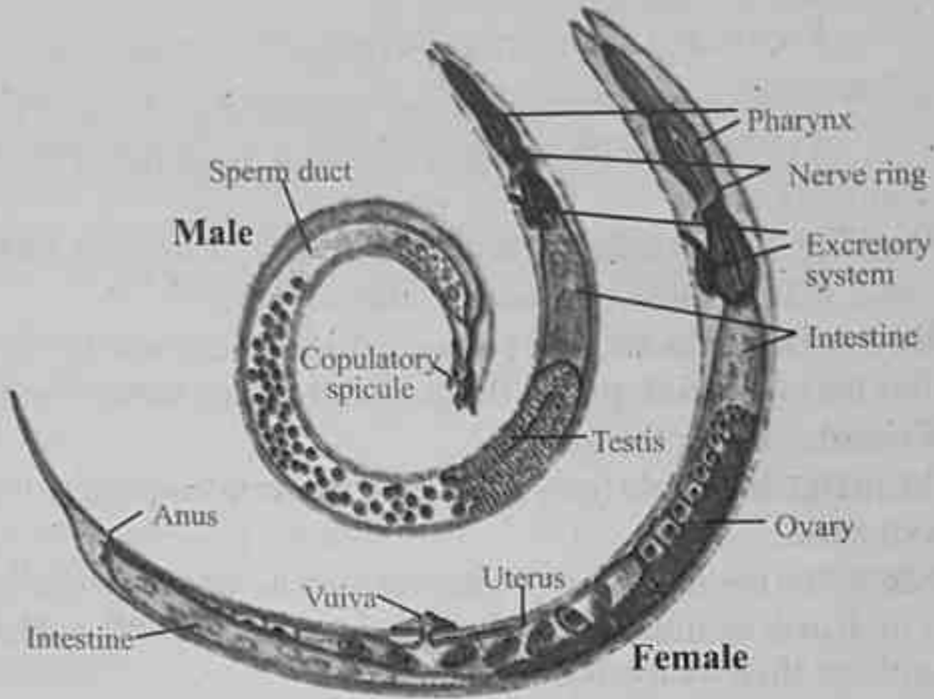


Fig.9.10 Ascaris

Size: varies from microscopic to large such as *Ascaris*, more than one feet in length. Examples: among parasites are *Ascaris*, pinworm and guinea worm, *Gaenorhabditis* (free living) etc.

> **Activity**
>
> *What are endangered species? Make a list of endangered animal species of Pakistan by searching internet and other reliable sources.*

Evolutionary adaptation in Aschelminthes:

These worms have adopted themselves in almost all types of habitat. This is the first phylum in which complete digestive system appeared, begin from mouth and end at anus. The circulatory and respiratory organs are still not appeared, however, excretory system consists of canals and protonephridia. Nervous system is also better developed than Platyhelminthes, possesses pharyngeal ring and many nerves.

Importance of Nematodes:

Aschelminthes (nematodes) are cause of many serious parasitic diseases, such as:

1. *Ascaris lumbricoides* is a human intestinal parasite which causes anemia, abdominal pain, fever, it also migrates to the lungs and causes cough and other complications.
2. *Rhabditis:* many species of this genus live in soil, organic matter, water and feces of many animals.
3. *Enterobius vermicularis* (pinworm): It is found all over the world especially in Europe, America live in caecum, appendix and colon of man, causes itching of anus, inflammation of colon and appendix, resulting insomnia and loss of

appetite.

4. Hook worms: *(Acyclostoma duodenale)* it is also parasite of human intestine and cause bleeding.
5. Free round worm: in soil, causes disease to potato, onion, cotton, apple etc.

9.3.5 Phylum Mollusca (Soft Bodied Animals) (L. Mollis, soft).

The term mollusk was introduced by Kontson in 1650 (about 50,000 species are recorded).

Habitat and habits: mostly free living, some are attached (sessile) found in fresh water, marine, moist soil and mountain rocks.

Body: Triploblastic, soft bodied animals. They are mostly haemocoelomate, coelom is divided into blood spaces. Body contains head, visceral region and muscular foot.

Found: all over the world.

Mantle: the whole body is covered in an envelope of glandular epithelial tissues known as mantle.

Shell: the mantle in many cases secretes a calcareous shell, which may be internal (cuttle fish) or external (snail), some without shell (octopus).

> ***Do you know?***
> *Squid is largest invertebrate 15 meters long, including tentacles.*

Systems: most systems are well developed (such as digestive, circulatory, respiratory, nervous and reproductive systems). **Respire** through gills or mantle. **Blood circulatory system** is of an open type (except, class cephalopods).

Radula: Tongue like structure provided with horny teeth. **Nephridia** are their excretory organs (may be one, two or six). **Nervous system** consists of a collection of ganglia in the head region forming a ganglionic mass, which is connected with the ganglia of foot and visceral mass. Mostly **Unisexual** few are bisexual. **Indirect development** (trochophore larva). **First invertebrate** in which both endo and exoskeletons were originated.

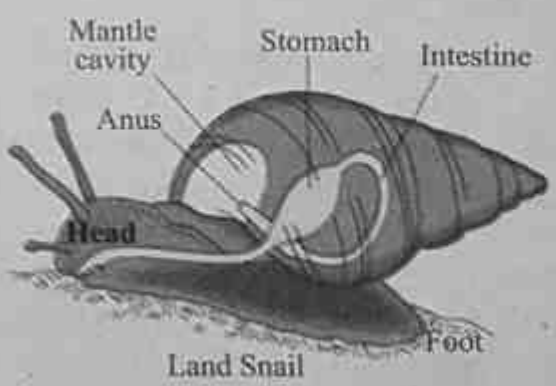


Fig.9.11 Molluscs

Evolutionary Adaptations in Molluscs:

Molluscs have complete digestive system, in the mouth cavity of many molluscs has rasping tongue (Radula) having many horny teeth, help in scraping flesh of animals and wood of ship.(e.g., *Toredo*)

Respiration occurs through gills, in many snails the mantle cavity is converted by a lung. Most molluscs possess open blood cirulatory system, consist of heart and blood spaces (sinuses). Excretion takes place through metanephridia, which open into the pericardial cavity, nervous system consists of three pairs of interconnected ganglia in the head, foot and viscera. The brain of octopus is large and complex enclosed in a shell and has got great ability to learn.

Economic importance of Molluscs:

They are both useful and harmful.

Useful Mollusks:

1. Some oysters make precious pearls e.g., pearl oyster.
2. Used in button industry (such as shell of fresh water mussel).
3. Used in road building (oyster shells are mixed with tar).
4. Used for the making ornaments.
5. Source of food in many countries (such as oyster, mussel, clam).
6. Oysters are used as for decoration.

Harmful Molluscs:

1. They cause injuries while working in garden e.g., slugs.
2. They destroy woods of ships e.g. *Toredo* a ship worm.
3. They destroy plants by cutting up their roots and stems.

9.3.6 Phylum Annelida (Segmented Worms)

(Latin, annulus; a little ring, Greek: eidos means form).

Habit and habitat: Free living, found on soil (earthworm) fresh water and marine (*Nereis*), some are ectoparasites (leech).

Body: Triploblastic, **metamerically segmented** (**Metamerism**: body is divided into segments both internally and externally by a transverse partition called septa **(septum** is a membrane) between segments. **Possess true coelom**, divided into compartments by septa contain coelomic fluid also acts as **hydrostatic skeleton** (i.e., become hard by fluid pressure).

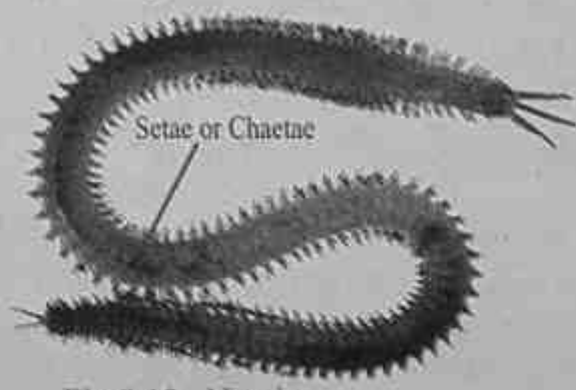


Fig.9.12 Nereis

Digestive system: It is simple in free living annelids while less developed in parasitic forms, consist of straight alimentary canal with mouth and anus at opposite ends.

Circulatory system: It consists of closed blood circulatory system.

(Note: first animal group, in which Closed Blood vascular system originated).

Excretory system segmentally arranged nephridia are their excretory organs.

Nervous system: Central nervous system is present having a dorsal pair of cerebral ganglia (a ventral double ganglionated nerve cord from which nerves arise.

Respiration is through skin.

Locomotion: The body wall is muscular in which there is an outer circular and inner longitudinal muscles. Muscles with hydrostatic skeleton help in locomotion. Chitinous **chaetae or setae** are locomotary organs in earth worm (embedded in sacs) while in *Nereis* **parapodia** are present. Leech is without locomotory organs.

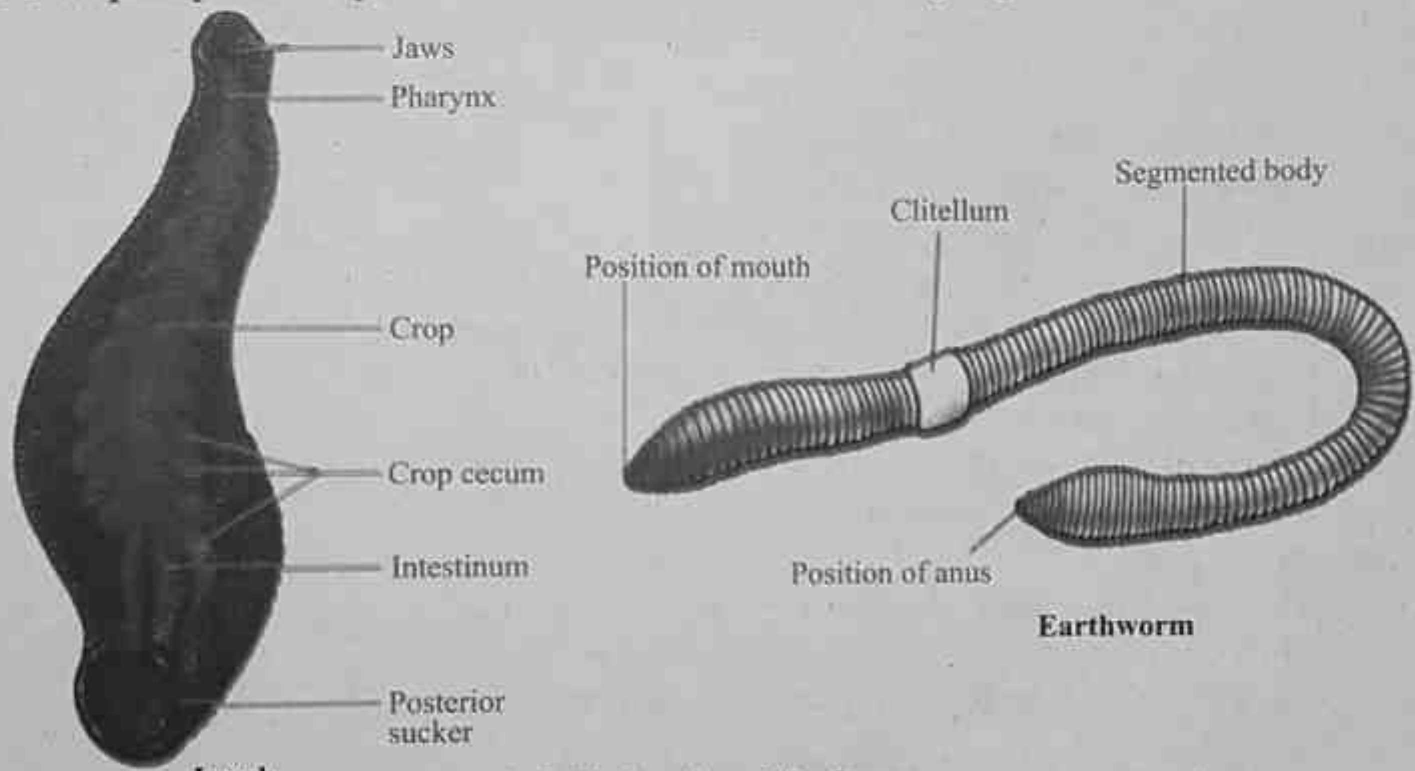


Fig.9.13 Leech and Earthworm

Reproduction: Most animals are bisexual or monoecious (e.g., leeches, earthworm), some are unisexual or dioecious (nereis).

Development: Either direct or indirect through trochophore larva.

Regeneration is present.

Evolutionary adaptation in Annelida:

There is great evolutionary adaptation in terms of feeding, that is from the sucking pharynx of the class oligochaeta and the chitinous jaws of carnivorous in class polychaeta to specialized tentacles and **cirri** of the ciliary feeders. The organs of locomotion are chitinous chetae or setae (in earth worm) and parapodia (in *Nereis*), in circulatory system formation of specialized blood vessels is another evolutionary adaptation.

Economic importance of Annelida:

Earthworms burrow itself in the soil thus permits great penetration of air into soil and improve **drainage capacity** of the soil and make the soil soft. It eases the penetration of roots. The earth worms are also known as the **nature's plough**. Many worms are used as food by fishes.

Table 9.6 Comparing Flatworms, Roundworms and Annelids

Characteristic	Flatworms	Roundworms	Annelids
Shape	Flattened	Cylindrical with tapering ends	Less cylindrical
Segmentation Body cavity	No Acoelomate	No Pseudocoelomate	Yes Coelomate
Digestion and excretion	Gastrovascular cavity with one opening only; flame cells remove metabolic wastes	Tube-within-a-tube digestive tract; opening at each end; metabolic wastes excreted through body wall	Tube-within-a-tube digestive tract; opening at each end; nephridia remove metabolic wastes
Respiration	Through skin; no respiratory organs	Through skin; no respiratory organs	Through skin; aquatic annelids breathe through gills

9.3.7 Phylum Arthropoda

(Gk. Arthron; jointed, pous; foot). Joint footed animals.

(The name was given by Ernst Von Siebold 1845).

Habit and Habitat:- May be free living or parasitic, found almost in all habitats.

Number: The biggest phylum comprised about 75% of the animal kingdom.

Body: (i) Segmented body (which are attached with one another by thin, flexible cuticle).

(ii) Possess several pairs of jointed limbs (appendages),

(iii) Body is usually divided into head, thorax and abdomen.

(iv) Body is covered with chitinous cuticle.

Coelom: Reduced haemocoel (connected with open blood vascular system).

Digestive system: Well developed with mouth and anus or cloaca.

Nervous system: Consists of paired ganglia

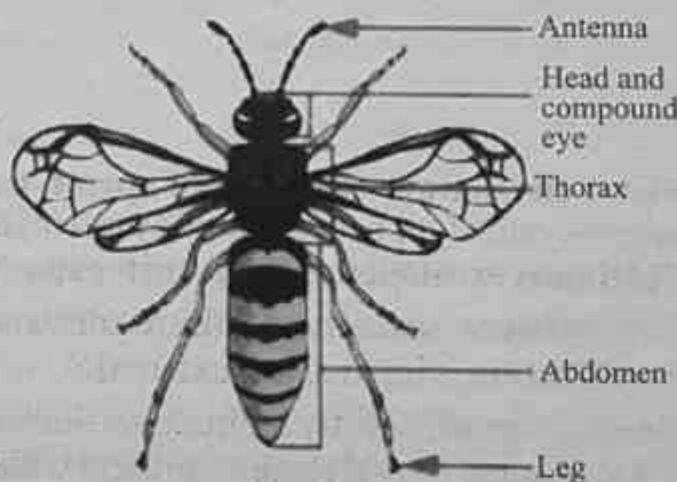


Fig.9.14 Wasp


Fig.9.15 Scorpion

which is simple brain and a central ganglionated nerve cord.

Sensory receptors especially eyes are present and also cuticular hairs. The mechanoreceptors e.g antenna.

Excretory system: Uric acid and guanine is their nitrogenous waste, removed through unique excretory organs called **Malpighian tubules** or **green glands.**

Respiration: Through trachea or gills.

Millipede Crab Centipede

Fig.9.16

Activity

Insects are most diverse and successful group of animals. Find out the secrets of their success through internet or any other source available to you and make a list of their adaptive characters.

Blood circulatory system is of open type, blood is colorless without haemoglobin but haemocyanin (copper containing protein) is present.

Chitinous exoskeleton is present for attachment of muscles.

Reproduces: sexually and all are unisexual.

Fertilization is internal and external.

Development; Mostly indirect, accompanied by metamorphosis, which is of two types: a) Incomplete (larval stage) is present which is similar to adult and known as nymph e.g., cockroach, b) Complete metamorphosis through egg, larva, pupa and adult e.g., butterfly.

Ecdysis or moulting: The periodic shedding of exoskeleton occurs during metamorphosis.

Why Arthropods are successful among Animals?

They possess jointed feet, segmented body, which provides them great mobility. Chitinous exoskeleton protects the body, and makes it light. Internal fertilization and development within egg case (coccoon). Appendages perform various functions such as quick movement, defense and offense and help them to live in variety of habitat.

Origin of Arthropods: It seems that both annelids and arthropods have some common ancestors because both groups possess segmented body, presence of cuticle, appendages but arthropods evolved several new advanced characters which made them most successful phylum in the animal kingdom.

Evolutionary Adaptation in Arthropods:

- There is great variation in the respiratory system of arthropods. e.g, marine arthropods respire through gills (prawn), terrestrial form have tracheae (cockroaches), book lungs (spiders) their blood circulation system is open type, i.e., no capillaries but possess dorsal contractile heart, arteries and blood sinuses which are formed by reduced haemocoel.
- Well developed complete digestive system with mouth and anus (cloaca). Mouth parts have modified forms of appendanges which are adapted for different methods of feeding.
- Excretory organs are paired with excretory glands known as coxal, antennae or maxillary glands. In many forms Malpighian tubules act as excretory organs.
- Central nervous system has dorsal brain connected by ring around the oesophagus with double ganglionated ventral nerve cord. Compound eyes and some other receptors (ocelli) are also recorded.

9.3.8 Economic importance of Arthropods

They are both useful as well as harmful to mankind.

Crustaceans: Provide food directly and indirectly to human (such as prawn, crab, lobster etc. Some are harmful because act as intermediate host for human parasite (larvae of nematodes) is carried by Cyclops.

Beneficial insects: Help in **pollination** (such as ants, butterfly, bees).

Used as food in some parts of world (such as grasshopper, cricket).

Scavengers; Eat dead and decaying plants and animals.

Commercial substances such as honey, bee`s wax, silk and shellac are produced by the honey bees, silkworms, and lac insects respectively.

Destroy useless weeds by feeding upon them.

Eat other harmful insects such as dragon fly feed on mosquitoes.

Scientific use: Several insects are being used for scientific studies, such as cockroach, fruit fly, grasshopper etc.

Harmful insects:

Destroy stored foods, grains.(ants and weevils).

Carrier of many parasitic diseases (mosquito; malaria), (Tse tse fly; sleeping sickness).

Damage crops, fruit trees and timber tree: For example grass hopper, bugs, locusts, beetles, caterpillars, weevils, aphids etc.

Damage books (silver fish), house hold articles (such as white ants destroy furniture).

They irritate human in various ways, such as bees sting, causes many eye diseases. There are certain blood sucking insects e.g., Louse.

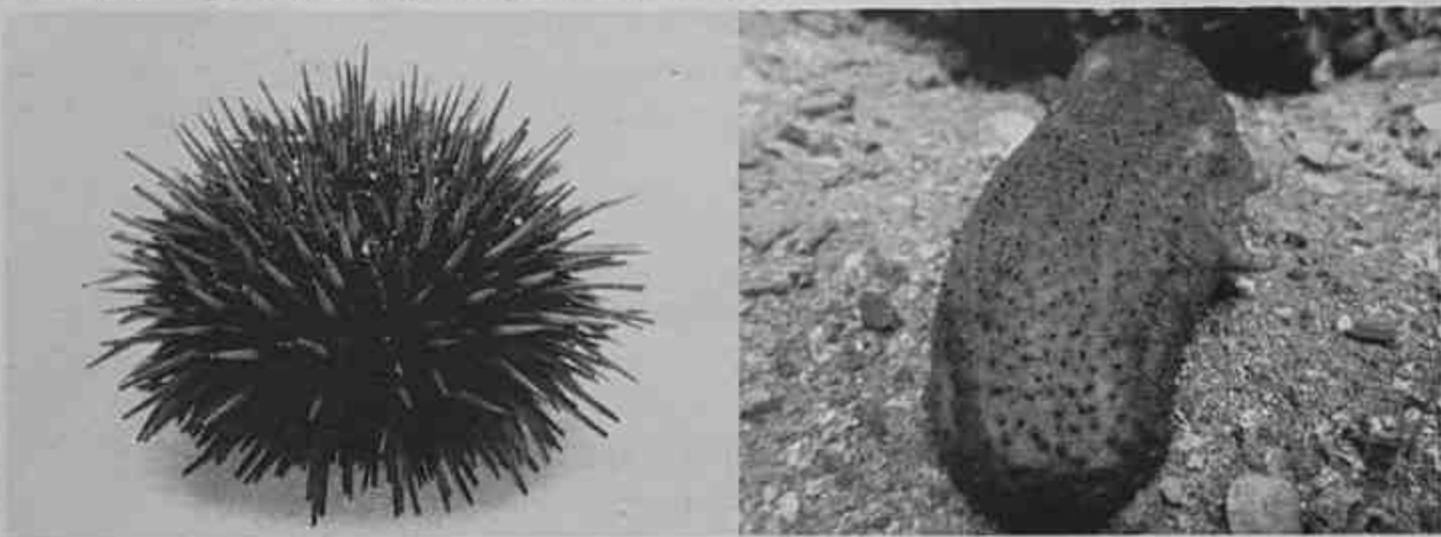
Arachnida: Poisonous arachnids like scorpion, certain spiders sting human. Ticks and

mites are parasitic disease carriers. Mites destroy crops.
Beneficial arachnids like scorpion and spiders feed on injurious insects.

9.3.9 Phylum Echinodermata (Spiny skinned animals)

(Greek: Echinos means spine, derma means skin)

Habit: Mostly free living, some are attached to substratum.
Phylum name was given by Leuckert in 1847.
Habitat: Exclusively marine.
Numbers: More than 5,000 known species are so far recorded.
Body: a) Triploblastic, b) Coelomate. c) Adult is radially symmetrical, d) A delicate epidermis covers the body, under which there is a firm mesodermal calcareous exoskeleton. e) The mouth is on lower surface (oral) and anus is on upper surface (aboral). f) From a central disc arms are radiated.



Sea urchin Sea cucumber

Fig.9.17(a) Sea Urchin and Sea Cucumber

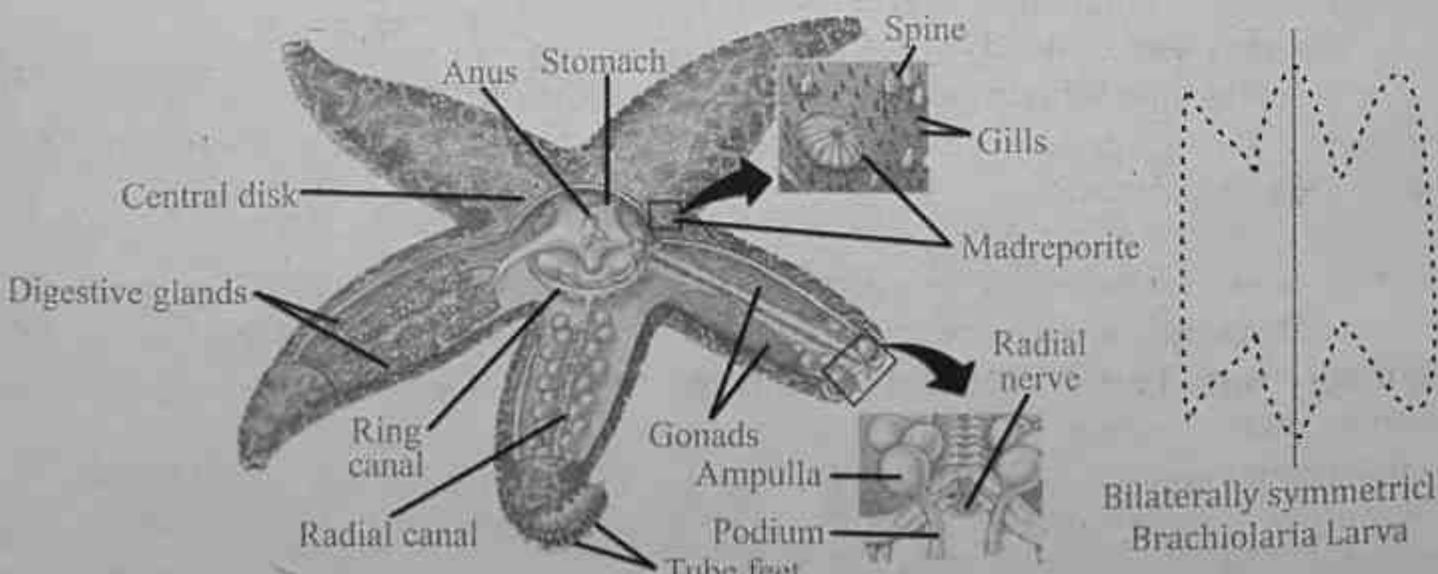


Fig.9.17(b) Sea Star

Shape: Biscuit shape, (such as cake urchin), star shaped with short arms (star fish), globular (sea urchin), star shaped with long arms (brittle star) or elongated (sea cucumber).

Water vascular systems: It is a system of complex tubes and spaces surrounding the mouth and passing into the arms and tube feet. In echinoderms water circulates through these coelomic channels, which enter through a sieve like plate called **madreporite** (present in the aboral body surface).

Locomotion occurs through tube feet.

Digestive and reproductive systems are well developed.

No specialized organs for respiration or excretion.

Poorly developed nervous system, consist of only a pharyngeal nerve ring.

Circulatory system is also less developed.

Fertilization is external and these are unisexual.

Development is indirect (complex and bilaterally symmetrical larva named as Bipinnaria and Brachiolaria.

Regeneration is common.

Examples: star fish, sea cucumber, sea Lilly, brittle star and sea urchin.

Evolutionary Adaptations in Echinoderms:

Echinoderm are first and only invertebrates which are deuterostomes, therefore, these are placed at the top of invertebrates, near to chordates.

Their body structure is simple, exclusively marine, (either **benthic or pelagic**). Digestive System usually complete, axial or coiled anus, absent in group ophiuroids. Nervous system become reduced due to marine nature, no brain, only nerve ring and radial nerve cord is present. Breath by dermal gills, tube feet and respiratory tree. No excretory organs.

Economic importance of echinoderms:

Many are used as food, starfish act as scavenger and thus clean sea water. Many echinoderms are used as fertilizer, because their dried skeleton contain large amount of calcium and nitrogenous compounds. Many echinoderms are poisonous such as sea urchin, sting human and other animals. They also damage oyster beds.

9.4 (a) Phylum Hemichordata (affinities)

Hemichordates closely resemble with both echinoderms and chordates because only these three groups are deuterostomes. So far only 70 species of them are recorded.

Hemichordates were earlier placed in chordates as a group, but now they are placed in a separate phylum. Although these animals have some chordate like characters such as deuterostome, pharyngeal gill slits, a dorsal nerve cord (some time may be hollow). However lack a complete chordate like notochord, Blood vascular system is non chordate like i.e., dorsal heart, epidermal nervous system like non-chordates characters. Thus given an independent phylum of its own and named hemichordata, and placed at the top of invertebrate phyla.

9.4 (b) General characteristics of Hemichordates (Tongue worms)

- Their body is soft and unsegmented and mostly worm like in shape.
- Body can be distinguished into proboscis, collar and trunk.
- Epidermis contains mucus secreting cells.
- Bilaterally symmetrical and triploblastic.
- Coelom consists of three portions.
- Gills are their respiratory organs.
- Blood is colorless and without cells.
- A dorsal heart having invertebrate like blood vessel.
- Well developed excretory system (glomerulus is present).
- Epidermal nervous system.
- These are either unisexual or bisexual.

Fertilization is external, indirect development.

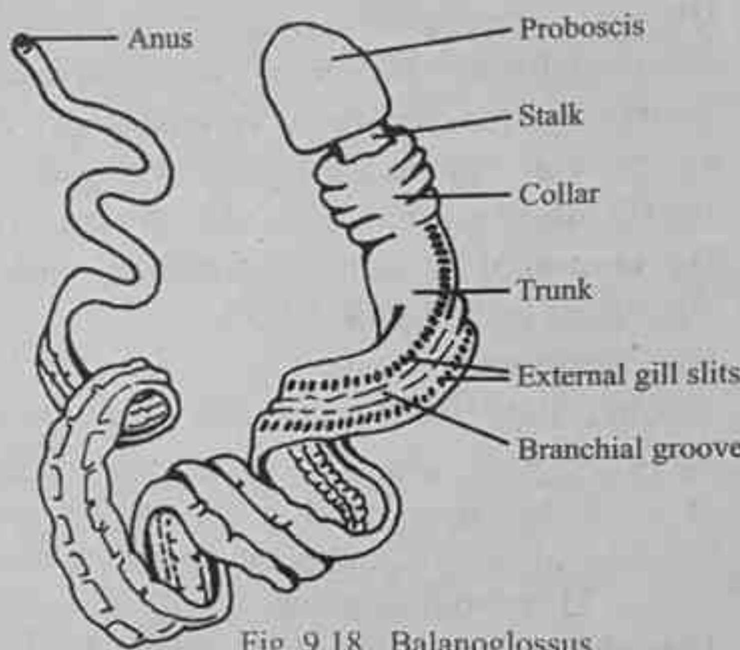


Fig. 9.18 Balanoglossus

Habits: Marine, either solitary or colonial, free living or fixed.

Nutrition: Feed on micro living things. Examples: Balanoglossus, Saccoglossus.

Phylum Chordata: The most successful, well known and widely distributed animals are chordates. Chordates exhibit great diversity of form, habitat and habit.

This phylum is divided mainly into two groups, invertebrate chordates (acrania) and vertebrate chordates (Craniata).

9.4.1 Fundamental or Basic Characteristics of Chordates

All chordates possess three basic or fundamental characteristics, during some stages or in whole life that is notochord, dorsal hollow nervous system, gill slits and as a fourth character and some times tail is also present.

Notochord is unjointed solid skeleton, placed above the alimentary canal and below the dorsal body wall and central nervous system appeared in the embryo of all chordates. In invertebrate chordates, it is present as such throughout life but in the vertebrates replaced into vertebral column, which is segmented. Serves as axial endoskeleton and give support to the body.

Dorsal hollow nervous system:

The central nervous system in chordates is dorsally placed, located above the notochord. It is hollow and fluid filled and non ganglionated nerve cord.

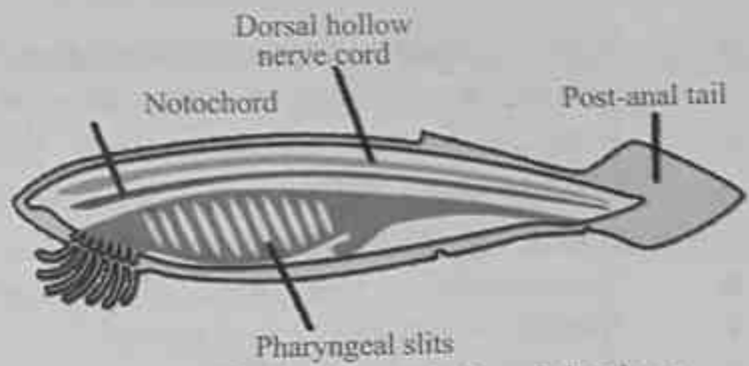


Fig. 9.19 Basic characteristics of chordates

Pharyngeal Gill slits and gill pouches are paired sets of openings in the pharyngeal region, in aquatic chordates it persists and functions as respiratory organ but in terrestrial vertebrates it is replaced into Eustachian or auditory tube, Parathyroid, tonsils and thymus.

Table 9.7 Classification of Chordata

- **Phylum Chordata**
  - Group Acrania (without skull)
    - Subphylum Urochordata
    - Subphylum Cephalochordata
  - Group Craniata (with skull)
    - Subphylum Vertebrata
      - Super class Agnatha
        - Class Cyclostomata
      - Super class Gnathostomata
        - Class Chondrichthyes
        - Class Osteichthyes
        - Class Amphibia
        - Class Reptilia
        - Class Aves
        - Class Mammalia

9.4.2 Invertebrate Chordates (Acrania)

The term Acrania means "without skull"

This division includes animals with following characteristics:

- These are without brain and cranium (brain box).
- Jaws, RBC and paired appendages are absent.
- Notochord never changed into vertebral column.
- This group consists of two subphyla.

Subphylum Urochordata (Uro; tail):

- In this sub phylum notochord is present only in tail region of larva while disappeares in adult.

- Nerve cord also disappeares in adult, only dorsal ganglion is present.
- The larvae are free swimming while adult are non motile.
- Body is covered with tunic (test). therefore also called **tunicata** e.g., ascidia, herdmania, molgula.

Subphylum Cephalochordata (Cephalo; head):
- Notochord runs mid dorsally throughout the body.
- Notochord and nerve cord persist throughout life.
- Example Amphioxus (Branchiostoma).

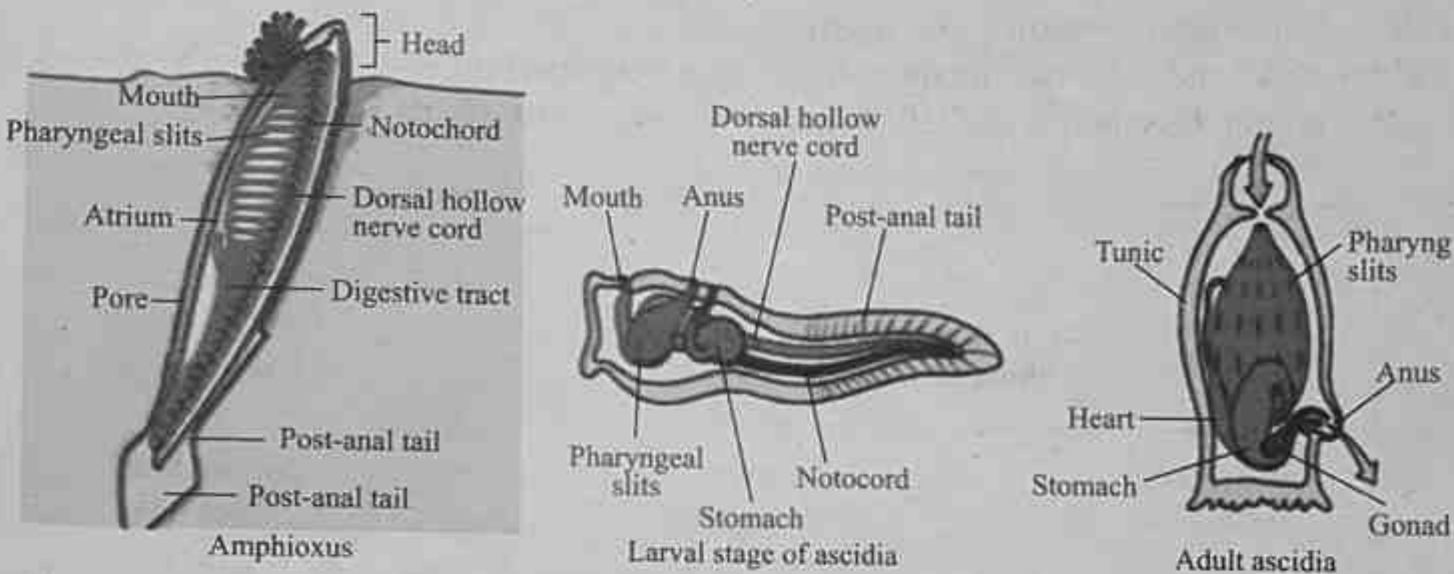


Fig. 9.20 Some Invertebrate Chordates

9.4.3 Vertebrate Chordates (Craniata)

It has only one subphylum known as **vertebrates.**
Vertebrates possess following characteristics:-
- Notochord replaced into vertebral column.
- Brain and cranium or brain box is present.
- Paired appendages are present. Teeth and jaws are present. RBC are present.
- Kidneys are their excretory organs. Tail is also present.
- Either aquatic or terrestrial. Many are aerial and arboreal.

The vertebrate chordates are divided into two super classes, Agnatha and Gnathostomata.

The **Agnatha** are without true jaws and no paired appendages while **Gnathostomata** with true jaws and paired appendages.

Agnatha: It has only one living class Cyclostomata.

9.4.4 Class Cyclostomata

(Cyclo; circular, stoma; mouth, because their mouth is circular).

These fishes are without true jaws and the most primitive group of living vertebrate. Their body is eel shaped and scales are absent. The skin is smooth and soft.

Cartilaginous skeleton and suctorial mouth. No paired appendages. Two chambered venous heart and many aortic arches. Digestive system without stomach. These animals contains 6-14 pairs of gills for respiration. Either unisexual (such as lamprey) or bisexual (such as hag fish). Cyclostomes have single testis or single ovary and without ducts. Fertilization is external, both direct and indirect development is present. In Lamprey prolonged larval period. Example; Myxini and Lamprey.

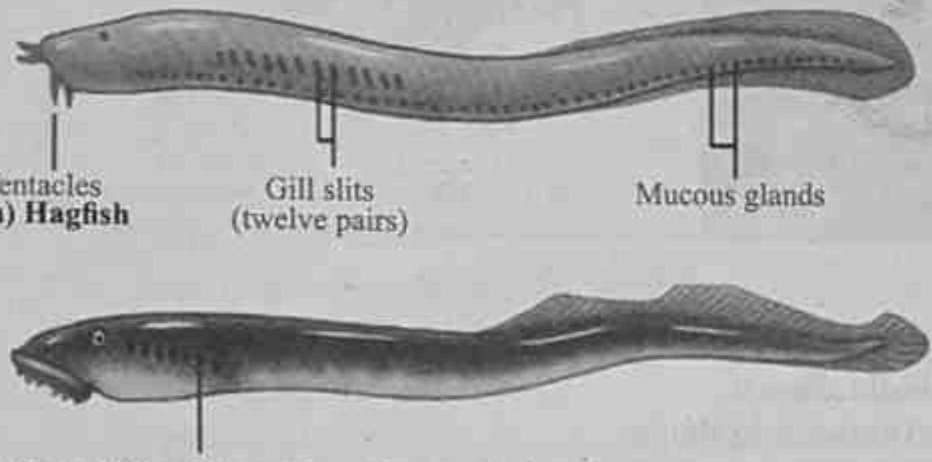


Fig. 9.21 Hagfish and Lamprey

> **Activity**
>
> *All vertebrates are chordates but all chordates are not vertebrates, Why? Echinoderms have been placed closet to chordates, write their affinities with chordates.*

9.4.5 Gnathostomata

This super class is divided into six classes, (Chondrichthyes, Osteichthyes, Amphibia, Reptilia, Aves, Mammalia). The gnathostomata have true jaws and paired appendages.

Class Chondricthyes (Cartilaginous fishes):

- These have spindle shaped body.
- The mouth is ventral and semi circular and nasal sacs do not open to the oral cavity.
- Tough skin is covered with sand paper like placoid scales.
- Respire through 5-7 pairs of gills, without operculum (lid).
- Endoskeleton is completely cartilaginous.
- Swim bladder is absent. They have cloaca.
- Stomach is J-shaped.
- Venous or branchial or single circuit heart; consists of a single auricle and single ventricle. 5-7 pairs of aortic arches.
- Sexes are separate and possess paired gonads. Fertilization is internal, oviparous or ovoviviparous.
- The largest of all fishes are included in this group (30-50 feet long).
- Examples: skate, rays, sting ray, electric ray, dog fish (sharks) etc.

> **Tit bits**
>
> *Two classes of fishes that is Chondrichthyes and Osteichthyes, some time together placed in a division known as **Pisces.***

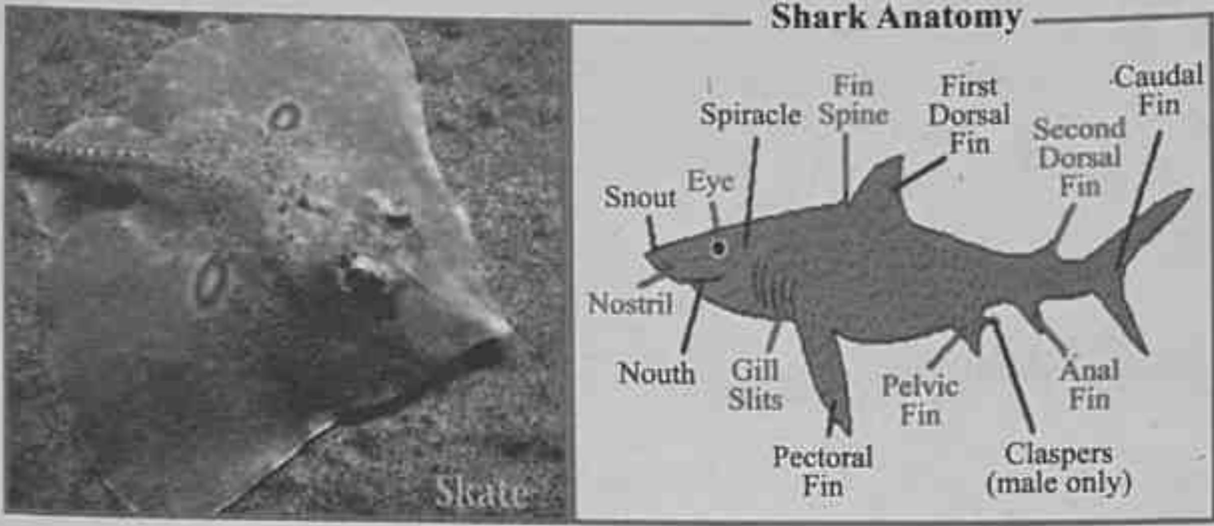


Fig. 9.22 Skate and Shark

9.4.5 Class Osteichthyes (Bony fishes).

- Their body is also spindle shaped.
- Mouth is terminal and variable in shape.
- The dermal scales are non placoid, either provided by ganoid, cycloid or ctenoid scales.
- Respire through, four pairs of gills which are supported by bony arches and covered with lid called operculum.
- Mostly possess bony endoskeleton.
- Swim bladder usually present which help in buoyancy.
- They have anus.
- Stomach is variable in shape.
- Venous heart consists of two chambers (an auricle and a ventricle).
- They have 4 pairs of aortic arches.
- Sexes are separate and paired gonads.
- Mostly external fertilization, few exhibit internal.
- Mostly oviparous however some are ovoviviparous.
- Brain has ten pairs of cranial nerves. Examples:- trout, cod, carp, catfish etc.

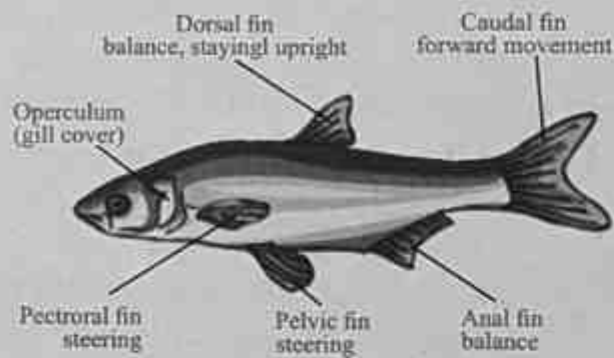


Fig. 9.23 Rohu

Economic Importance of Chondrichthyes:

Beneficial (1) Source of food (especially sharks and rays).

(2) Many commercial products are prepared by them (such as oil of shark liver is the source of vitamin A and D.

(3) The skin leather of shark is being used for making bags and shoes.

(4) Great medicinal value of pituitary gland of shark.

Harmful effect: Sharks feed on most of sea food which are used by human like prawn, crab, lobster and palatable fishes.

Economic Importance of Osteichthyes:

Beneficial effects:

1. Both fresh water and marine bony fishes are important source of our food such as cod, herring and salmon are examples of marine and trout, carp, catfish and mullet are fresh water fishes.
2. Commercial products such as fish oil, fish meat and liquid glue are made by bony fish.
3. Cod liver oil is the source of vitamin A and D.

Adaptation of Aquatic Life in Fishes (Pisces):

1. Their body becomes streamlined, which offer little resistance to water during swimming.
2. Presence of swim bladder in bony fishes help in buoyancy.
3. Fins: paired and unpaired fins help them in swimming and maintain their balance.
4. Gills for respiration.
5. Developed central nervous system and sensory organs.

Adaptation of Animals for Terrestrial (Land) Mode of Life:

Following adaptations are made by animals for terrestrial mode of life,

1. The skin is developed for protection against dry conditions.
2. Shelled eggs prevent the embryo from drying.
3. Large quantity of yolk as stored food in eggs.
4. Development of lungs for terrestrial respiration.
5. Modification of jointed appendages for running, walking, climbing and flying.
6. Well developed senses and specialized central nervous system.

9.4.6 Class Amphibia (Gk.Amphi;both, bios; life)

First land vertebrates (i.e., transition from aquatic to land habitat).

Origin: probably originated from Dipnoi which are lobe fin lung fishes.

Skin: smooth, moist, scale less and with many mucus glands, (also poisonous glands in some amphibians, chromatophores are also present).

Body form:- divided into head, trunk, tail or without tail.

Appendages: usually two pairs of legs but some are leg less (caecilians).

Respiration: In larvae it occurs through gills while in adult mostly through lungs and skin or few with gills e.g. in Siren.

Blood vascular system:- five chambered heart (right and left auricle, a single ventricle, sinus venosus and truncus arteriosus).

Sexes are separate with paired sex organs. Fertilization usually external (in some internal).

Mostly oviparous and exhibit Indirect development through metamorphosis.

They are Anamniotes (The embryo lacks protective membrane), **Poikilothermic** (cold blooded) that is why they hibernate in winter. Examples: frogs and toads tailless, salamanders are tailed amphibians. Caecilian are limbless.

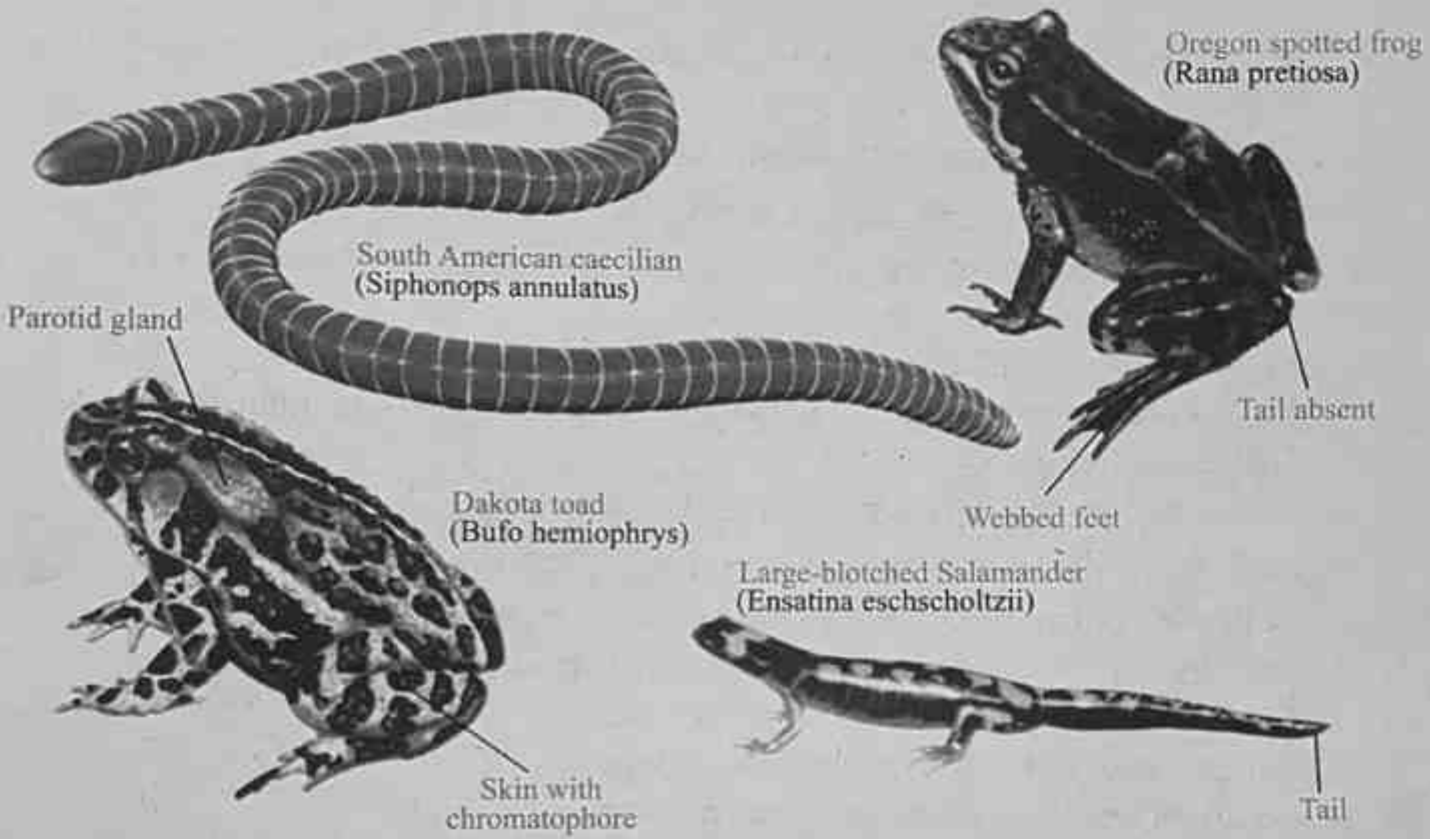


Fig. 9.24 Amphibians

9.5.7 Class Reptilia (Latin. Repere; to crawl)

Skin: Dry non-gladular scaly skin (snakes and lizards) or bony plates (tortoise and crocodile).

Appendages: either tetrapod and pentadactyl or some reptiles are limbless . They have four chambered heart (right and left auricle, a partly divided ventricle & a sinus venosis) except crocodile which have completely divided right and left ventricles and right & left atria.

All are cold blooded thus hibernate in winter.

Unisexual and fertilization is internal.

Mostly oviparous and amniotic eggs. Lays large yolky shelled eggs.

Skull with one occipital condyle.

They respire through lungs thus predominantly terrestrial and **first successful terrestrial group** .

Examples: cobra, wall lizard, turtle, crocodile.

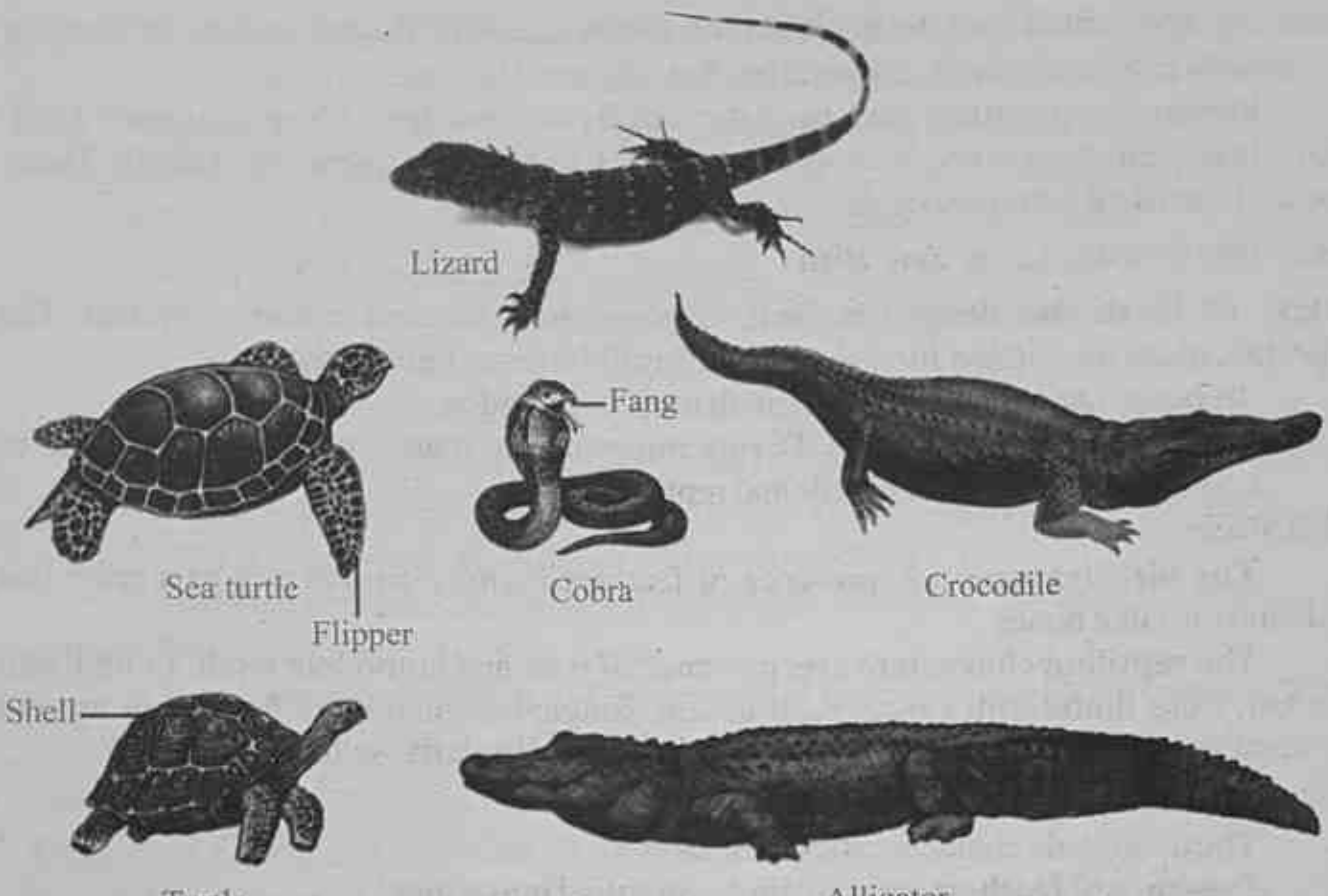


Fig.9.25 Reptilians

History of Reptiles:

The reptiles were flourished dominantly throughout Mesozoic period (i.e., about 225 millions to 65 million years ago) in geological time scale, during these periods they were represented by some giant species commonly known as dinosaurs. Today they are extinct (now only fossils record found). Most reptiles became extinct during tertiary period (about 50 million years ago) due to adverse climatic conditions.

Reptiles, in present

Fig.9.26 Archaeopteryx

times are represented by four evolutionary lines i.e., Lizards and snakes, sphenodon (found only in New Zealand), Crocodiles, Tortoises and turtles.

Present day's reptiles have been derived from dinosaurs of Jurassic period (196-136 million years before) and cretaceous period (136-65 million years ago (mya)). Today reptiles flourished in tropical zones.

Class Aves (Birds) Latin: avis; Bird

Origin of Birds:-No doubt that birds evolved from ancient running reptiles. The important discovery of two Jurassic (144-208 million years ago) birds:

1. *Archaeopteryx,* preserved in British museum London.
2. *Archaeornis,* preserved in Berlin museum Germany, provided evidence of connecting link between birds and reptiles.

Affinities:

The bird features are, presence of feathered wings; similarities to a crow like skull and bird like bones.

The **reptilian characters are**: presence of jaws and homodont teeth. Long lizard like tail. Fore limbs with claws. Keel absent. Single occipital condyle. Bones are not pneumatic. Except feathers fossils birds showed great similarity with dinosaurs.

9.4.8 Characteristics of Aves

The diagnostic characteristics of birds are:

Presence of feathers and fore limbs modified into wings.

Beak is present and teeth are absent.

Sternum is with keel.

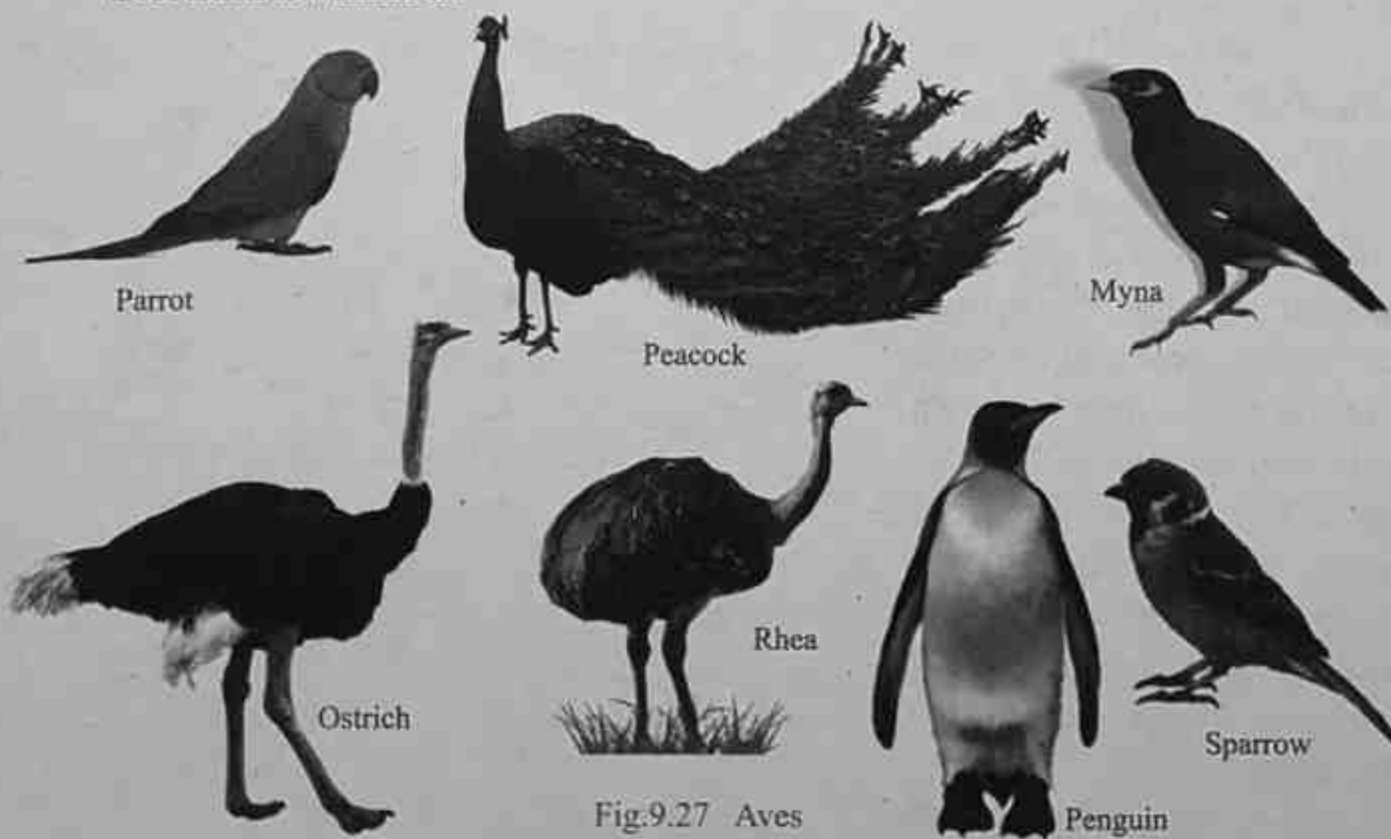


Fig.9.27 Aves

They have Single occipital condyle. Warm blooded **(homeothermic).**

Stream lined body is divided into a head, neck, trunk and a tail.

Bipedal locomotion and hind limbs are also modified for **perching.**

Hind limbs contain scales and claws and endoskeleton light and hollow.

Four chambered heart (two auricles and two ventricles) is present.

Only right aorta (aortic arch) is present.

Lungs are their respiratory organs, which are supplemented with **air sacs** and exhibit double respiration..

Syrinx is voice box in birds.

Kidneys are their excretory organs. Urinary bladder is absent to reduce weight.

Nitrogenous waste is uric acid which is removed as crystals through feaces.

Gizzard is grinding organ in their digestive system.

Unisexual and fertilization is internal. Birds lay large yolky eggs (Oviparous. Left ovary is functional.

Some birds have secondarily lost power of flight and are called running birds, such as kiwi, ostrich, emu, etc. Examples of flying birds: parrot, crow, pigeon, sparrow, kite etc, Example of aquatic bird is penguin.

Origin of Class Mammalia: (The Hairy Animals):

- There is no doubt that mammal forms the highest group in animal kingdom. They attained the most complete structural, physiological and developmental adaptations to terrestrial life and some secondarily also form aquatic life.
- Two most remarkable features of mammals are mammary gland in females and presence of hairs.
- Mammals have been evolved from cotylosaurian reptiles (evidence from fossil record).
- Fossil record exhibits that ancestral mammals and reptiles lived together during Jurassic period and have been called mammal like reptiles (in size mice like and were arboreal, One of these was genus varanops found as fossil in Taxas in USA).
- Mammals became dominant in coenozoic period (66.4 millions years ago till now).

9.5.9 General Characteristics of Mammals

The name was given by Linnaeus in 1785.

The diagnostic characteristics of mammals are presence of **mammary glands** (by which females nurse their young ones).

Body is mostly covered with **hairs** or **fur**.

The CNS is highly developed. Lungs possess numerous alveoli and bronchioles.

Diaphragm is present (muscular partition between chest and abdomen).

External ears (pinnae) are mostly present.

Sweat and **sebaceous (oil) gland** are also present.

Their bodies are of different shapes and mostly divided into head, neck, trunk and tail. **Warm blooded** animals. They have two pairs of pentadactyle limb modified for different habitats.

These have two occipital condyles in the skull and a large cranium.

Two sets of teeth during their life span (milk teeth and permanent teeth) dentition is heterodont. Heart with two atria and two ventricles and only **left aorta** is present.

Non nucleated Red blood cells except camels.

Testes mostly extra abdominal and urinogenital opening and anus is separated. Fertilization is internal and they are mostly viviparous (Birth of living young ones).

Classification of mammals:

The class mammalia is divided into three sub classes: Prototheria, Metatheria and Eutheria.

Sub Class Prototheria: (Egg Laying Mammals): Order Monotremes

They are connecting link between reptiles and mammals because they exhibit the characteristics of both groups.

Mammalian characters are: the presence of mammary glands, hair, diaphragm, left aorta.

Reptilian characters are: presence of cloaca, lay eggs, some reptilian skeleton, found only in Australia.

Examples:
1. **Echidna (spiny ant eater).**
2. **Duck billed platypus** are adaptive for aquatic life, the bill is modified like the beak of duck and webbed feet.

Class Metatheria: (Pouched Mammal; Marsupial).

Females possess an abdominal pouch (marsupium) in which they rear their immature young ones.

Mammary glands and nipples are present inside pouch.

They are generally burrowing and herbivorous.

Found in Australia and America. Examples: Opossum, Kangaroo, Tasmanian wolf.

Sub Class Eutheria: (Placental Mammals):

It is the largest group of mammals in which development of young one takes place inside the body of mother. The young are nourished through placenta thus true viviparous. Anus and urinogenital openings are completely separated. Possess almost all mammalian Characteristics i.e., diaphragm, external ears, hair and mammary glands.

In some forms hair modified into spines like porcupine and hedge hog while in pangolin into scales. Examples: Goat, dog, horse, elephant, seal, whale, dolphin, man, monkey etc.

Fig.9.28 Mammals

Do you know?

Shrews have so little body fat that they cannot go more than a couple of hours without food. Missing a meal is a sure way to a quick death. A good night's sleep could be fatal.

Do you know?

A female Pacific Grey Whale gestates and delivers a 2000 pound baby, migrates over 10,000 miles, and produces 6 tons of breast milk without eating a bite of food using just her blubber for fuel.

SUMMARY

- Radially-symmetrical animals are diploblastic, developing two germ layers: an inner layer (endoderm) and an outer layer (ectoderm). Diploblasts have a mesoglea between the endoderm and ectoderm. Bilaterally-symmetrical animals are called triploblastic, developing three tissue layers: an inner layer (endoderm), an outer layer (ectoderm), and a middle layer (mesoderm).
- True animals can be largely divided into three groups based on the type of symmetry of their body plan: radially symmetrical, bilaterally symmetrical, and asymmetrical.
- Triploblasts can be differentiated into three categories: those that do not develop an internal body cavity called a coelom (acoelomates), those with a true coelom (coelomates), and those with "false" coelom (pseudocoelomates).
- Bilaterally symmetrical, tribloblastic coelomates can be further divided into two groups based on differences in their early embryonic development. These two groups are separated based on which opening of the digestive cavity develops first: mouth (protostomes) or anus (deuterostomes).
- Poriferans are characterized by the presence of minute pores called ostia on their body.
- Cnidarians contain specialized cells known as cnidocytes "stinging cells", which contain organelles called nematocysts (stingers).
- Phylum Platyhelminthes is composed of the flatworms: acoelomate organisms that include many free-living and parasitic forms.
- The name "mollusk" is derived from the Latin molluscus ("soft"), indicating that the mollusks are soft bodied animals. The group includes the snails, bivalves, chitons, squid, octopus.
- The clitellum is the reproductive structure of an annelid. It creates mucus that aids in sperm transfer and gives rise to a cocoon within which fertilization occurs.
- The name "arthropoda" means "jointed legs" (in the Greek, "arthros" means "joint" and "podos" means "leg").
- Among the hexapods, the insects are the largest class in terms of species diversity as well as Biomass in Terrestrial habitats.
- Echinodermata are so named owing to their spiny skin (from the Greek "echinos" meaning "spiny" and "dermos" meaning "skin").
- Echinoderms possess a unique ambulacral or water vascular system, consisting of a central ring canal and radial canals that extend along each arm.

EXERCISE

Section I: Objective Questions

Multiple Choice Questions

A. Choose the best correct answer.

1. Vertebrates and tunicates share
   (a) Jaws adapted for feeding
   (b) A high degree of cephalisation
   (c) A notochord and a dorsal, hollow nerve cord
   (d) The formation of structures from the neural crest
2. The water vascular system of echinoderms
   (a) Functions as a circulatory system
   (b) Functions in locomotion, feeding, and gas exchange
   (c) Is bilateral in organization,
   (d) Involves suspension feeding
3. Acoelomates are characterized by
   (a) The absence of brain
   (b) The absence of mesoderm
   (c) A solid body without a cavity surrounding internal organs
   (d) A coelom that is not completely lined with mesoderm
4. Gastrovascular cavity is present in
   (a) Porifera (b) Annelida
   (c) Nematoda (d) Coelenterata
5. All monotreme species are found in
   (a) Australia (b) Asia (c) Europe (d) Africa
6. Gemmules are helpful in
   (a) Digestion (b) Sexual reproduction
   (c) Secretion of spicules (d) Survival in drought
7. Nematocysts are the organs of:
   (a) Sensation (b) Reproduction
   (c) Defence and offence (d) Respiration
8. Liver fluke belongs to
   (a) Arthropoda (b) Platyhelminthes
   (c) Annelida (d) Nematoda

9. Ascaris normally inhabits the lumen of:
   (a) Stomach (b) Small intestine
   (c) Appendix (d) Large intestine
10. Echidna belongs to subphylum
   (a) Prototheria (b) Metatheria
   (c) Eutheria (d) Cyclostomata

B. Fill in the blanks.

1. Cnidarians are included in grade__________.
2. In protostomes the cleavege is__________.
3. Jaws less fishes belong to class__________.
4. The gastrovascular cavity in cnidarians also known as ______.
5. Cephalochordata and________ belong to group invertebrate chordates.
6. __________ is the only phylum which is acoelomate.
7. __________ is the only phylum which is psuedocoelomate.
8. A tongue like structure with horny teeth found in Mollusca is called_________.
9. Malpighian tubules are excretory organ in__________.
10. Bipinnana and brachiolaria larvae are present in the animal of phylum __________.
11. Swim bladder is recorded in class of fishes named_________.
12. __________ locomote either with chaetae or setae and few with parapodia.
13. The presence of different zooids in the same organism is called __________.
14. The group of vertebrate which need water for their reproduction are called__________.
15. The round worms which are psuedocoelomates placed in phylum __________.

Section II: Short Questions.

1. How useful is the study of the nature of body cavity and coelom in the classification of animals?
2. Distinguish between incomplete and complete digestive system.
3. What is the difference between direct and indirect development?
4. What are the peculiar features that you find in parasitic platyhelminthes?
5. What are the reasons that you can think of for the arthropods to constitute the largest group of the animal kingdom?

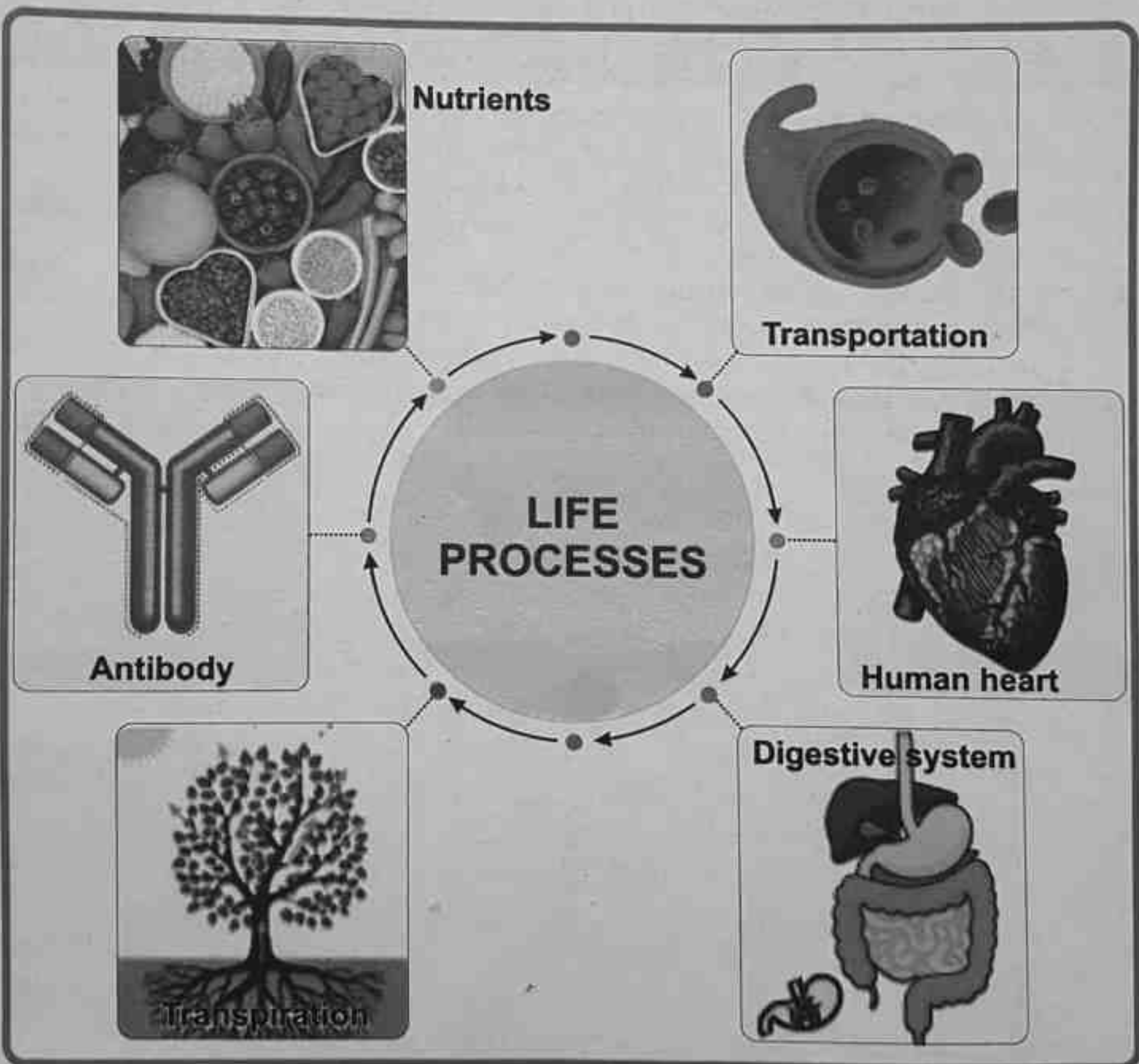
6. "All vertebrates are chordates but all chordates are not vertebrates". Justify the statement.
7. Write note on the importance of presence of swim bladder, gills and fins in Pisces.
8. What are the modifications that are observed in birds that help them fly?
9. Write note on marsupium.
10. What do you know about egg laying mammals.
11. Write any three diagnostic characters of mammals.
12. How radially symmetrical animals differ from bilateral symmetrical animals.
13. Define coelom, how psuedocoel differ from true coelom.
14. Write three differences between protostomes and deuterostomes.

Section III: Extensive Questions

1. What are pinacocytes and choanocytes? Explain general characterstics of sponges.
2. Differentiate between diploblastic and triploblastic.
3. Define the term acoelomate, describe characteristics of any acoelomate worms which you have studied.
4. Explain general characteristics of coelomate segmented worms.
5. Write note on spiny skinned invertebrates .
6. Differentiate between Chondricthyes and Osteichthyes.
7. What is poikilotherms? write general characterstics of birds.
8. Explain general characterstics of hairy animals.

Section 03

LIFE PROCESSES

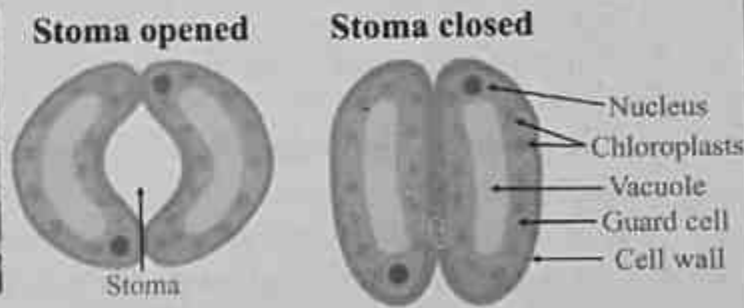


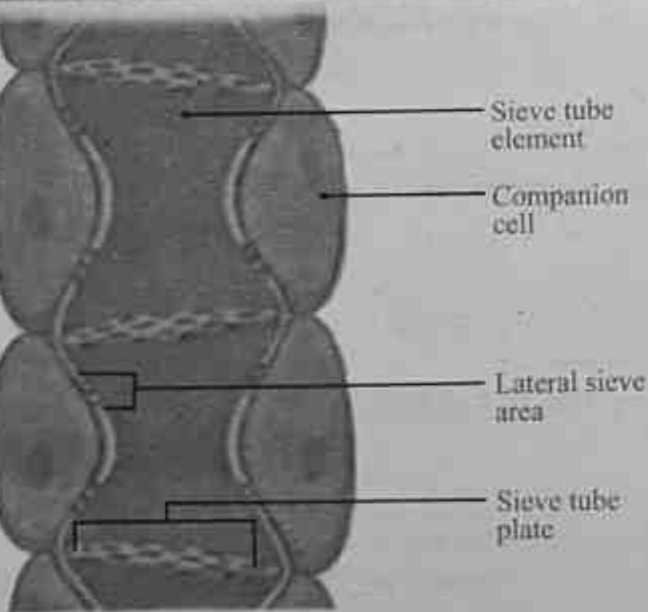
UNIT 10

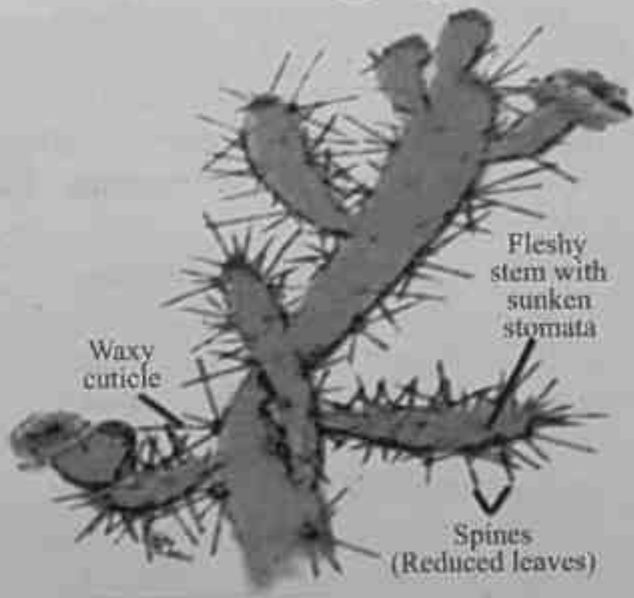
FORM AND FUNCTION IN PLANTS

Major Concepts

10.1 Nutrition in Plants
10.2 Gaseous Exchange in Plants
10.3 Transport in Plants
10.4 Homeostasis in Plants
10.5 Support in Plants
10.6 Growth and Development of Plant
10.7 Growth Response in Plants







Students Learning Outcomes

On completion of this unit students will be able to:

- List the macro and micro-nutrients of plants highlighting the role of each nutrient.
- State the examples of carnivorous plants.
- Explain the role of stomata palisade tissue in the exchange of gases in plants.
- Relate transpiration with gas exchange in plants.
- Describe the structure of xylem vessel elements, sieve tube elements, companion cells, trachieds and relate their structure with function.
- Explain the movement of water between plant cells, and between the cells and their environment in terms of water potential.
- Explain the movement of water through roots in terms of symplast, apoplast and vacuolar pathways.
- Explain the movement of water in xylem through TACT mechanism.
- Describe the mechanisms involved in the opening and closing of stomata.
- Explain the movement of sugars within plants.
- Identify vessel elements and phloem sieve tubes from the microscopic slides of L.S. of a dicot stem.
- Illustrate diagrammatically the pathway of water in root, stem and leaf.
- Define osmotic adjustment.
- Explain movement of water into and out of cell in isotonic, hypotonic and hypertonic conditions.
- Describe osmotic adjustments in hydrophytic (marine and fresh water), xerophytic and mesophytic plants.
- Explain the osmotic adjustment of plants in saline water.
- List the adaptation in plants to cope with low and high temperatures.
- Explain the turgor pressure and explain its significance in providing support to herbaceous plants.
- Describe the structure of supporting tissues in plants.
- Define growth and explain primary and secondary growth in plants.
- Describe the role of apical meristem and lateral meristem in primary and secondary growth.
- Explain how annual rings are formed.
- Explain influence of apical meristem on the growth of lateral shoots.
- Explain the role of important plant growth regulators.
- Explain the types of movement in plants in response to light, force of gravity, touch and chemicals.
- Define photoperiodism.
- Classify plants on the basis of photoperiodism and give examples.
- Describe the mechanism of photoperiodism with reference to the mode of action of phytochrome.
- Explain the role of low temperature treatment on flower production especially to biennials and perennials.

Introduction

It is common observation that organ and organ system level of organization is poorly developed in plants than animals. Although plants are more ancient but they are less developed because plants have to perform less range of activities and functions.

However, processes like nutrition, gaseous exchange, transport, homeostasis, support, growth and development and movements in response to external and internal stimuli etc., occur in plants.

10.1 Nutrition in Plants

Plant nutrition is the study of chemical elements and compounds necessary for plant growth, plant metabolism and their external supply. A **nutrient** is a component in food that an organism uses to survive and grow. Almost all plants are autotrophs, i.e., they can manufacture their own organic compounds by obtaining inorganic nutrients such as water, CO_2 and certain minerals from environment. A nutrient that is able to limit plant growth is considered as essential plant nutrient. There are **16 essential plant soil nutrients** besides the three major elemental nutrients, i.e. carbon, hydrogen and oxygen. Plants must obtain these mineral nutrients from their growing medium. Some of these minerals required in comparatively large amount are called **macronutrients**, e.g., nitrogen, phosphorous, sulfur, magnesium, iron, carbon, hydrogen, oxygen. Some mineral nutrients required in **trace amount** are called **micronutrients**, e.g., boron, chlorine, manganese, zinc, copper, molybdenum, cobalt, sodium. These elements are present in soil as salts which ionize in water so plants absorb them in the form of ions.

Table 10.1 Minerals Nutrition (Nutrients) in Plants

Macronutrients	Functions	Deficiency Symptoms
Carbon, hydrogen and oxygen	Needed for all biological organic substances (lipids, proteins, carbohydrates and nucleic acids).	Most plants get these nutrients regularly from air and water thus deficiency chances are less.
Nitrogen	Needed for the formation of proteins, nucleic acids, chlorophyll and coenzymes.	Chlorosis (lack of chlorophyll) delayed flowering, reduction of leaf size and early defoliation.
Phosphorus	Components of nucleic acids, phospholipids and ATP.	Stunted growth of root and shoot, premature fall of leaf and delayed flowering.
Calcium	Activator for many enzymes, helps in formation of cell wall and involved in membrane permeability.	Premature fall of flowers. Chlorosis leading to necrosis.

Macronutrients	Functions	Deficiency Symptoms
Magnesium	Activator of enzymes (needed for carbohydrate metabolism).	Chlorosis (inter veinal), also produce anthocyanin, sometime necrosis.
Sulphur	Amino acid formation and part of many vitamins.	Chlorosis and stunted growth.
Potassium	Enzyme activator, stomatal opening, osmosis and ionic balance.	Decreases apical dominance, retards growth and causes chlorosis.

Do you know?

Mineral deficiency is a lack of dietary minerals. The cause may be a poor diet, impaired uptake of minerals.

Table 10.2 Mineral Nutrients in Plants (Micronutrients)

Micronutrients	Functions	Deficiency Symptoms
Iron	Component of enzymes, which are needed for respiration, photosynthesis and nitrogen fixation.	Chlorosis
Zinc	Part of photosynthetic enzymes.	Growth decreases, mottled leaves.
Manganese	Part of respiratory enzymes and nitrogen metabolism.	Mottled leaves, chlorosis.
Boron	Helps in utilization of calcium and membrane transport system.	Thick, brittled and curly leaves, number of flower decreases.
Molybdenum	Needed for enzymes involved in nitrogen metabolism.	Causes Whiptail disease in cauliflower and necrosis in old leaves.
Chlorine	Maintains ionic balance, needed for photosynthesis.	Necrosis, chlorosis of leaf tips.
Copper	Part of photosynthetic enzymes.	Necrosis

in the same soil again and again. The possible remedy for this problem i
fertilizers in soil and cultivation of different crops alternatively in the same
cultivation of legume plants along with normal crops.

10.1.1 Nutrition in Carnivorous Plants

Insectivorous or carnivorous plants are those types of plants that o their nutrients especially nitrogen by consuming insects or protozoans. Th adapted to grow in places where the soil is thin and poor in nutrients. The plants include the **Venus fly trap, pitcher plants** ***(Nepenthes)*****, butterw** **cobra lily** and hundreds of others. However, these plants do not deper insects and small animals for their nutrition. The main source of er autotrophic mode of nutrition like other plants. These plants trap inse animals just to fulfill their mineral nutrient deficiency. These plants have s capture prey and enzymes to digest the prey.

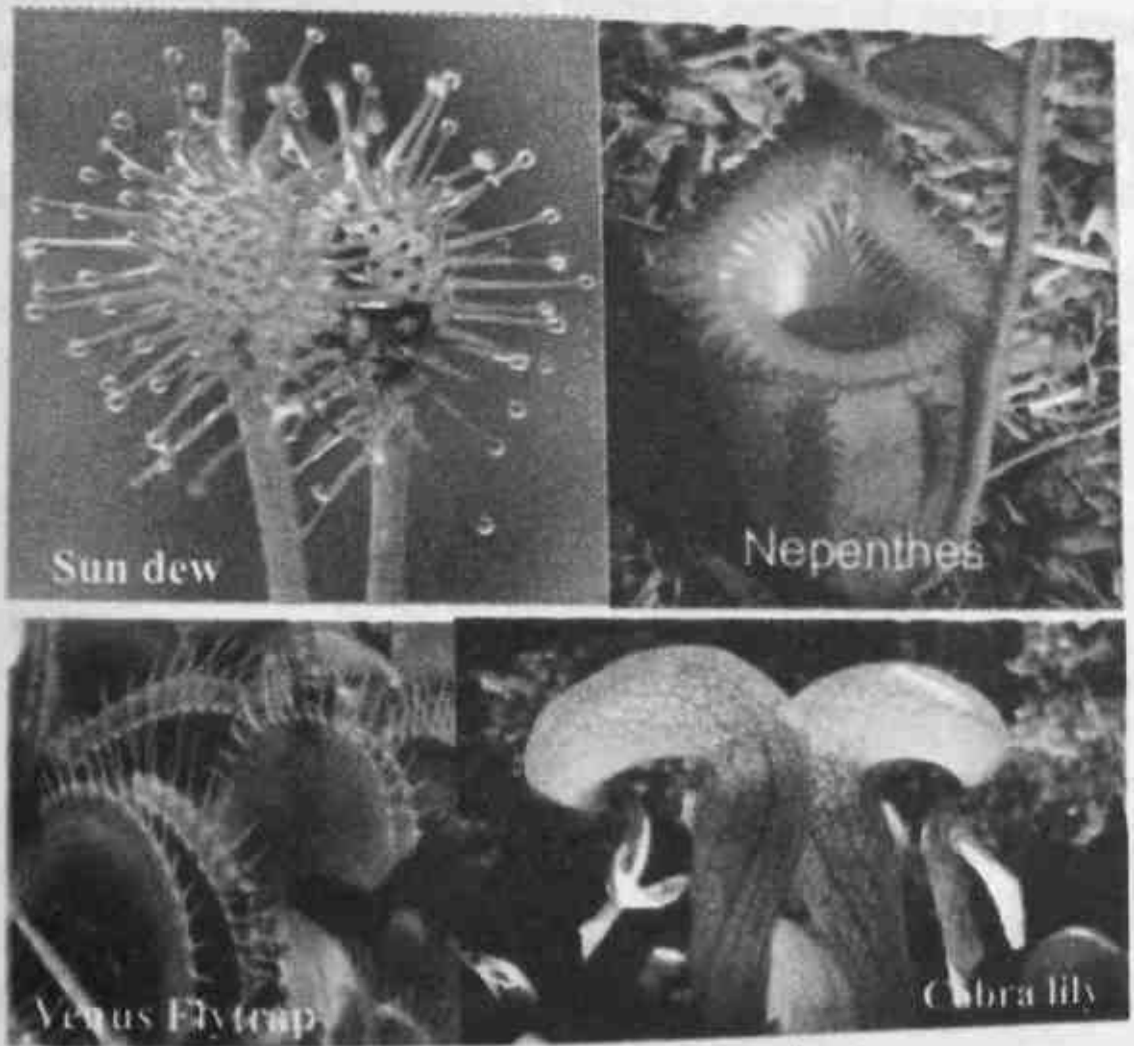


Fig. 10.1 Insectivorous plants

10.2 Gaseous Exchange in Plants

Like animals, plants also need oxygen for cellular respiration and get rid of CO_2 produced during this process. This exchange of gases takes place by diffusion. In the daytime, leaves are photosynthesizing, so oxygen produced during photosynthesis is enough for respiration. At night oxygen diffuses into the leaves through the stomata. This oxygen dissolves in the thin layer of moisture around the cell and diffuses across the cell wall and cell membrane. The roots get their oxygen from the air space in the soil.

> **Tit bits**
>
> *All respiratory surfaces need to be thin, have a large surface area, be kept moist and have a good supply of oxygen.*

10.2.1 Role of Palisade and Spongy Mesophyll in Exchange of Gases

Most of the interior of the leaves between upper and lower side of epidermis contains **parenchyma** or **chlorenchyma** tissue called **mesophyll** (Greek for middle leaf). This tissue is the primary location of photosynthesis. The mesophyll is divided into two layers. An **upper palisade** layer of vertically donated cells one or two cells thick and obtain more chlorophyll and without spaces between them. Beneath the palisade layer is a **spongy layer**. The cells of this spongy layer are not tightly packed so there are large intercellular spaces thus exchange of gases takes place more easily. These cells contain less chloroplast.

Types of mesophyll in dicot and monocot:

In dicot both spongy and palisade mesophyll cell layers are present, such leaves are called **bifacial leaves**. In monocot only spongy mesophyll layer is present between both upper and lower epidermis, such leaves are called **monofacial leaves**. The mesophyll cells are metabolically active cells due to photosynthetic process, therefore, these cells are rapidly involved in exchange of gases.

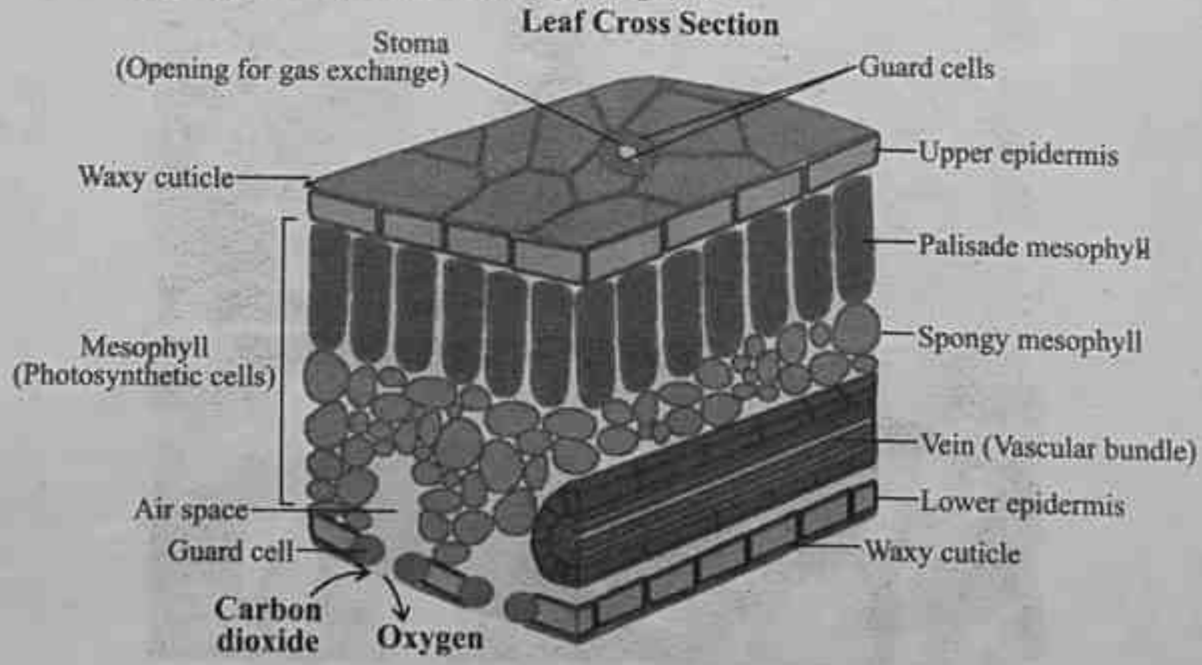


Fig. 10.2 Cross Section of Bifacial leaf

10.2.2 Role of Stomata in Gaseous Exchange and Transpiration

Stomata (singular stoma) are pores found in the epidermis of leaves, stems and other organs that facilitate gas exchange.

Stomata structure: Each pore of stomata is surrounded by two guard cells. In dicot plants guard cells are bean or kidney shaped while in monocot plants guard cells are dumb-bell shaped. The inner wall of guard cell is non elastic and thick while the outer wall is elastic and thin. In each guard cell nucleus and many chloroplasts are present. The opening and closing of stomata are regulated by change in the shape of guard cells.

Transpiration: The escape of water in the form of vapours from the surface of plant is called transpiration. Transpiration mostly takes place through stomata. During day light stomata are widely open, therefore, transpiration rate is high as compared to night. The other factors like air, temperature, humidity, concentration of CO_2 and water also contribute in the rate of transpiration.

10.2.3 Pattern of Exchange of Gases Between Plants and Environment

In plants pattern of exchange of gases is different in day and night. This difference is due to the fact that during day time both photosynthesis and respiration occur in plant but at night only respiration takes place.

Exchange of gases in day:

In day time plants absorb CO_2 and release O_2 because CO_2 consumption or fixation is more in photosynthesis than produced in respiration.

Exchange of gases at night:

At night photosynthesis slows down. Therefore, the pattern of exchange of gases in plants become animal like, i.e., release CO_2 and absorb O_2. As a result oxygen deficiency occurs near plants at night.

Compensation point of photosynthesis:

When the rate of photosynthesis exactly matches the rate of respiration, the uptake of CO_2 through photosynthetic pathway is exactly matched to respiratory release of CO_2 and the uptake of O_2 by respiration is equal to the photosynthetic release of oxygen. This time is called **compensation point** of photosynthesis. The compensation point is reached during early morning when sun arises (dawn) and late evenings when sun is about to set (dusk). At this level product of photosynthesis is used up in respiration so that plants are neither consuming nor building biomass.

10.3 Transport in Plants

The movement of materials into the body, within the body and out of the body of the organism is called transport. In plants the examples of transport are absorption of water and minerals from the soil through roots and the movement of organic solutes from leaves to different parts of the plants.

10.3.1 Movement of water between plant cells and their environment

The movement of water between plant cells and their environment takes place by osmosis. **Osmosis** is the movement of water from a region of higher water concentration towards lower water concentration through a semipermeable membrane. The absorption of water from soil to roots is example of osmosis in plants. If water moves into the cell by osmosis then it is called endosmosis and if water moves out of the cell then it is called exosmosis.

Water relations of the cells:

On the basis of movement of water into and out of cell, there are three kinds of water relations, i.e., water potential, solute potential and pressure potential.

Water potential:

The total kinetic energy of water molecules due to which they move from place to place is called water potential. The greater concentration of water molecules in a system, the greater is the kinetic energy of water molecules. The potential is denoted by a Greek symbol Ψ (Psi), so water potential is denoted by Ψw. The Potential is expressed in the unit of pressure called Pascal (Pa).

Two factors determine the water potential in plants:

i) Solute concentration, i.e., osmotic potential of solute (Ψs)

ii) Pressure polential (Ψp) so $\Psi w = \Psi s + \Psi p$

Pure water has maximum water potential. Thus water potential is zero. By definition water molecules always move from a region of higher water potential to a region of lower water potential.

> **Critical Thinking**
>
> *Do you know why we usually water plants in the morning or evening but not in the afternoon?*

Applications of water potential:

There are following applications of water potential.

i) Water potential can be used to measure the tendency of water to move between any two systems.

ii) Water potential can also be used for movement of water from soil to roots, from leaf to air, from air to soil.

The following example will help to understand the concept of water potential. Two adjacent vacuolated cells are shown with Ψw, Ψp, Ψs. The kPa = 1000 pascal.

Example

Cell A		Cell B	
Ψw	=-1400 kPa	Ψw	= -600 kPa
Ψs	= 600 kPa	Ψs	= 800 kPa
Ψp	= -2000 kPa	Ψp	= -1400 kPa

Qusestions

- Which cell has higher water potential?
- In which direction will water move by osmosis?

- What will be the water potential of the cell at equilibrium?
- What will be the solute potential and pressure potential of the cell at equilibrium?

Solute potential: (Osmotic potential):

The change in water potential of a system due to addition of solute is called osmotic potential or solute potential. **Solute potential** is always negative, i.e., with increase in solute the osmotic pressure will also increase. **Osmotic pressure** is an important factor affecting cells. In hypotonic solution the cell gets swell, in hypertonic solution the cell gets shrink while in isotonic solution the cells retain their shape and size.

Pressure potential (Ψp):

The pressure exerted by the protoplast against the cell wall of plant cell is called pressure potential. Water potential increases when pressure greater than atmospheric pressure is applied on pure water solution. It is equivalent to pumping water from one plant to another. Such situation may arise when in living cells the water enters into plant cell by osmosis. This water builds up pressure inside the cell and make the cell turgid. It also increases the pressure potential. The pressure potential helps to maintain the shape of the cell.

10.3.2 Uptake of Water by Roots and Pathways

The root hairs are located on the edge of the roots while xylem vessels are in the center. Before the water can be taken to the rest of the plant, it must reach to xylem vessels through root hairs. There are following three pathways taken by water to reach the xylem vessels.

a. Apoplast pathway
b. Symplast pathway
c. Vacuolar pathway

Apoplast pathway:

The movement of water through the extra cellular pathway between the cell walls of adjacent cells is called apoplast pathway. The ions easily reach the endodermis by this

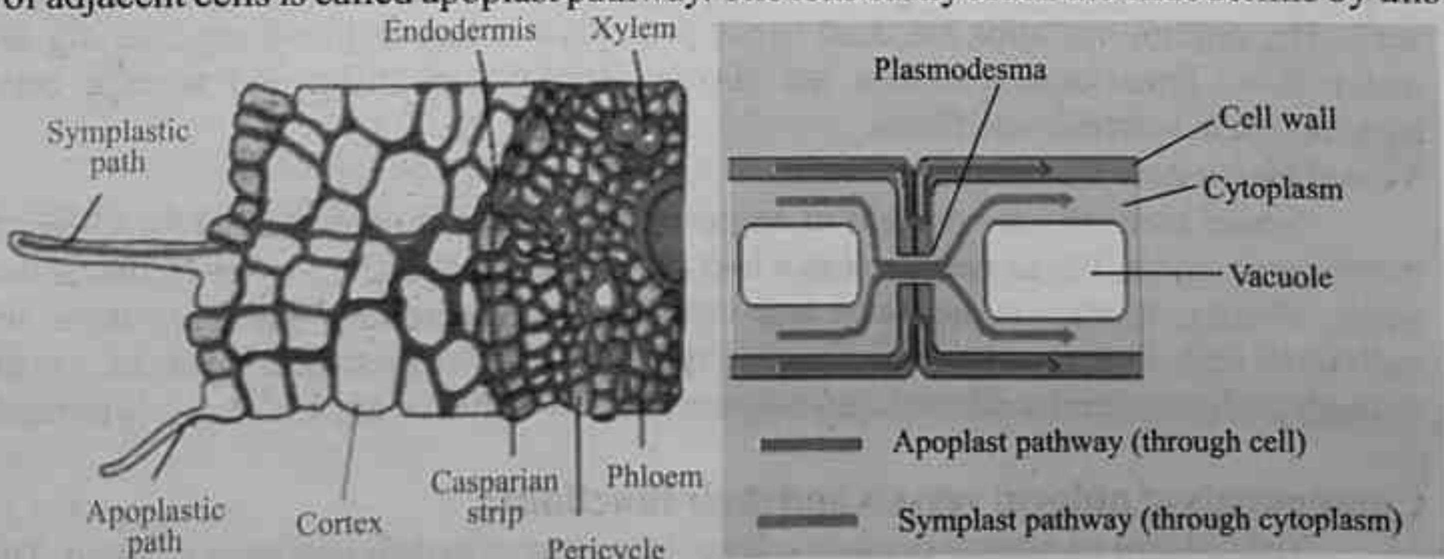


Fig. 10.3 Pathway of water

pathway, but the **casparian strips** prevent further movement. The casparian strip is a band of cell wall material deposited in the radial and transverse walls of root endodermal cells. It is chemically composed of suberin (a water proof waxy substance). Thus these ions must enter into the endodermal cells by diffusion or active transport. They enter into cytoplasm or vacuole of the endodermal cells.

Symplast pathway: The movement of cell sap through the plasmodesmata of cell is called symplast pathway. **Plasmodesmata** (singular plasmodesma) are cytoplasmic microscopic channels between cell walls of adjacent plant cells which enables transport and communication between them. There is a concentration gradient down the cells of cortex, endodermis, pericycle and sap of xylem so minerals move down through plasmodesmata into the cells of cortex, endodermis, pericycle and then to the sap of xylem.

The vacuolar pathway: The movement of water molecules in plant cells via the vacuoles located in the cytoplasm of the cell. The water molecules encounter high resistance and as a result little flow usually occurs, making this pathway less efficient than apoplast and symplast pathway. Water moves by osmosis across the vacuoles of the cells of root system.

10.3.3 Structure and Function of Xylem and Phloem

Xylem and phloem are two types of transport tissues in vascular plants. The basic function of xylem is to transport water from roots to shoots and leaves but also transport some nutrients. The phloem transports organic food from photosynthetic cells to all parts of plants for use and storage.

Components of xylem: The word xylem is derived from the Greek word *"xylon"* meaning wood. These are elongated cells and tubular water transport system because these cells are connected end to end with each other. There are two main kinds of cells in xylem, i.e. Tracheids and Vessel elements.

Tracheids: Tracheids are elongated cells up to 80 nm wide with secondary lignified cell wall. The mature tracheids are dead hence protoplast is lost and creating opening for water flow. Functional tracheids are surrounded by supporting and storage cells paraenchyma, sclereids and fibres.

Vessel elements:

Vessel elements are present in angiosperms. These are specialized for efficient water conduction. These reduce water loss by transpiration. The vessel elements are wider, shorter, thinner walled and less tapered than tracheids. Vessel elements are individual cells linked end to end froming xylem vessel. Water stream from cell to cell through perforated end walls and also migrate laterally between adjacent vessels through pits.

Components of phloem vessels and their functions:

The phloem transports organic solutes from leaves to different parts of plant. The phloem tissue is present on outside of xylem tissue. The phloem is a permanent tissue that is composed of three living cells and one dead cell. The living cells are sieve tube elements, companion cells and the phloem parenchyma while the dead cell is sieve tube. The **sieve tube** are long elongated cells placed end to end with the walls composed of cellulose. The end walls of sieve tubes are perforated. The perforated area looks like a sieve thus known as sieve plate. These pores of sieve tube help in translocation of solutes. The **companion** cells are thin walled elongated cells associated with sieve tube. These are living cells containing cytoplasm and elongated nucleus. The companion cell and sieve tube are in communication with each other through plasmodesmata. The companion cells provide energy to sieve tubes. The phloem tissue also possesses parenchyma that has storage function and very thick walled fiber cells which provide support.

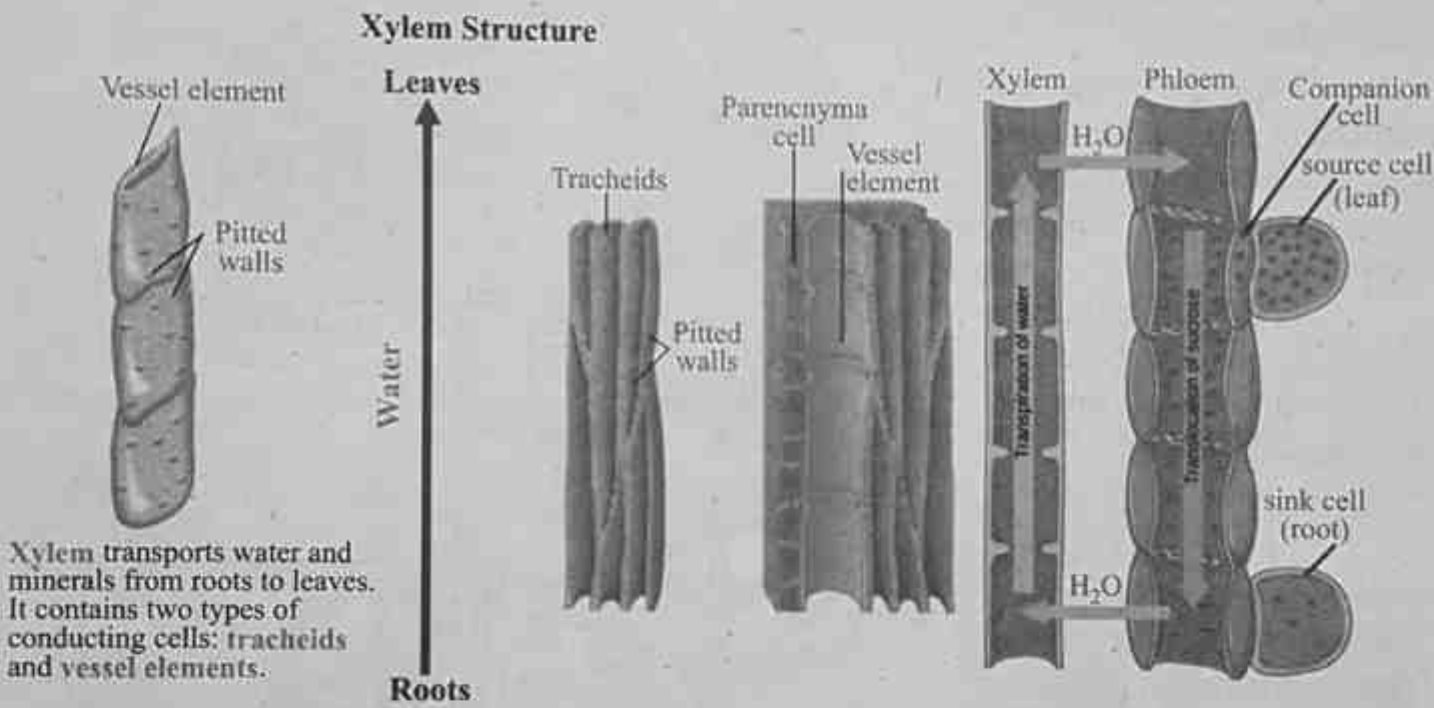


Fig.10.4 Structure of Xylem and phloem

10.3.4 Ascent of sap

The pull of water and dissolved minerals through the xylem tissue towards the leaves is known as ascent of sap. The water and dissolved minerals are collectively called sap and ascent means upward movement. Dissolved minerals from soil enter in root hairs and then move through the following path ways:

Epidermis ⟶ cortex ⟶ endodermis ⟶ pericycle ⟶ xylem ⟶ leaves

As the ascent of sap is against the gravity, therefore, a considerable force is required to transport the sap especially in tall plants. The sap is transported from roots to leaves through xylem by TACT forces. These TACT forces also known as TACT theory, responsible for ascent of sap.

TACT theory:

The TACT stands for Transpiration pull, Adhesion, Cohesion, Tension. The ascent of sap through "these forces" are called TACT theory.

Transpiration pull:

The transpiration involves in the pulling of water upward by utilizing the energy of evaporation. Transpiration pulls the water at much higher speed (upto 8 m/h). About 99% of pulled water is transpired while remaining 1% is used for various activities like photosynthesis.

Adhesion:

The force of attraction between the water molecules and other substances is called adhesion. The water and cellulose are polar molecules, therefore, strong attractive forces are present between water and cellulose, so the water molecules adhered to xylem tissue and column of water does not break.

Cohesion:

The forces of attraction present between the molecules of same substances are called cohesion.

The high cohesive force is present between water molecules due to hydrogen bonding.

Tension:

The pulling of water upward produces tension in xylem tubes. The transpiration provides the necessary energy. The hydrogen bonds between water molecules produce this tension. In xylem water tension is much stronger. It can pull the water upto 200 m (more than 600 feet) in plants.

Mechanism of TACT force:

The evaporation of water from the aerial parts of plants especially through stomata of leaves is called **transpiration.**

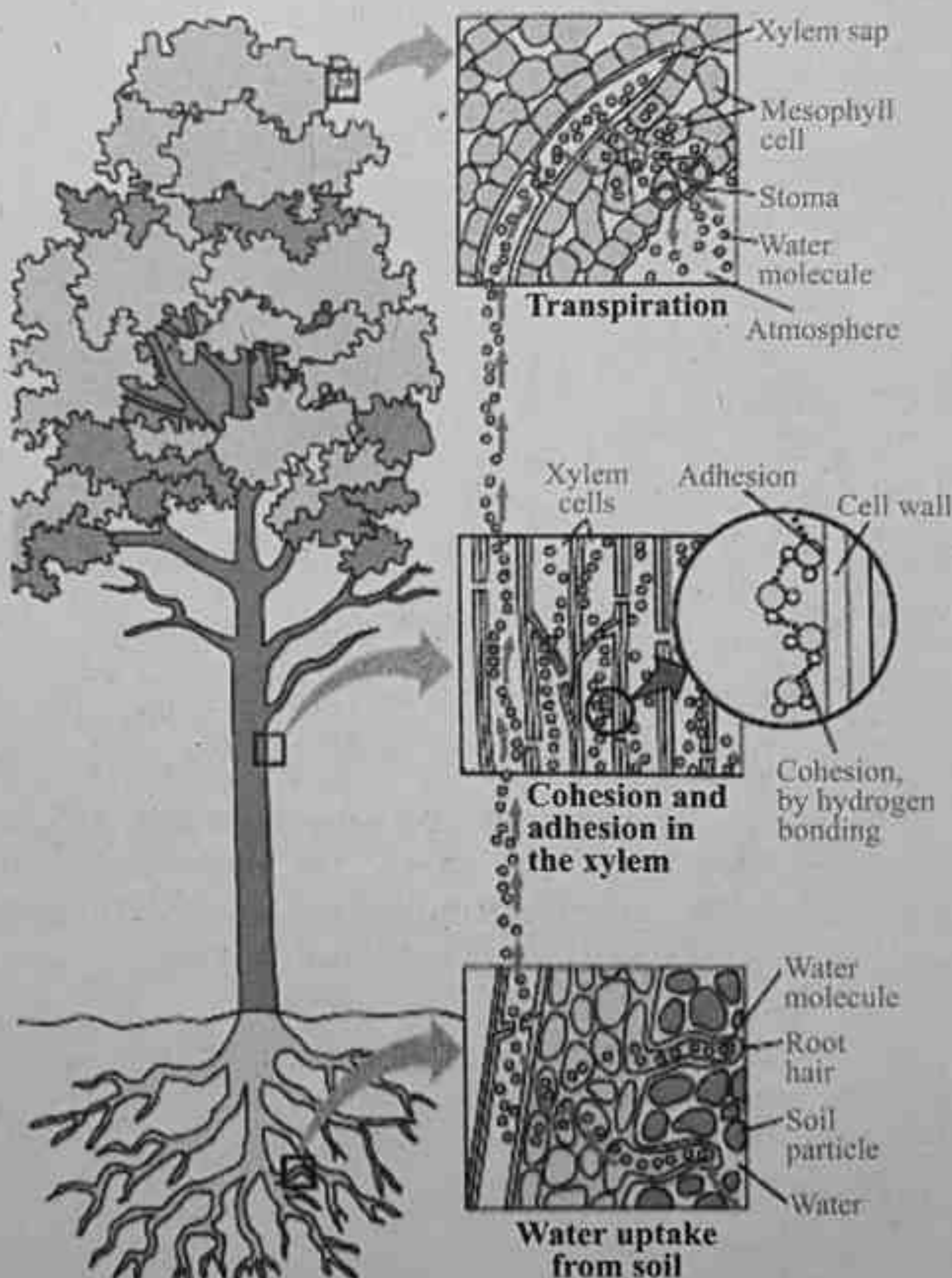


Fig. 10.5 Movement of water in xylem through TACT mechanism

Due to transpiration water potential of mesophyll cells drops which causes water to move by osmosis from xylem cells of leaf into dehydrating mesophyll cells. The water molecules leaving the xylem are attached to other water molecules in the same xylem tube by hydrogen bonds (cohesion of water molecules), therefore, when one water molecule moves in the xylem, the process continues all the way to the roots where water is pulled from xylem.

> **Tit bits**
> *The combination of adhesion, cohesion and surface tension allow water to climb upward. It is called capillary action.*

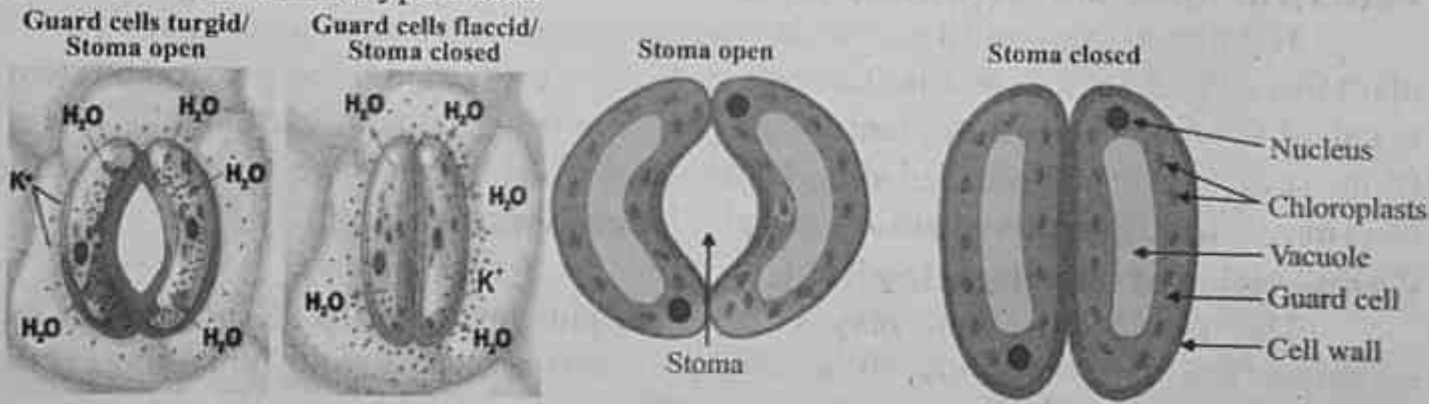
This pull also causes water to move down its concentration gradient transversely from root epidermis (root hairs) to the cortex endodermis and to pericycle. It is estimated that the column of water molecules within the xylem is atleast as strong as a steel wire of the same diameter.

10.3.5 Opening and closing of stomata

As discussed earlier in this chapter stomata are the openings between two guard cells. The guard cells play important role in opening and closing of stomata. There are two hypothesis for explaining the opening and closing of stomata.

a. Starch sugar hypothesis.

b. K^+ ions influx hypothesis.



(b) Role of potassium in stomatal opening and closing

Fig. 10.6 Opening and closing of stomata.

a. Starch sugar hypothesis:

This hypothesis was proposed by German botanist Hugo von Mohl. According to this hypothesis the guard cells are the only photosynthesizing cells of leaf epidermis because they have high contents of chlorophyll than the surrounding epidermal cells.

Opening of stomata: Photosynthesis takes place during day time so sugar is produced in the guard cells during day time. The increase in sugar level increases the solute concentration in the cell. Therefore, water potential in the cell decreases. As a result the guard cells absorb water and become turgid and curved. This creates an opening in stoma.

Closing of stomata: The process of photosynthesis slows down at night. The already present sugar is utilized in respiration or stored in the form of insoluble starch. So the osmotic potential of guard cells is higher. Thus water leaves the guard cells, they become flaccid and stomata are closed.

b. K^+ ions influx hypothesis:

According to this hypothesis when photosynthesis starts in morning, this causes a decrease in level of CO_2 in guard cells. The low level of CO_2 stimulates the inward movement of K^+ ions into the guard cells.

Opening of stomata: The accumulation of K^+ ions in guard cells decreases the osmotic potential so water enters the guard cells by osmosis. As a result guard cells become more turgid so stomata are opened.

Closing of stomata: The stomata close by reverse process. There is a passive diffusion of K^+ ions from guard cells to outside so water also moves out by osmosis. The guard cells become flaccid and close the stomata. The level of CO_2 in the space inside the leaf and light control the movement of K^+ ions into and out of guard cells.

10.3.6 Translocation of organic solutes

The movement of sucrose and amino acids in phloem, from region of production to region of storage or to regions of utilization is called translocation of organic solutes.

Pattern or direction of translocation:

The direction of translocation of food is always from source to sink. The part of plant from which sucrose and amino acids are being translocated (green leaves and stem) is called **source.** The part of plants where they are being translocated (yellow leaves, fruits, seeds and roots) is called **sink.** During cold when there is no photosynthesis, the food moves from the parts where it is stored to the parts where it is utilized.

Composition of translocating fluid:

The translocating fluid may be called as phloem sap. 10-25% of phloem sap consists of dry matter and about 90 % of this dry matter is sucrose while remaining are the other organic molecules like proteins, lipids etc.

Mechanism of translocation:

There are different views about the mechanism of translocation but most acceptable one is pressure flow or mass flow theory.

Pressure flow theory:

Ernst Munch proposed a hypothesis in 1927 to explain the mechanism of translocation. This hypothesis states that an osmotically generated pressure gradient between source and sink drives the solution through the **sieve elements.** Now this hypothesis has been given the status of theory. The pressure flow theory accounts for the mass movement of molecules within phloem. It may be noted that carbohydrates from the mesophyll cell to phloem tissue involve diffusion and active transport. Then in phloem tissue the movement of materials takes place in bulk and according to the pressure flow mechanism.

10.4 Homeostasis in Plants

The ability of an organism to maintain its internal environment at nearly constant state is called **homeostasis**. As the external environment is always changing which may disturb their internal environment. The plants have many adaptations to prevent such harmful changes. There are three elements of homeostasis, i.e., osmoregulation, thermoregulation and excretion.

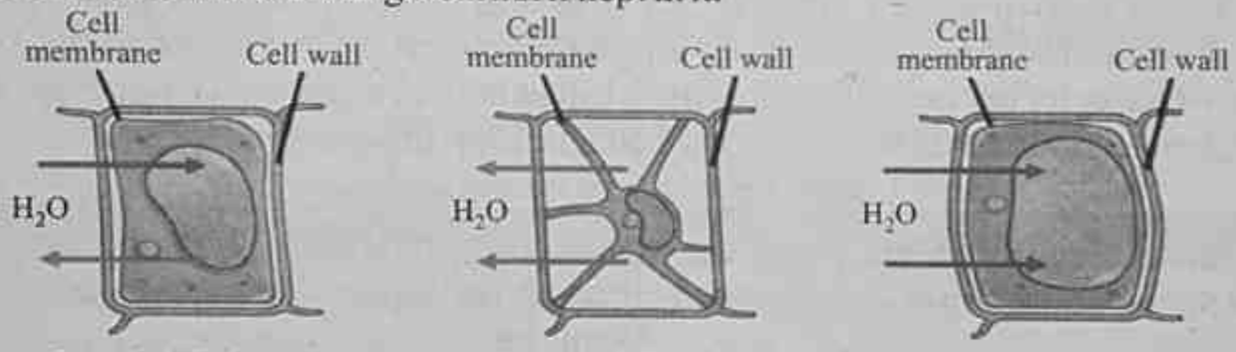
10.4.1 Osmoregulation (Osmotic Adjustment)

The maintenance of water and solute level in the body at nearly constant state is known as osmo-regulation. There are three kinds of situations on the basis of water and solute concentration such as hypotonic, hypertonic and isotonic conditions.

Isotonic solution: It is a type of solution in which the amount of solute is exactly similar to that of cell. The cell will retain its shape and size if kept in such solution.

Hypotonic solution: It is a type of solution in which the amount of solute is less as compared with cell so the cell will swell up if kept in such solution.

Hypertonic solution: It is a type of solution in which the amount of solute is higher than the cell and the cell will get shrink if kept in it.



a. Isotonic Solution
No net movement of water particles. Cell membrane is attached to cell wall.

b. Hypertonic Solution
Water particles move out of the cell. Cell membrane shrinks and detaches from cell wall (plasmolysis).

b. Hypotonic Solution
Water particles move into the cell. Cell wall counteracts osmotic pressure to prevent swelling and lysis.

Fig. 10.7 Types of solutions and their effects on cell

10.4.2 Osmoregulation in Plants of Different Environments

Due to the ability of osmoregulation plants are able to grow in wide range of habitats. On the basis of water availability plants are classified into following four groups.

1. **Hydrophytes:** Such plants which live in fresh water or damp places where abundant water is available in soil. These plants face the problem of flooding and excess of water. Following adaptations are made to overcome the problem of excessive supply of water such as short roots having no or less root hairs, no cuticle, long monofacial leaves having large number of stomata etc.

2. **Halophytes:** Such aquatic plants which live in very salty and hypertonic

medium. These plants have to face the problems of excess of solutes and shortage of water because water continuously comes out of the surface of plants due to hypertonic surrounding. These plants show some adaptations to prevent water loss and absorb more water such as long roots with huge number of root hairs, thick cuticle, small leaves, salt tolerance and excretion of extra salts through hydathodes etc.

3. Mesophytes: These are terrestrial land plants which are adapted to neither a particularly dry nor particularly wet environment. Mesophytes are largest group of plants.

These plants face the problem of shortage of water. To meet with this challenge, these plants generally show some adaptations like extensive fibrous root system to absorb water, bifacial leaves to minimize water loss through stomata, automatically regulated stomata, have structures like rhizomes and bulbs to store food and water during drought.

> **Activity**
> *Make a list of adaptive characters of Xerophytes, Mesophytes, Hydrophytes and halophytes through field survey or searching encyclopedia.*

4. Xerophytes: (from Greek xeros: dry, phyton: plant): These plants are adapted to survive in an environment with little water such as desert or an ice or snow covered region in arctic. These plants show many adaptations to conserve water and to store large amount of water for dry periods. such as thick leaves to store water, sunken stomata, short stature, long period of seed dormancy, thick cuticle, short life cycle etc.

Table 10.3 Comparison between stomata and hydathodes

Stomata	Hydathodes
Found in epidermis of leaves, young stem etc.	Present on the tips of the leaves at the vein end.
These are surrounded by pair of chlorophyllous guard cells.	These are surrounded by a ring of cuticularised achlorophyllus cells.
Stomata are surrounded by subsidiary cells.	Subsidiary cells absent.
These are concerned with transpiration.	These are concerned with guttation.

10.4.3 Thermoregulation in Plants

The ability of an organism to keep its body temperature within certain boundaries even when the surrounding temperature is very different is known as thermoregulation. Like animals, plants also need a suitable temperature for their metabolic activities. Plants show many adaptations to tolerate low and high temperature changes.

Adaptations in plants to tolerate low temperature:

The low temperature mainly affects permeability of cell membrane by changing the phospholipids into crystalline structure, as a result solutes may come out of the cell.

Moreover, low temperature also affects enzyme activity and protein structure, formation of ice crystals in cytoplasm. To avoid these problems of low temperature plants show adaptations, such as:

- Increase the proportion of unsaturated fatty acids to maintain structure of cell membrane.
- Possess antifreeze proteins to prevent crystal formation.
- Low transpiration rate due to fall of leaves to reduce cooling.
- The stems and leaves are mostly hard to tolerate low temperature.
- Well developed bark and fast life cycle.

Adaptations in plants to tolerate high temperature:

The high temperature may affect plants in different ways, e.g., it may cause dehydration in plants by increasing transpiration rate, slow down or stop metabolic activities by denaturing enzymes and proteins.

To escape from these damaging effects plants show different adaptations such as:

- Shiny cuticle which reflects much of radiations of sun.
- Heat resisting proteins to avoid denaturation.
- High transpiration rate which keeps plants cool.
- Extensively branched root system to absorb more water from soil to keep plant cool.
- Thick waxy cuticle to prevent the entrance of strong harmful radiations.

10.5 Support in Plants

All organisms need support against gravity. Terrestrial organisms need more support than aquatic organisms. In plants, support is mainly provided by parenchyma, collenchyma and schlerenchyma tissues.

Parenchyma Tissues:

In herbaceous plants the mechanical supporting tissues, i.e., collenchyma and sclerenchyma are not common. Therefore, support is mainly provided by parenchyma tissues. These tissues consist of thin walled living cells, containing large central vacuole filled with water. The vacuole applies pressure on the cell wall and make it turgid. So this pressure is called **turgor pressure.** The turgidity of cells provides strength and support to the different parts of plant. The cells of parenchyma tissues are usually spherical or oval in shape. The parenchyma cells make the bulk of the soft part of plant, including the inside of leaves, flowers and fruits.

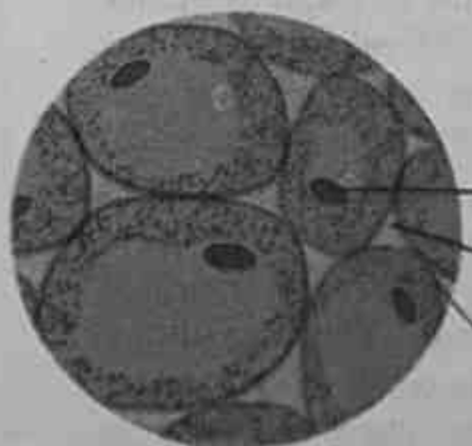


Fig. 10.8 (a) Parenchyma Tissue

Activity

Land plants usually have bifacial leaves. What are the advantages of such leaves for them.

Mechanical Supporting Tissues:

Such tissues having thick walled cells and provide mechanical support and specific shape to parts of body are called mechanical tissues. In plants mechanical tissues include collenchyma and sclerenchyma.

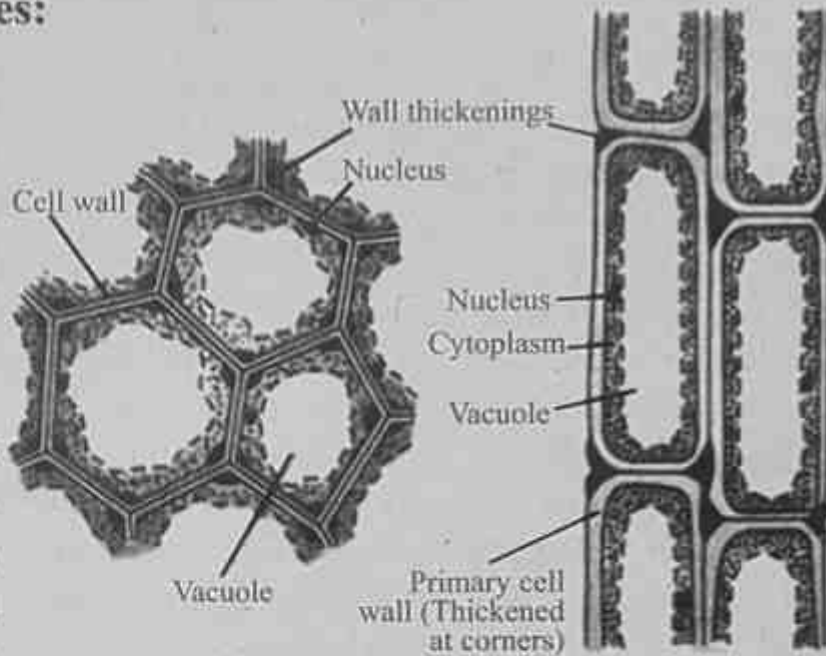


Fig. 10.8 (b) Collenchyma Tissue

Collenchyma Tissues:

These are composed of elongated cells with irregularly thickened walls. They provide support to growing shoot, located beneath the epidermis of dicot stems, petioles of leaves and pedicel of flowers. These tissues are usually living and having only thick primary cell wall composed of cellulose and pectin.

Sclerenchyma Tissues:

These are also supporting tissues that make the plant hard and stiff. The mature sclerenchyma is composed of dead cells with extremely thick cell wall that make up the 90% of cell volume. The sclerenchyma cells are principal supporting cells in plant tissues that have ceased elongation. Two types of sclerenchyma cells exist, fibers and sclereids. Fibers are elongated slender like cells. The sclereids are roughly spherical or variously shaped. Fibers are usually found associated with xylem, phloem and

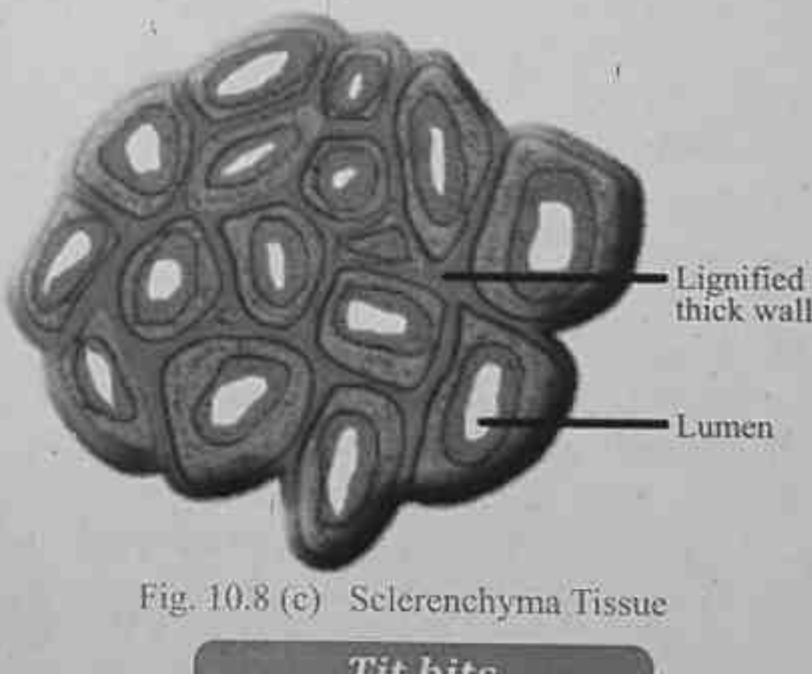


Fig. 10.8 (c) Sclerenchyma Tissue

Tit bits

The term meristem was first used in 1858 by karl Wilhelm Von Nageli. It is derived from the Greek word "Merizein" meaning to divide.

pericycle of stem, while sclereids are mostly found in seed coats, nuts, drupes.

The ring arrangement of vascular bundle in dicot plants also provide support to plant body.

10.6 Growth and Development in Plant

Growth means increase in size or mass of cells over a period of time. The **development** is a programmed series of irreversible changes in shape, form, complexity in structure and function.

Phases of growth in plant: There are four phases of growth in plant.

Cell division phase: Production of new cells.

Cell elongation phase: Enlargement in size of cell.

Cell maturation phase: The attaining of maximum size and starting function.

Cell differentiation phase: A process where a cell changes from one cell types to another.

10.6.1 Meristematic Tissues (Meristems)

In lower plants, entire body of a plant is capable of growing but in higher plants cell division and growth is localized. Infact it can only occur in particular regions called meristems. A **meristem** is a group of plant cells which retain the ability to divide by mitosis. When a meristem cell divides, one of the cells produced remains meristematic while the other give rise to specialized cells. There are three types of meristematic tissues.

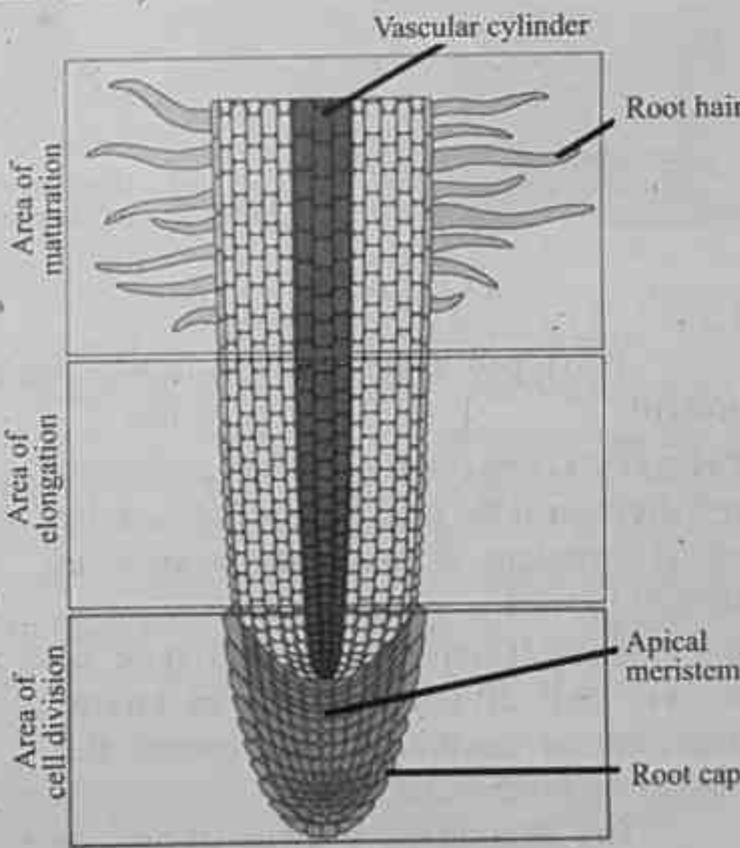


Fig.10.9 Apical Meristematic Tissue

Tit bits

In plants growth continues throughout life. This pattern of growth is called open growth.

1. **Apical Meristem:** This type of meristem is located at the tips of stems and roots and is responsible for primary growth of the plants, i.e., increases the length of stem and root. The meristem of stem tip is called stem apical meristem (SAM) and meristem of root tip is called root apical meristem (RAM).

2. **Intercalary Meristem:** This type of meristem occurs in between permanent tissues as in internodes of

grasses, bamboos, sugar canes etc. This meristem allows an increase in length in position other than the tips.

3. **Lateral Meristem:** This type of meristem is also called secondary meristem, occurs as cylinder towards the outer part of the stem. It is responsible for secondary growth, resulting in thickening. There are two types of lateral meristems, i.e., **vascular cambium** which produces secondary xylem and phloem. **Cork cambium** which gives rise to periderm that replaces the epidermis. The cork cambium is also called phellogen.

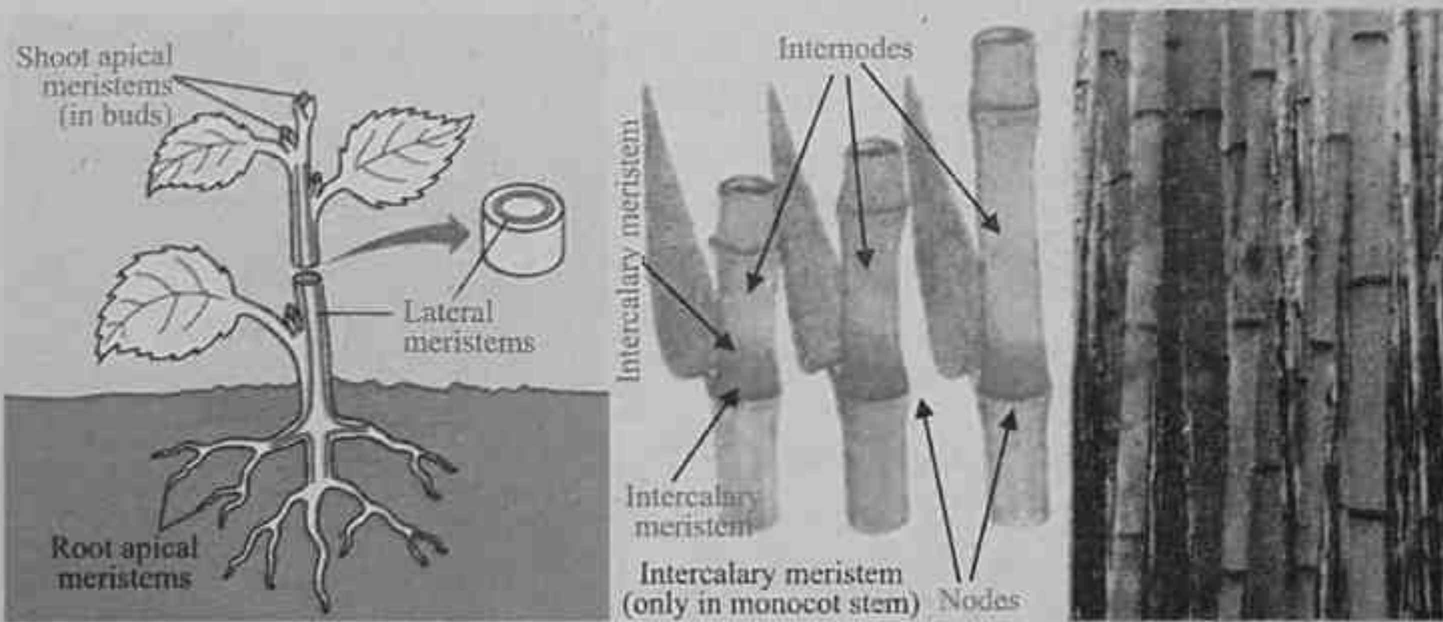


Fig. 10.10 Three Types of Meristem

10.6.2 Types of Plant Growth

Two types of plant growths are noticeable. That is Primary growth and Secondary growth.

Primary Growth: It occurs as a result of cell division at the tips of stem and roots by apical meristem. It causes the increase in length of plants.

Secondary Growth: In this type of growth cell division occurs in lateral meristem or cambium. This causes the thickening of stem and roots.

The secondary growth occurs in most seeded plants, but monocot usually lack secondary growth. The tissues produced as a result of secondary growth are called secondary tissues while the tissues that are already present in plant are called primary tissues.

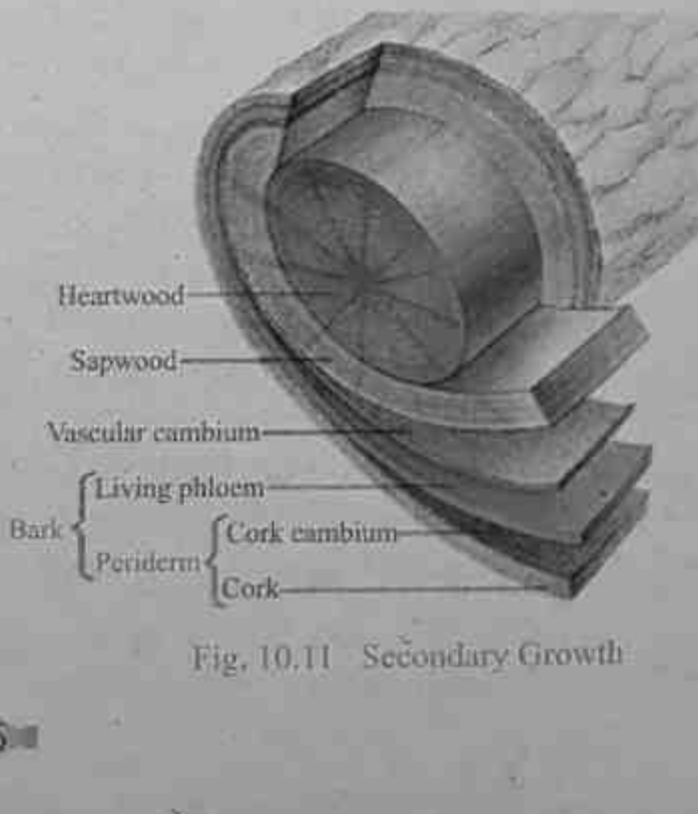


Fig. 10.11 Secondary Growth

The secondary growth causes thickness of stem, branches and roots. This thickness is helpful to support growing plants.

Growth Rings or Annual Rings: The growth rings also known as tree rings or annual rings. These rings can be seen in horizontal cross section cut through the trunk of a tree. These rings are formed as a result of new growth in the vascular cambium. Visible rings result from change in growth speed through the seasons of the year. The growth takes place during spring is called **spring wood** or early wood. The growth is rapid and less dense and usually lighter in colour due to more concentration of minerals in soils. In **autumn or late wood** secondary growth occurs slowly and the wood formed is more dense and darker due to less concentration of minerals in soil. Both spring and autumn wood is collectively called one annual ring. By counting annual rings at basal trunk help to determine the age of a tree. The study of properties of annual rings can also be used to determine past climate.

Fig. 10.12 Annual Rings

Wood and Bark: Wood is a porous and fibrous structural tissue found in stems of woody plants. It is an organic material mainly composed of cellulose and lignin. In living trees it performs support functions and also help in transport of water and nutrients. The inner dead darker part of the wood is called **heart wood.** The woody plants usually store wastes in this part of wood. The outer softer living part of wood containing vascular tissues is called soft wood or **sap wood.** This part of the wood is lighter in colour.

The outer most layer of stems and roots of woody plants, the bark is usually composed of tannins, lignin, suberin and polysaccharides. The bark overlaps the wood and consists of inner bark and outer bark. The inner bark is a living tissue while outer bark includes the dead tissues.

10.6.3 Growth Correlations

The conditions prevailing in one part of plant body affect the growth of other parts. This phenomenon is called growth correlations, e.g., growth of vegetative parts sharply checked during fruiting. The growth correlation may be inhibitory or compensatory.

Tit bits

Dendrochronology:
It is the scientific method of dating tree rings to the exact year they were formed in order to analyse atmospheric conditions during different periods in history.

Inhibitory growth correlation (Negative growth): In this type of growth correlation, growth of one part of plant inhibits the growth of other part. e.g., apical dominance.

Apical dominance: In many plants it has been observed that unless apical bud is removed, lateral bud is unable to develop. It is called apical dominance. The apical dominance is due to auxin produced by apical meristems. The apical dominance may be complete or incomplete.

Compensatory growth correlation (Positive growth): In higher plants by reducing the number of repeated parts the extra ordinary growth of remaining parts can be achieved, e.g., positive growth in *Chrysanthemum* by reducing the number of flower buds larger flowers can be obtained. This type of growth correlation is called positive or compensatory growth correlation.

Application of apical dominance: Apical dominance inhibits the sprouting of lateral buds, e.g. eyes in potatoes by using synthetic auxin which increase the storage period of potatoes from one to three years. It also plays an important role in the tap root development. It`s application in horticulture and everyday gardening, increase the number of lateral branches and large size flowers.

10.7 Growth Responses in Plants

Plants respond to environmental changes usually by growing in different directions. These growth changes are controlled by plant **hormones** also called plant **growth regulators** (PGRs). Plant growth regulators are chemicals produced in very small quantities in one part of the plant and transported to another part where they promote, inhibit or modify growth. There are five classes of plant growth regulators i.e. Auxins, Gibberellins, Cytokinins, Abscisic Acid and Ethylene.

> **Tit bits**
>
> *The substantces that inhibit the action of auxins are called antiauxins.*

Auxins: These are a class of plant hormones which are mainly responsible for bringing about cell elongation in shoots. They are also known as to control many physiological processes and influence other hormones. The principal natural auxins are chemically indole acetic acid (IAA). Its formula is $\mathbf{C_{10}H_9N\,O_2}$. Besides the natural auxins, a number of synthetic auxins have been developed. These include 2-4 dichlorophenoxy acetic acid, alpha naphthalene acetic acid etc. Auxins are synthesized in the tips of shoots and roots.

Gibberellins: These are growth regulating substances bring about a rapid and great elongation of the stem and various other developmental processes like germination, dormancy, flowering, leaf and fruit senescence (ageing). There are more than 75 different types of gibberellins have been discovered. They are named as GA_1, GA_2, GA_3 and so on. The most active and best known gibberellins is Ga_3 (Gibberellic acid, $\mathbf{C_{19}H_{22}O_6}$) obtained from rice fungus.

Cytokinins: These are a class of plant growth hormones that promote cytokinesis so called cytokinins. Chemically these are derivatives of adenine like kinetin and zeatin

($C_{10}H_{13}N_5O$). These are synthesized in the tissues of plants where cell division occurs.

Abscisic Acid (ABA): It is the plant hormone which helps in many plant developmental processes, including bud dormancy, fruit drop, leaves drop and also involve in stress responses. ABA is chemically a terpenoid and is formed in leaves, fruits and seeds. Like the other growth substances ABA moves in the vascular system.

Its formula is $C_{15}H_{20}O_4$. The abscisic acid owes its name to its role in abscission of plant leaves.

Ethylene: It is relatively simple organic molecule that exists as a gas at normal temperature. It is produced naturally in trace amount in most of the organs of higher plants. The main role of it is to promote fruit ripening. However, it also involves in breaking bud dormancy, promote abscission of fruit and leaves etc. Its formula is C_2H_4.

10.7.1 Growth Movements in Plants (Tropic movements)

Plants do not show locomotion. However, organs of higher plants, i.e., stems, roots and leaves exhibit movement that are usually very slow to be noticed. Plants show different types of movements in response to different stimuli such as tactic, tropic and nastic movements. In this chapter we will learn about tropic movement and its types.

Tropic movement: A tropic movement or tropism (Greek *Tropos*: a turning) is a biological phenomenon indicating growth or turning movement of plant in response to an environmental stimulus. In tropism this response is either towards stimulus (positive tropic movement) or away from stimulus (negative tropic movement).

Types of tropic movements: There are many types of tropic movements on the basis of stimulus. Some noticeable tropic movements are as under.

Geotropism: Growth in response to gravity is called geotropism.
Phototropism: Growth movement in response to light or colour of light.
Thermotropism: Growth movement in response to temperature.
Thigmotrpism: Growth movement in response to touch or contact.
Hydrotropism: Growth movement in response to water.
Chemotropism: Growth movement in response to chemicals.
Aerotropism: Growth of plant towards or away from a source of oxygen.

10.7.2 Protoperiodism

The photoperiodism is the physiological reaction of organism to the length of day or night. The length of day light period has a marked influence on the behaviour of the plants, particularly on the development of flowers and fruits. The relative length of day and night to which the plant is exposed is called the photoperiod while the response of plant to photoperiod is called photoperiodism.

Tit bits

Pfr can also be converted into Pr by a process called dark reversion where long period of darkness triggers the conversion of Pfr.

Classification of plants based upon photoperiodism:

According to photoperiod response, the plants are classified into three groups.

Short day plants: These plants require a relatively short day light period for flowering. Therefore, in these plants by shortening the photoperiod flowering can be hastened. Usually the plants which develop flowers in late summer are known as short day plants. All short day plants have a certain critical photoperiod and will blossom only when the day length is below that photoperiod, otherwise these plants will continue to grow vegetatively. Examples of short day plants are *Maryland mammoth*, *Cocklebur*, *Chrysanthemum*, sugar cane etc.

Long day plants: These plants require a comparatively longer photoperiod for flowering. These plants have a critical photoperiod which must be exceeded before the start of flowering. Examples of long day plants are spinach, sugar beet, henbane, cabbage, spring wheat etc.

Day netural plants: Some plants are quite indifferent to photoperiod as far as their flowering is concerned. These plants are called day neutral, photoneutral or indeterminate plants. The examples of day neutral plants include rose, tomato, sweat pea, beans etc.

> **Tit bits**
>
> ***New concept:***
>
> *Now it has been discovered that the actual stimulus for flowering is uninterrupted dark period rather than the light period. So short day plants are actually long night plants and long day plants are actually short night plants.*

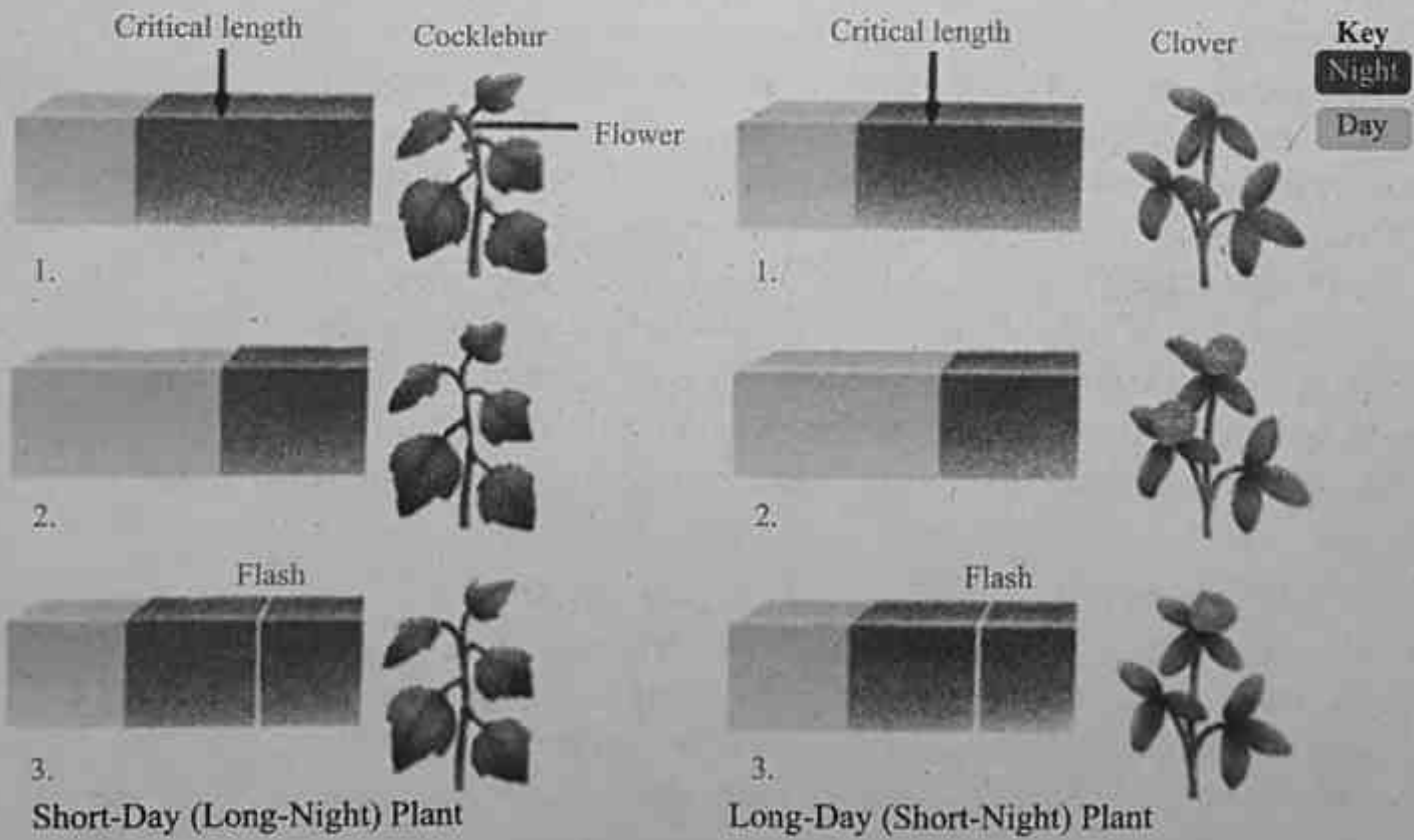


Fig.10.14 Effect of light on flowering plant

Florigen concept: It is believed that the effect of photoperiod is due to the formation of flowering hormone called florigen, i.e., "flower maker". This hormone is synthesized in the leaves and transferred to the bud meristems where it induces flowering. The florigen consists of two parts, gibberellins and anthesins. Flowering occurs only if both of these substances are present.

Phytochrome concept: The phytochrome is a type of photoreceptor that plants use to detect light. They are sensitive to light for red and far-red region of the visible spectrum. Therefore, there are two types of phytochrome, i.e., phytochrome red (Pr) which receives red light (660 nm) and phytochrome far-red (Pfr) which receives far-red light (730 nm).

The short day plants require higher ratio of Pr while long day plants require higher ratio of Pfr so both types of phytochromes, i.e., Pr and Pfr induce flowering but Pr induces flowering in short days and Pfr in long days.

> **Tit bits**
>
> *Day length is also very vital for many animals. A number of biological and behavioral changes are affected by day length. e.g., Colour of fur and feathers, migration, entry into hibernation, sexual behavior etc.*

Interconversion of phytochrome: As mentioned earlier in this chapter phtyochrome exists in two forms, i.e., Pr and Pfr. Red light (which is present during the day) converts phytochorme to its active form Pfr. This, then triggers in plant growth of flower. In turn, far red light is present in night (dark) and this converts phytochrome from Pfr to Pr. Pr is the inactive form of phytochrome and will not allow for plant growth.

This system of Pfr to Pr conversion allows the plant to sense whether it is night and or it is day. This conversion of Pfr into Pr and Pr to Pfr is important with regards to flowering in short day and long day plants.

Stimuli required for induction of flowering: In short day plants the inactive phytochrome Pr causes flowering. In short days the ratio of inactive phytochrome is higher than active phytochrome due to long period of darkness.

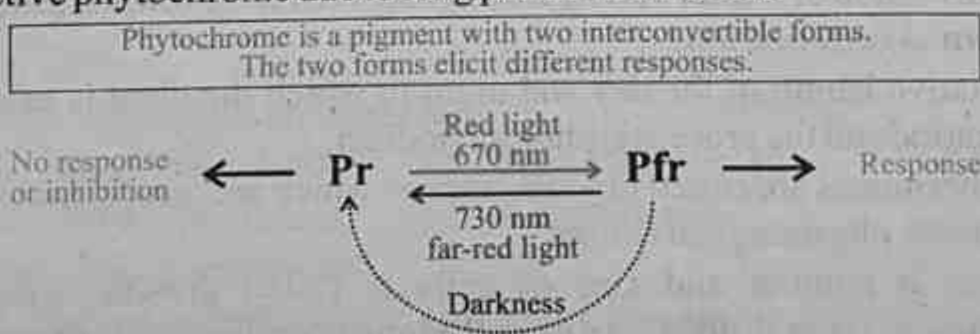


Fig. 10.15 Interconversion of two forms of phytochromes

On the other hand long day plants need active phytochrome (Pfr) to induce flowering. In long days the ratio of active phytochrome (Pfr) is higher than inactive phtochrome (Pr) due to long period of light.

10.7.3 Vernalization (Latin *Vernus*; the spring)

It is the induction of a plant's flowering process by exposure to prolonged low temperature of winter or by an artificial equivalent. After vernalization plants have acquired the ability to flower. It is because low temperature stimulates production of an hormone **vernalin.** This hormone transforms vegetative buds to the floral bud thus flowers are produced. Typical vernalization temperature are between $0-10^{\circ}C$. However, $4^{\circ}C$ is best temperature for vernalization for most of plants. The biennial plants are other group of plants which are generally vernalized. Biennials are monocarpic plants that normally flower and die in second season. Sugar, cabbage and carrot are some of the common biennial plants.

Critical Thinking

Predict what would happen if there were no transpiration?

Activity

Find out how the different factors affect the rate of transpiration in plants through searching internet.

SUMMARY

- Nutrition in plants is the source of inorganic minerals requirements obtained directly or indirectly from the soil.
- Turgor pressure is caused by the uptake of water through the cytoplasm of the cells so that pressure is exerted at the plasma membrane on the cell wall.
- Carnivorous or insectivorous plants commonly grow in areas where nitrogen is deficient due to unfavorable atmosphere for nitrifying bacteria.
- Each stoma is formed by two bean- shaped guard cells.
- The inhibition of lateral buds to develop by the activity of apical bud is called inhibitory correlation or apical dominance.
- The conversion of winter variety into spring variety by low temperature exposure is known as vernilization.
- The relative length of the day and night to which the plant is exposed is called photoperiod and the process is photoperiodism.
- Plants hormones are called phytohormones which are mostly protein, control the growth and physiological factors.
- Increase in number and size of cells is called growth, which consist of four phases. (i) cell division (ii) cell elongation (iii) cell maturation and (iv) differentiation.
- Thigmotropism is the movement due to the touch stimulus.
- Geotropism is the movement of plants parts, either towards or away from force of gravity.

- An auxin was the first plant hormone identified. It is manufactured primarily in the shoot tips.
- In some plants, the requirement of low temperature period is absolute, meaning that they will not flower without vernalization.

EXERCISE

Section I: Objective Questions

Multiple Choice Questions

A) **Select correct answer.**

1. Which of the following is an essential element of organic compounds
   (a) Manganese (b) Nitrogen
   (c) Carbon (d) Sodium
2. Which one of following is the micronutrient
   (a) Oxygen (b) Calcium
   (c) Copper (d) Nitrogen
3. Apoplast is the movement of water through
   (a) Interspaces (b) Chloroplast
   (c) Vacuole (d) Cell wall
4. Plants which live in fresh water are called
   (a) Hydrophytes (b) Xerophytes
   (c) Mesophytes (d) Halophytes
5. Carnivorous plants use insects as source of
   (a) Water (b) Glucose
   (c) Oxygen (d) Nitrogen
6. Collenchyma is the supporting tissue in
   (a) Seeds (b) Trees
   (c) Herbs (d) Leaves
7. Thigmotropism is an example of
   (a) Nastic movement (b) Tactic Movement
   (c) Tropic Movement (d) None of these
8. Spinach is an example of
   (a) Day natural plants (b) Short day plants
   (c) Long day plants (d) Halophytes
9. The effect of duration of light on flowering is called
   (a) Geotropism (b) Phototropism
   (c) Photoperiodism (d) Thigmotropism

10. The optimum temperature required for most of plants for vernalization is

(a) $10^{\circ}C$ (b) $4^{\circ}C$

(c) $20^{\circ}C$ (d) $0^{\circ}C$

11. The primary growth is due to

(a) Apical meristem (b) Lateral meristem

(c) Pholem tissue (d) Xylem tissue

B. Fill in the blanks.

1. The promotion of flowers by exposure to low temperature is known as ________.
2. Plant hormones are also called growth ________.
3. Annual rings help to determine the ________ of plants.
4. Plants living in saline environment are called ________.
5. The theory that explains the mechanism of translocation of organic solute is known as ________ theory.
6. Photosynthesis in leaves takes place in ________ cells.
7. The minerals required in large amount are called ________.

Section II: Short Questions.

1. Make a list of macro minerals.
2. What are mesophyll tissues and their types?
3. What is meant by compensation point of photosynthesis?
4. Differentiate between water potential and solute potential.
5. Differentiate between Apoplast and symplast.
6. Define TACT theory and write the components of this force.
7. Differentiate between sink and source.
8. Define Hydrophytes, Mesophytes and Halophytes.
9. Differentiate primary growth and secondary growth.

Section III: Extensive Questions.

1. What are different pathways of uptake of water? Explain them in detail.
2. Explain the ascent of sap by relating to TACT theory.
3. Explain the mechanisms involved in opening and closing of stomata.
4. Describe the mechanisms of photoperiodism in detail.
5. Explain the role of different types of plant hormones in detail.
6. What are meristematic tissues? Explain the role of different types of meristematic tissues in plant growth.

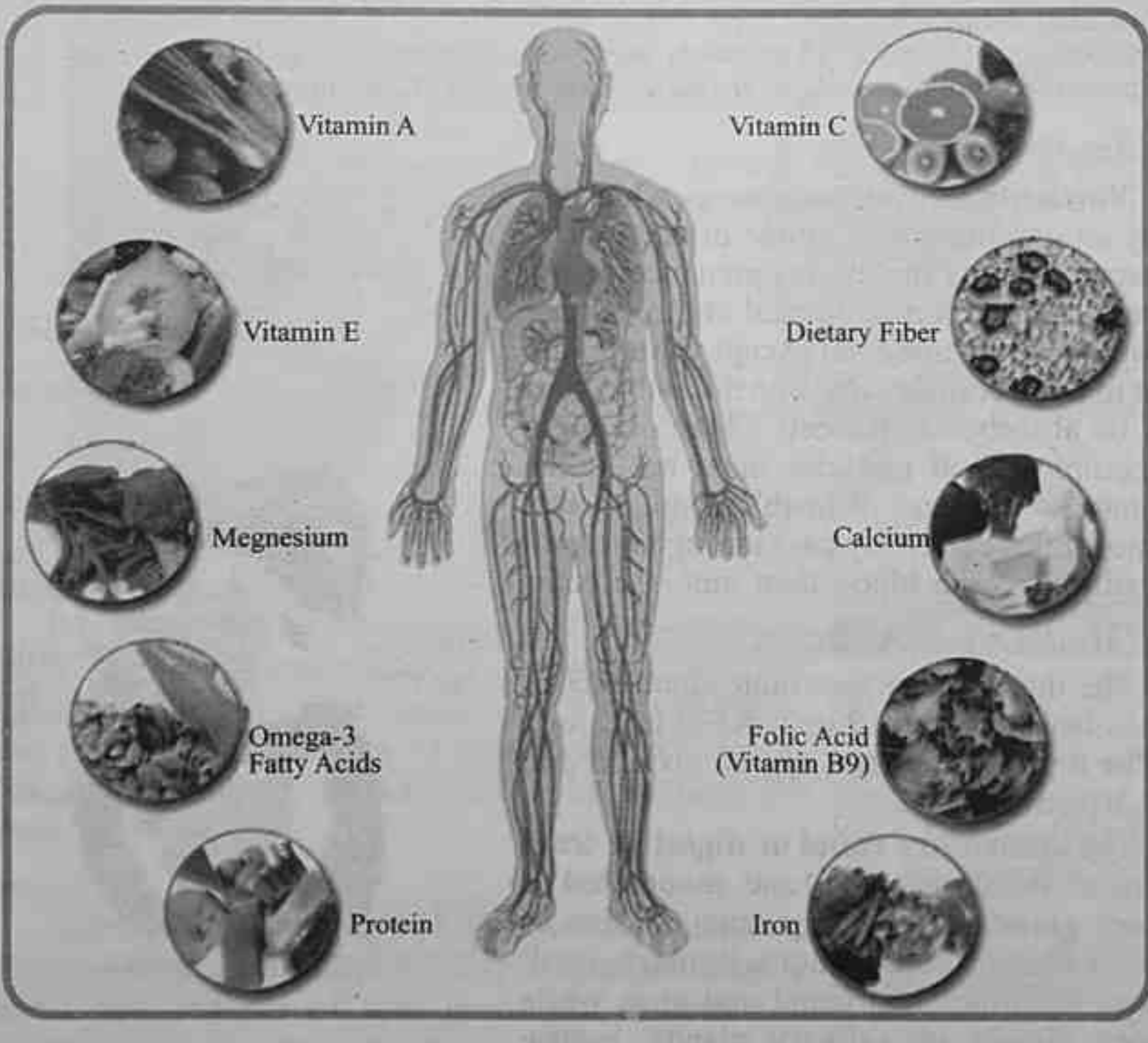
UNIT 11

DIGESTION

Major Concepts

11.1 Alimentary Canal; Structural and Functional Details
11.2 Role of Accessory Glands
11.3 Disorders of Digestive System.

SOME ESSENTIAL NUTRIENTS FOR YOUR BODY



Students Learning Outcomes

On completion of this unit students will be able to:

- Describe the mechanical and chemical digestion in oral cavity.
- Explain swallowing and peristalsis.
- Describe the structure of stomach and relate each component with the mechanical and chemical digestion in stomach.
- Explain the role of nervous system and gastrin hormone on the secretion of gastric juice.
- Describe the major actions carried out on food in the three regions of the small intestine.
- Explain the absorption of digested product from the small intestine lumen to the blood capillaries and lacteal of the villi.
- Describe the component part of large intestine with their respected roles.
- Correlate the involuntary reflex for egestion in infants and voluntary control to adults.
- Explain the storage and metabolic role of liver.
- Describe composition of bile and relate the constituents with respective role.
- Outline the structure of pancreas and explain its function as an exocrine gland.
- Relate the secretion of bile and pancreatic juice with the secretin hormone.
- Describe the causes, prevention, and treatment of the following disorders; ulcer, food poisoning, dyspepsia.
- Describe obesity in terms of its causes, preventions and related disorders.
- Explain the symptoms and treatments of bulimia nervosa and anorexia nervosa.

Introduction

Nutrients are food substances which are used by an organism as a source of energy and necessary elements for the maintenance of life and growth. The food is utilized at the cellular level, but most organic food except vitamins are present in large complex and non diffusible, thus cannot be absorbed in the cell. Therefore these large complex food particles must be broken down into simple and diffusible food, so that these molecules can easily pass through the wall of intestine into the blood then upto the cells.

11.1 Digestive System of Man

The digestive or gastrointestinal tract of human consists of about 9 meters (30 feet) long tube. The digestive system, can be divided into two main parts:

The **alimentary canal or digestive tract** or gastrointestinal tract (GIT) and **associated or accessory glands**. Alimentary canal consists of oral cavity, pharynx, oesophagus, stomach, small and large intestine, anal canal and anus while accessory glands are salivary glands, gastric

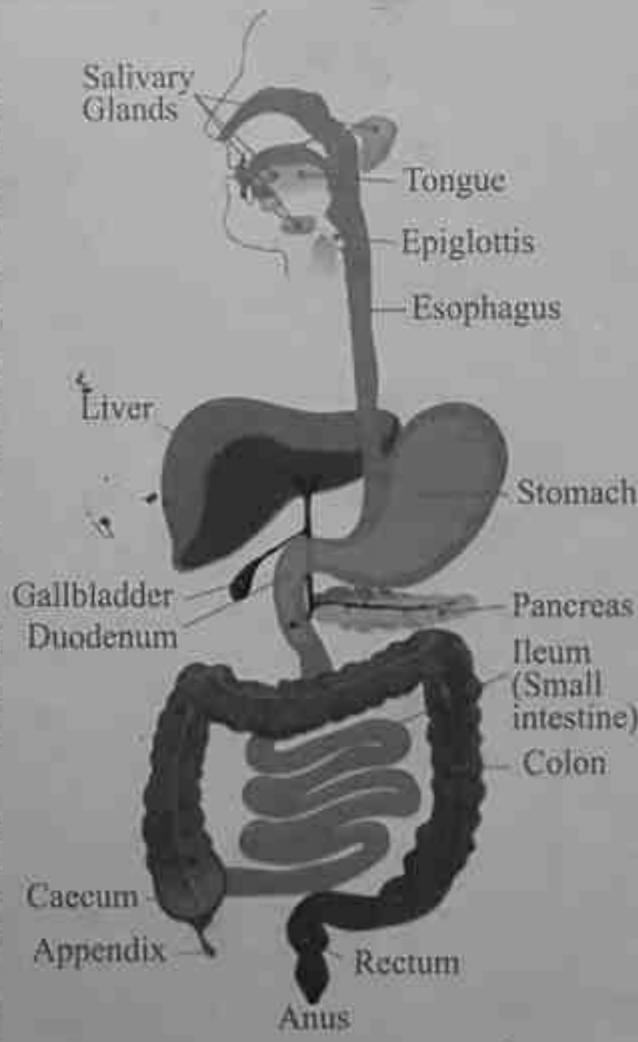


Fig. 11.1 Digestive system of man

glands, liver, pancreas and intestinal glands.

Entire alimentary canal consists of three main layers (tunics), an internal epithelium, mucosa and submucosa, muscular layers and external serosa.

Oral Cavity or Buccal Cavity:

The opening of oral cavity is mouth. The mouth is bounded by upper and lower lips. The oral cavity contains upper and lower jaws, palate, tongue and **salivary glands**. The salivary glands are present in three pairs, **sub lingual, sub mandibular and parotid glands**. These glands secretes saliva into the oral cavity. The tongue is muscular organ and is attached to the floor of oral cavity, it is freely movable and bears many taste buds. The roof of oral cavity is called **palate,** which is hard in anterior and soft at posterior.

Pharynx:

It is the posterior part of the oral cavity extended upto oesophagus and larynx, gives passage to air and food.

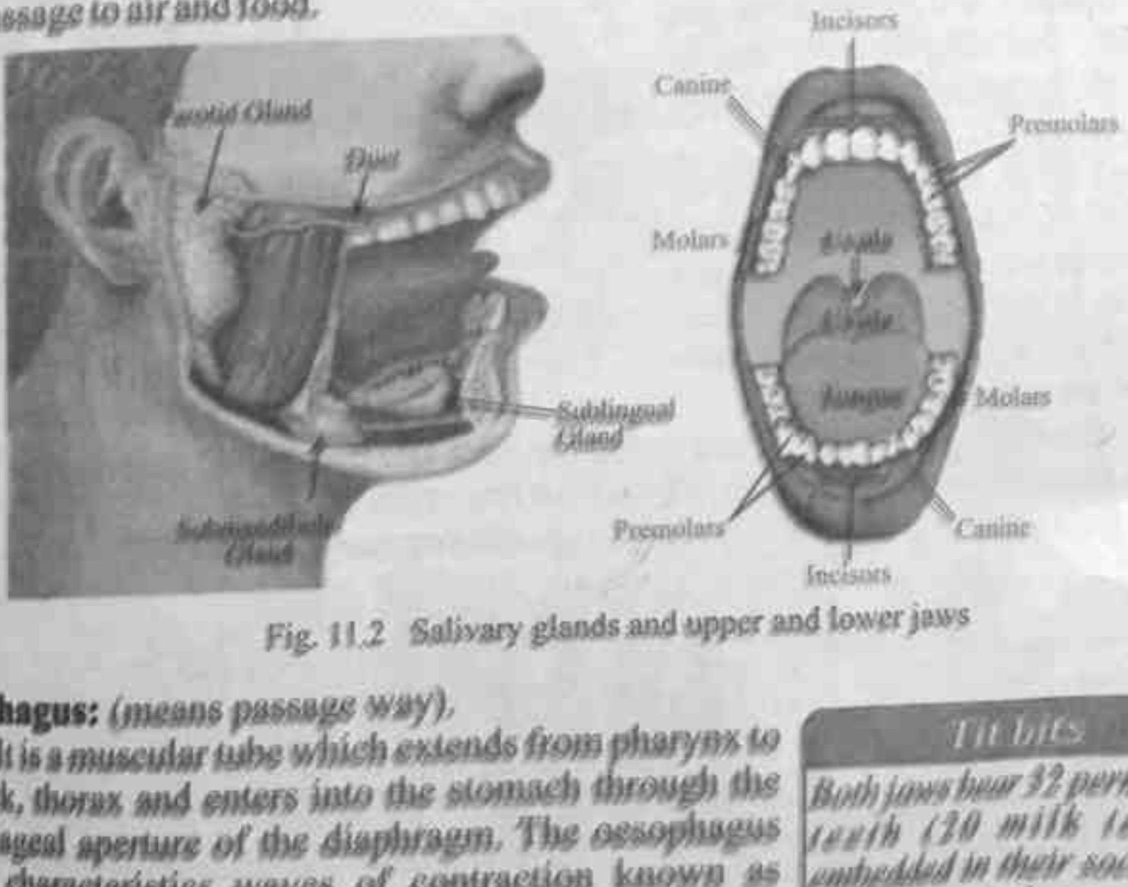


Fig. 11.2 Salivary glands and upper and lower jaws

Oesophagus: *(means passage way).*

It is a muscular tube which extends from pharynx to the neck, thorax and enters into the stomach through the oesophageal aperture of the diaphragm. The oesophagus shows characteristics waves of contraction known as peristalsis, which help to drive the food towards the stomach.

> **Tit bits**
>
> *Both jaws bear 32 permanent teeth (20 milk teeth), embedded in their sockets in the gums, teeth are of four types i.e., incisor 2/2 canine 1/1, premolar 2/2, and molar 3/3.*
>
> *Teeth help in grasping and grinding of food.*

Stomach:

Stomach is **widest part of digestive tract,** located at left side of abdomen, below the diaphragm. It is roughly J-shaped and consists of four prominent regions i.e., cardiac, fundus, body and pyloric regions. Cardiac sphincter (a ring type muscle) present at the cardiac end of stomach and oesophagus while pyloric sphincter at the opening of stomach into the duodenum both sphincter prevent backward flow of food.

Tit bits

Tooth decay and Gum bleeding are very common human diseases. Make a list of their main causes and possible remedies of these diseases through the different sources available to you.

Layers of stomach: The inner most layer of stomach is **epithelium** below it is **mucosa,** consists of connective tissues, rich in blood vessels, glands and nerves. Next to mucosa is **submucosa** having outer longitudinal muscles, inner circular and inner most oblique muscles. The contraction and relaxation of these muscles are responsible for grinding, churning and mixing of food with the help of enzymes in the stomach.

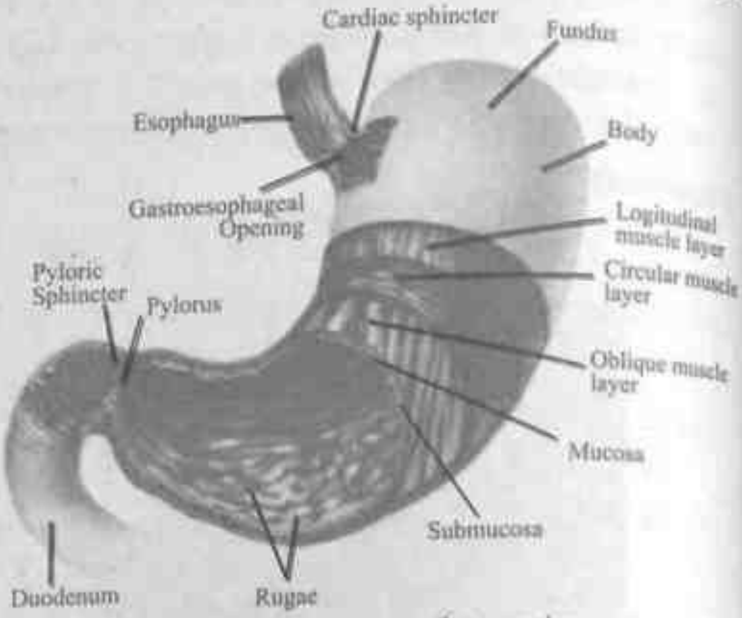


Fig. 11.3 Anatomy of stomach

Serosa: It is the thin outermost layer which connects the stomach to the abdominal wall. The folds and wrinkles in the wall of the stomach are called **rugae**, which increases the surface area of the stomach.

The mucosal surface forms numerous tube like pits, called **gastric** pits. The pits are the opening for gastric glands, which have four types of cells.

a) Zymogen or principal cells, secrete gastric enzymes (pepsinogen).

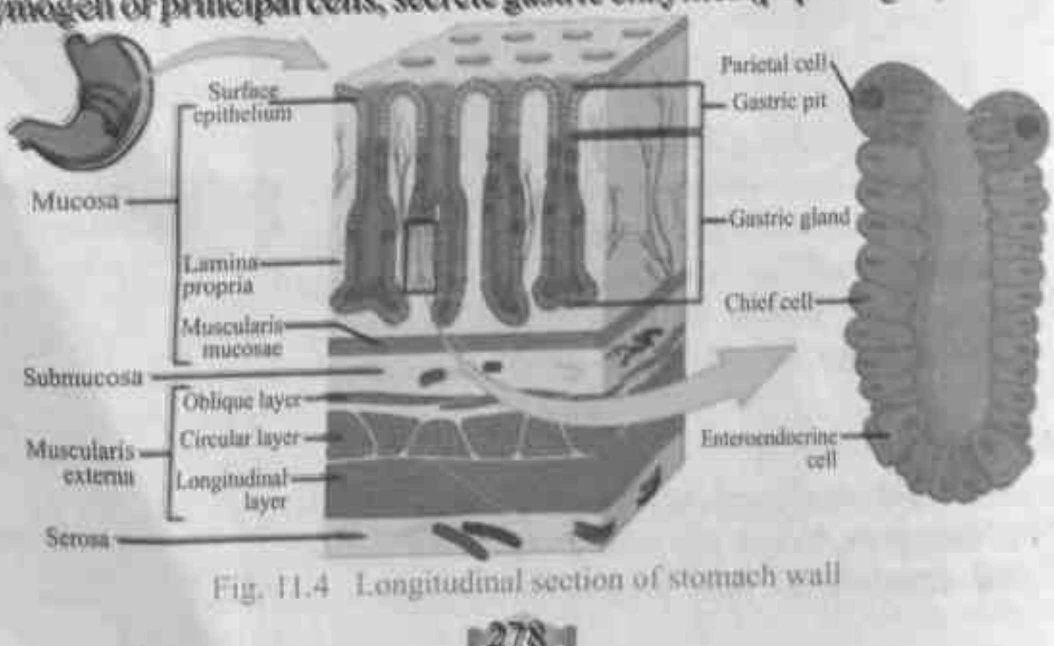


Fig. 11.4 Longitudinal section of stomach wall

- Oxyntic cell or parietal cells, secrete hydrochloric acid.
- Goblet cells secrete protective mucus.
- Endocrine cells secrete gastrin hormones.

Small intestine: Small intestine begins from end or pylorus of stomach, it is highly coiled tube about 6 to 7 meter long and about 2 to 4 cm in diameter. The small intestine consists of three parts, duodenum, jejunum and ileum.

Duodenum (Latin Twelve fingers breadth in length) is the first part of the small intestine, starts from pylorus of stomach and is "C" shaped, about 20 to 30 cm in length. It receives two alkaline fluids from liver and pancreas by a common duct called the **hepatopancreatic ampulla.**

Jejunum (Latin empty and hungry) is the second part of the small intestine, about 2.5 meter long.

Ileum (Latin twisted or coiled) is third part of small intestine, about four meter long. Ileum is highly convoluted and major part, where food is digested and absorbed. It contains **Brunner's gland** which produce intestinal juice. There is no clear cut demarcation between jejunum and ileum, except there is gradual decrease in the diameter of small intestine and thickness of its wall.

> **Tit bits**
>
> ***Appendicitis:***
> *It is an inflammation of appendix, occur due to entrapping of undigested food, which on decomposition cause pain, thus must be removed through surgery before bursting.*

The internal lining of the small intestine is thrown into numerous finger like tiny projection called **villi** that increase the surface area for absorption of nutrients. Each villus contains blood capillaries, lacteal vessels covered with columnar epithelial cells and have mucus secreting goblet cells.

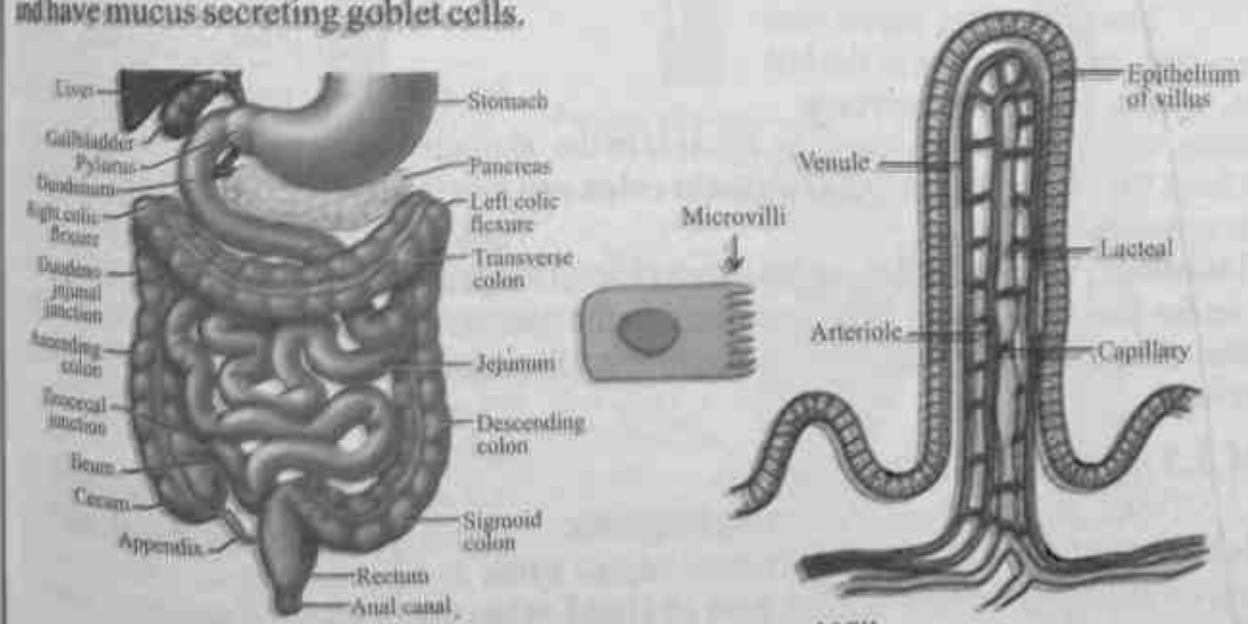


Fig. 11.5 Small, Large Intestine and Villus

There is **ileocecal** sphincter between ileum and caecum which prevent backward flow of undigested food from large intestine.

Large intestine: The large intestine is a wide tube which begins from the ileum of small intestine and ends to anus. It is about 2 meter long and divided into three parts i.e., caecum, colon and rectum.

Activity

How the large sized digestive tract is beneficial for human.

Humans are not carnivorous, still canines are present in their jaws can you guess why?

Tit bits

Antiperistalsis:

The reversal of peristalsis is called antiperistalsis which results in vomiting The cause of this reversal is irritation in the oesophagus or stomach due to intake of toxic food.

Caecum: (Latin blind sac) It is a blind pouch, present between ileum and colon, extend about 6 cm behind the ileocecal junction, attached to the caecum a blind finger like projection known as vermiform appendix, which is non functional in man and about 10 cm long.

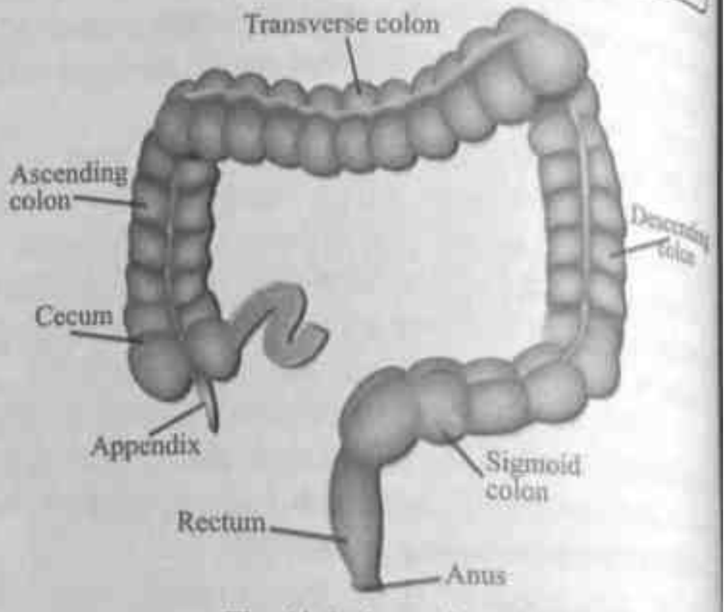


Fig. 11.6 Large intestine

Colon: The colon is second part of large intestine, about 1.5 to 1.8 meter long and consists of four parts.

The **ascending colon** runs upwards and then runs to the left transversly is called **transverse colon,** which goes down wards on left side of the abdomen known as **descending colon**. It form "S" shaped curve called **sigmoid colon** and join the last part of the large intestine known as rectum.

Rectum (L. rectus; straight) about 6 inch (15cm) long tube, runs straight downwards and join the anal canals(4cm long) and open to the external skin by a round opening called anus. The anus is guarded by two sphincter muscles (internal smooth and external striated).

11.1.2 Function of Oral Cavity

Oral cavity performs following functions:

Selection of food: First of all human beings smell and feel the food with the help of nose, eyes and hand, when the food enters the oral cavity it is tasted by tongue. The teeth and tongue help to find any hard object in the food e.g., piece of bone and stone.

Do you know?

A bolus (from Latin bolus "ball) is a ball like lump of food and saliva that forms in the mouth during the process of chewing.

Grinding of food: The food is chewed by ripping, crushing and grinding. These occur with the help of premolar and molar teeth, so can be easily passed through oesophagus and increase surface area for enzymatic action.

The salivary glands secrete mucus and saliva, mucus lubricates the food while sodium bicarbonate and other salts in the saliva are slightly antiseptic and kills the germs taken along with the food. It also maintains pH of food to alkaline level. The saliva also contain enzyme salivary amylase which digests the starch and glycogen, converts these into maltose.

Swallowing of food:

The semi digested and lubricated food arranged into small oval masses called bolus. The bolus are now pushed down into the pharynx and oesophagus by combined efforts of cheek muscles, floor of buccal cavity and tongue.

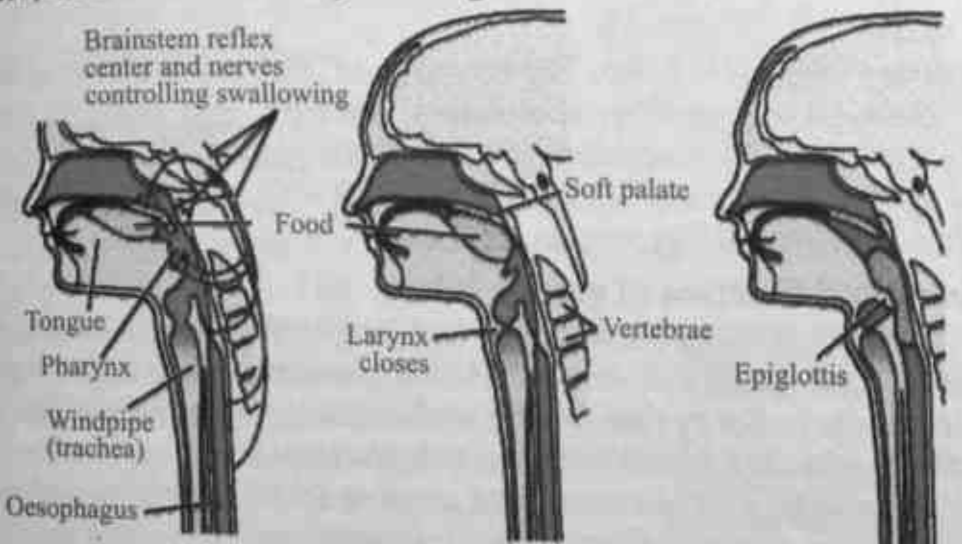


Fig. 11.7 Process of swallowing

Steps of swallowing:

i) The tongue move upward and backward for forcing the bolus towards the pharynx.

ii) The backward movement of the tongue pushes the soft palate up to close the nasal passage. At the same time the tongue forces the epiglottis into horizontal position to close the glottis.

iii) Larynx move upwards under the back of tongue. The glottis is partly closed by the contraction of ring muscles.

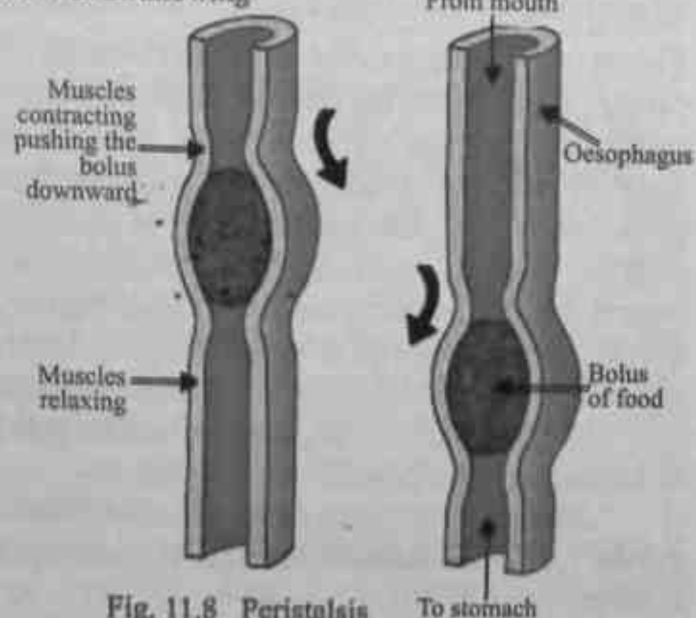


Fig. 11.8 Peristalsis

iv) The main muscles of pharynx contract and initiate peristalsis.

11.1.3 Function of Oesophagus

Oesophagus pushes the food from pharynx to stomach through the process of peristalsis, the salivary enzymes keep its action continue.

Peristalsis: (Gk. Peristalikis; to wrap around)

It is the movement of the gut to move the food to lower side. It consists of waves of contraction of circular and longitudinal muscles, preceded by waves of relaxation in circular muscle behind the bolus contract and a mechanical pressure propels the food, the circular muscle is relaxed in front of the bolus, thus the bolus move forward. Then the next one contract while the first one relax and so on.

11.1.4 Function of Stomach

Secretion of gastric juice. The secretion of gastric juice from gastric gland is caused by chemical and nervous stimulation, the sight and smell of food is also a stimulus. In the oral cavity food stimulates the gastric gland by impulse, more juices are secreted by gastric gland when the food touches the wall of the stomach. Adult human produces about three liters of gastric juice per day.

Composition and function of gastric juice:

It consists of mucin, pepsin, HCl and renin. The **mucin** forms a protective covering around the inner wall of stomach and prevent it from acidic and enzymatic action. It also acts as buffer by reducing the acidic effects of gastric juice for some time, if this protecting mechanism fails, it causes ulcer in the stomach.

The enzyme **pepsin** is secreted as inactive form known as pepsinogen from zymogen cells of gastric gland. It is activated into pepsin when exposed to acidic medium of stomach. Pepsin breaks protein into polypeptides and dipeptides.

Gastrin: The endocrine cells of stomach secrete gastrin, If our food contains more protein than endocrine cells of stomach secrete gastrin, which diffuses in the blood and return back to the stomach again. Gastrin stimulates gastric glands to secrete large quantity of gastric juice.The **oxyntic cells** secrete **HCl** in high concentration form with pH of about 1.3, but the final pH of gastric juice of stomach becomes 2 to 3 due to dilution. Acidic environment of stomach stops the reaction of ptyalin, kill micro organisms in food, activate pepsinogen into pepsin, also control the opening and closing of **pyloric aperture** of stomach. Gastric Juice also contains **prorenin** (more in infants) which become active to renin by HCl, it coagulate the casinogen, the soluble protein of milk into insoluble calcium salts of casein in the presence of calcium chloride ions which is then digested by pepsin.

The semi digested food of stomach becomes soupy mixture known as chyme. It passes to the duodenum through pyloric opening, when reaches a certain degree of acidity.

11.1.5 Function of Small Intestine

Most of digestion and absorption of nutrients occurs in small intestine. When food enters from stomach into duodenum, the acidity of food stimulates the pancreas and liver to secrete bile and pancreatic juices that are poured into the duodenum. The intestinal mucosa also secretes mucus and enzymes that remain associated with the intestinal epithelial surface. The mucus protects the intestinal wall from acidic chyme and digestive enzymes.

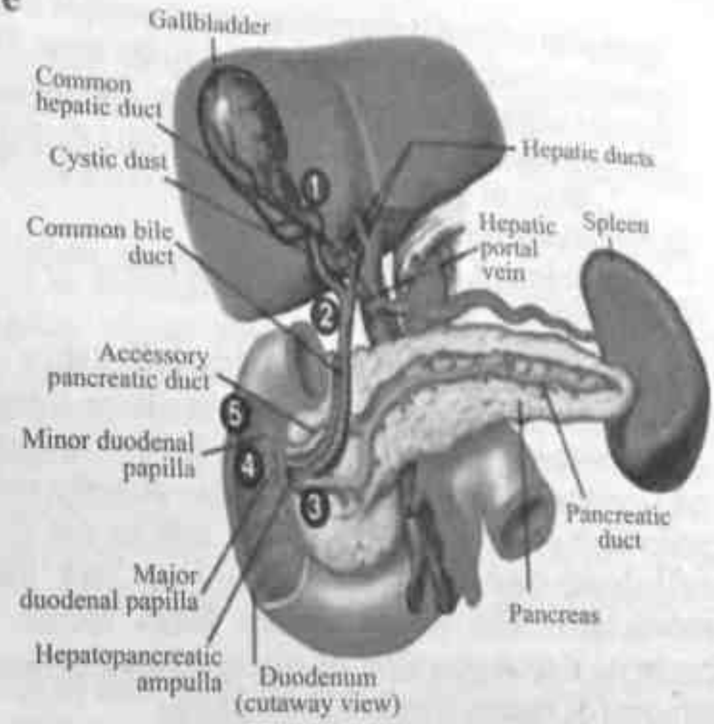


Fig. 11.9 Associated Glands of Digestive System

Pancreatic juice:

It is slightly alkaline with a pH-8 and neutralize the acidic chyme of provides suitable medium for the action of digestive enzymes. The pancreatic juice contains, many enzymes such as pancreatic amylase which converts starch into maltose and glucose. **Trypsin** is also secreted as inactive **trypsinogen,** which is activated by enterokinase, secreted by the lining of duodenum. It breaks proteins into peptone and polypeptides. Sodium bicarbonate partly neutralizes the acidic chyme coming from the stomach. The digestion of lipids is initiated in small intestine, firstly **bile,** secretion of liver emulisifies the fats then **lipase** secreted by pancreas digests lipid molecules. The primary products of this digestive process are free forms of fatty acids and glycerol. Phospholipids and cholesterol are also present in digested products. When lipid is digested in the intestine bile salts aggregate around the small droplets to form **micelles** (small morsel). The micelles passes by means of simple diffusion through epithelial lining of small intestine. In the intestinal epithelial cell, triacylglycerol is formed which become **chylomicrons** (lipoprotein) when mixed with proteins. The chylomicron leaves the epithelial cell and enters the lacteals of the lymphatic system within villi of intestine. From lymphatic system, it is poured in blood stream and before entering lipid storing tissues i.e., adipose tissues, triglyceride is broken down into fatty acids and glycerol. In adipose tissue these are again converted into triglycerol.

> **Do you know?**
>
> *Chyle from Greek word chylos juice, means a milky body fluid consisting of lymph and emulsified fats formed in small intestine during digestion.*

The peptone and polypeptide chains are broken down into **dipeptide,** amino acids by peptidase bound to the **microvilli** of small intestine, then enters the intestinal epithelial cells. All dipeptides are converted into aminoacids before entering the hepatic portal system, which carries them to the liver. The amino acids are either modified in the liver or released in the blood stream and distributed to entire body cells where amino acids are used as building blocks to form new proteins or used for energy.

Most of the water is absorbed in the small intestine and about 6 to 7 % is absorbed in the large intestine.

Calcium, potassium, magnesium, sodium and phosphorous ions are also actively transported.

11.1.6 Function of the Large Intestine

The material that reaches the large intestine contains water and dissolved salts along with waste and undigested food. Absorption of water and salts from the chyme takes place by large intestine. It also absorbs vitamin K and B. The remaining chyme is yellowish or brownish in colour due to the presence of bile pigments. It consists of cellulose bacteria, mucin, water and undigested substances. The odour of the feces comes from the bacterial decomposition of nitrogenous compounds. The removal of faeces is called **defecation.**

> **Tit bits**
>
> ***Constipation:***
> *Slow passage of wastes in large intestine result hardening of faeces. This cause constipation.*

Movement in the large intestine takes place:

The peristaltic waves push the chyme into the ascending colon. Distention of the rectal wall due to deposition of feces acts as a stimulus that initiates the defecation reflex.

The external anal sphincter (composed of striated muscles) is consciously controlled, prevents the movement of feces out of the rectum and through the anal opening. If this sphincter is relaxed voluntarily, feces is expelled.

> **Activity**
>
> *Why it is advised not to drink water right after meal? give medical/scientific reason.*

In infants, the defecation reflexe is involuntary, (unconsciously controlled).

11.2 Function of Accessory Glands

Liver: Liver is the largest internal organ and gland of the body, dark red in color, situated on the right side of the abdomen below the diaphragm. It is bilobed, the right lobe is larger than the left lobe. Liver is formed of hepatic cells. A pear shaped, sac like structure called **gall bladder** lies along the right side of liver, where the secretion of liver called bile is stored temporarily. The hepatic ducts transport bile out of the liver. The right and left hepatic ducts unite to form a single common hepatic duct. The common hepatic duct is joined by the cystic duct to the gall bladder to form the common bile duct, which empties into the duodenum at the major **duodenal papilla** in union with the pancreatic duct.

Function of liver: The liver have many roles in the body such as digestive and excretory function. It stores and processes nutrients, synthesizes new molecules and detoxifies harmful substances.

11.2.1 Composition of Bile

The secretion of liver is known as bile. It does not contain digestive enzymes, rather consists of water, bile salts, (sodium glycolate and sodium taurocholate) **bile pigment** (Bilirubin and biliverdin) lecithin (*Phospholipid*), cholesterol, mucus cells and cell debris.

Role of Bile:

It emulsify the fats into droplets to increase surface area for lipid digestive enzymes **(lipase).** It contains **bilirubin** which results from the breakdown of haemoglobin. In the intestine, bacteria convert bilirubin into urobilinogen which give brownish color to feces and yellowish color to urine when absorb again in blood stream. Bile salts help in the absorption of fatty acid from intestinal tract to circulatory system.

Role of secretin hormone to regulate secretion of bile:

The duodenal endocrine cells secrete an hormone known as **secretin,** poured in the circulatory system and carry to the liver and stimulates the secretion of bile juices. Its secretion depends on fats and acidity .

Storage Role of liver: The hepatocytes of liver with the help of insulin remove sugar from the blood and store in the form of glycogen. It also stores fats, Vitamins (A, B12, D, E and K), copper and iron. The stored substances are reused whenever needed thus storage function is usually short term.

Metabolic role of liver: Liver is involved in metabolism of glucose. It converts surplus glucose in the form of glycogen **(glycogenesis),** whenever glucose is needed it changes glycogen into glucose **(glucogenesis).** the amino acids, fatty acids, glycerol and lactic acid are also changed into glucose **(gluconeogenesis).**

- Liver cells denature the fatty acids and phosphorylate fats.
- Liver helps in the deamination of amino acids synthesize vitamin "A" from carotenoid and synthesis of albumin from amino acids.
- The formation of clotting proteins (prothrombin and fibrinogen) also occurs in it.
- It breaks RBCs after completion of 120 days life span. In embryo liver helps in formation of RBCs. (i.e., fetal RBCs).
- The bile pigments bilirubin and biliverdin are formed from break down of haemoglobin.
- Liver is the center of heat production (i.e., **geyser of body**).
- **Detoxification** of poisonous substances and formation of heparin which prevent clotting of blood inside blood vessels.

11.2.2 Pancreas (Sweet bread)

It is a soft gland, grayish pink in color, situated transversely beneath the stomach. It acts as both endocrine and exocrine gland. From the exocrine cells, a duct arises called pancreatic duct, which joins the common bile duct then together opens into the duodenum. The secretion of this gland is known as pancreatic juice.

- The endocrine part of the pancreas consists of pancreatic islets. (islets of

Langerhans) which mostly secrete insulin and glucagon hormone.

The secretion of pancreatic juice is related to secretin hormone:

The hormone secretin controls the exocrine secretions of pancreas, which maintain pH of chyme in the intestine, by secreting watery solution that contains a large amount of bicarbonate ions.

11.3 Some Common Diseases Related to Digestive System and Food Habits

Some common disorders of digestive tract are as under.

11.3.1 Dyspepsia

Incomplete digestion is called dyspepsia.

Symptoms: Abdominal discomfort due to over production of gas in the stomach is called **Flatulence** i.e., distension of stomach by gases formed during digestion. Other symptoms are **heart burn, nausea** (feeling of vomit) and vomiting.

Causes or reasons (Aetiology)

- Gastritis inflammation of lining of stomach.
- Excessive acidity in stomach.
- Alcohol and smoking.
- Insufficient quality and quantity of bile secretions.

Prevention and Treatment:

Avoid smoking, reduce body weight, use of light and easily digestible food, avoid alcohol, tea, fatty food, avoid over eating.

Antacid for heart burning, antibiotic can be used. Histamine blocking agents, which check acid production, stop non-steroid anti inflammatory drugs (NSAID) e.g., Aspirin while the stomach is empty.

11.3.2 Food poisoning

An acute illness caused by eating food containing toxic substances (contaminated food), occurs with in 12-24 hours after eating.

Symptoms: vomiting, diarrhea (it is persistent loosening of bowels). It also cause abdominal pain, dizziness, fatigue, double vision, nausea, headache and dehydration.

> **Do you know?**
> *The persons with blood group "O" are more prone to peptic ulcer. It is also hereditary.*

Aetiology (Reasons):

This disease is due to intake of contaminated food which contains toxin, produced by certain bacteria, such as *Salmonella* and *Campylobacter.*

Human may develop food poisoning by taking the liquid from defrosting (remove ice) frozen meat contains *Salmonella* bacteria. It also contaminate the unpasteurized milk, egg and meat which are not cooked properly.

Prevention and treatment:

- Use only freshly prepared hot food or thoroughly rewarmed food.

Physicians may treat water and salt deficiency which results from vomiting and diarrhea through oral rehydration solution (ORS).

- Loperamide antibiotic therapy against any infection can also be advised.
- The dishes and utensils should be washed before using.
- Unwashed fruits, precooked food should be washed before handling.
- Unsterilized water should not be used.

11.3.3 Obesity

When a person has over weight due to abnormal and excess body fat is called obesity.

Symptoms: An obese person mostly suffers from:

- Hypertension (high blood pressure).
- Heart disease (coronary heart disease).
- Diabetes mellitus.
- Bone pain in knees, hips and joints due to over weight.
- Stomach disorders.
- Gall bladder diseases.

Aetiology or Cause: When people eat more than their need, then excess calories are stored in their bodies as fats, so they become obese. The fats are mostly stored in adipose tissues in the abdomen. Genetic tendency is also a factor. Disorder of the thyroid, pituitary and adrenal glands, emotional disturbances also cause obesity.

Adipose tissue: Surplus food is stored in the form of fat droplets in cytoplasm. The droplets join and form large globule of fat in the middle of cell pushing the nucleus one side. Groups of fat cells form adipose tissues around the kidney and under the skin.

Fig. 11.10 Anorexia Girl

Prevention and Treatment: Gradual reduction in the food, regular exercise also increase metabolic rate.

Related Disorders: Obesity is also the cause of diabetes mellitus, cardiovascular disease and stroke, angina, heart failure, arthritis and anemia, obesity shortens life span.

13.3.4 Anorexia Nervosa

(Gk. An; with out: orexic: longing; intense desire; Nervosa: nervous)

It is the loss of natural strong desire towards food due to the fear of becoming obese. Such a feeling is common in female between the ages of 12 to 21 years.

Symptoms: Loss of appetite, anorexic girl over estimate the size of her own body. They do not mature psychologically and are unable to face the challenges of puberty and emerging sexuality. The patient is mostly emotionally disturbed in making new friends or maturing sexual relation. The patient may be seen engaged in prolonged exercises.

They loss feminine (women) characteristics and the girls retreat (retire) into childlike state in which she feels safe.

Treatment: Psychiatric therapy is usually required to treat anorexia girls. They are fed through other route than alimentary canal i.e, intramuscularly or intravenously. The recovery of anorexia is very slow. It may take 2 to 4 years or more. Group and family therapy is applied to reduce depression.

11.3.5 Bulimia Nervosa: (Gk. Bulimia; bous, ox, limous, hunger) (Nervosa; nervous)

It is a neurotic disorder in older girls.

Symptoms and cause: Bouts (a spell) of excessive eating of fattening food of high calories followed by self-induced vomiting, fasting or purgatives i.e., making stomach empty with a laxative. This frequent vomiting and purging (purify) may cause physical effects including serum electrolytes imbalance and frequent recurring infections.

> **For your Information**
> *Giardiasis is a disease of small intestine caused by giardia. It is most common pathogenic parasite of human gastro-intestinal tract.*

They develop ulcer due to regular use of laxatives.

Damage tooth enamel from acids in digestive fluids of vomits.

Treatment: the initial treatment of bulimics is to overcome the effects of weight loss and malnutrition, family therapy: antidepressant drugs can also be used. The patient should be admitted in hospital and treated under strict supervision.

11.3.6 Piles (Hemorrhoids)

Symptoms: painful masses of dilated, tortuous (full of twist and turns) and swollen vein in the anorectal (anus + rectum) mucosa. It causes itching and may bleed during bowl movement.

> **Can you guess?**
> *What is peptic ulcer and what are its causes?*

Causes:

- It may include prolonged constipation.
- During pregnancy.
- Liver disorder and gas of stomach and intestine.
- Fatty diet which cause gas.

Treatment:

- Improvement of the hygienic conditions .
- Use of food softeners such as roughage in food or laxative to prevent from constipation.
- The patients should not sit on hard seats.
- Hemorrhoids are also removed by surgery.

Activity

Stomach ulcer, food poisoning and dypepsia are common digestive system disorders of our society. Make a list of main causes of these disorders and their preventions through your personal observations and by searching different reliable sources.

11.3.7 Ulcer

The sore (pain) in the stomach and duodenum is called ulcer or peptic ulcer. It is more in man than women.

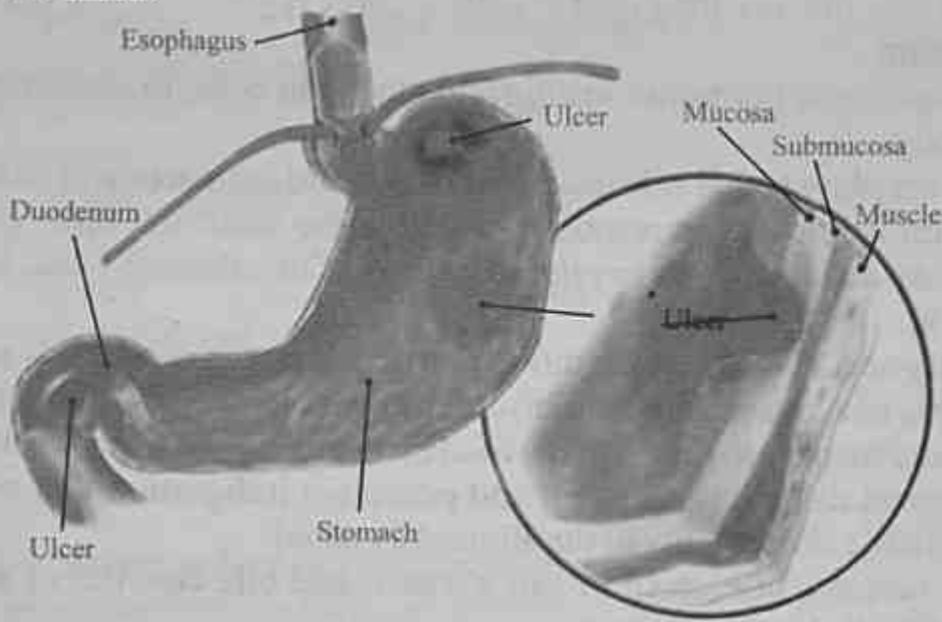


Fig. 11.10 Peptic Ulcer

Causes (Aetiology):

Break down of inner mucous layer of gastrointestinal tract by combine action of pepsin and HCl in the stomach cause peptic ulcer. Excessive alcohols. Stress, aspirin and anxiety (mentally troubled).

Helicobacter pylori bacterium is the most important factor in peptic ulcer.

Prevention and Treatment:

The patient should avoid spicy food and use simple food. Avoid excessive intake of tea and coffee.

The patient should also avoid from alcohol and smoking. Missing of meal are to be avoided. Antacids like milk and other drugs such as **cimetidine** reduce gastric secretions and help in healing ulcer. Sedative drugs help to reduce stress and tension. Vomiting relieves pain in gastric ulcer.

SUMMARY

- Digestion is the process by which polymers, large and complex food is broken down into monomers, small and simple food so the body can use them to build, nourish cells and to provide energy.

- Peristalsis occurs throughout the length of the digestive tract. It is responsible for keeping things moving, begins from esophagus.
- Stomach consists of four regions which are: the cardiac region, fundus, body and pylorus.
- Gastrin hormone controls the secretion of gastric juice. Protein containing food stimulates the endocrine cells of the stomach to secrete gastrin.
- The large intestine consists of three regions: the ceacum, colon and rectum.
- Small intestine is a long tube consist of three regions i.e., the duodenum, jejunum and ileum.
- The pancreatic hormones insulin and glucagon helps to maintain glucose level in our body.
- The liver plays a vital role in detoxification and destruction of harmful substances.
- Secretin is released in response to acid in the small intestine, and stimulates the pancreas and bile ducts to release a flood of bicarbonate base, which neutralizes the acid.
- Obesity occurs when we eat more food or calories than our body uses up.
- Bulimia nervosa is an eating disorder in which a person may eat a lot of food at once and then try to get rid of the food by vomiting and using laxatives.
- Dyspepsia describes recurrent and persistent indigestion that occurs without an identifiable abnormality of the alimentary canal.
- Liver secretes bile, store in gall bladder, and bile consists of salts, cholesterol, bilirubin etc. but no enzymes.
- Liver is store house of vitamins like **A, B12, D, E, K.**
- There are three pairs of salivary glands in our oral cavity, which secrete mucus and saliva.
- Chief cell of stomach secretes non functional pepsinogen which is later converted into active protein digesting enzyme called pepsin.
- Gluconeogenesis is the process of converting fats, proteins and lactic acid into glucose.

EXERCISE

Section - I: Objective Questions.

Multiple Choice Questions

A. Select the best option.

1. The teeth adapted for tearing are called .
   (a) Incisor (b) Canine
   (c) Molar (d) Premolar
2. The opening from the oesophagous into stomach is called.
   (a) Cardiac opening (b) Pyloric opening
   (c) Stomach opening (d) Oesophagous opening

3. Which of the following enzyme is secreted by gastric gland?
   (a) Amylase (b) Lipase
   (c) Pepsin (d) Trypsin
4. Excess intake of carbohydrate causes.
   (a) Obesity (b) Piles
   (c) Dyspepsia (d) Bulimia nervosa
5. Fatty acid and glycerol are first absorbed by.
   (a) Lymph vessel (b) Villi
   (c) Capillaries (d) None of these
6. *Helicobacter pylori* causes
   (a) Peptic ulcer (b) Piles
   (c) Bulimia (d) Anorexia
7. Bile is the secretion of
   (a) Pancreas (b) Liver
   (c) Stomach (d) Intestine
8. Stomach consists of _______ parts
   (a) 5 (b) 4
   (c) 3 (d) 2

B. Fill in the blanks.

1. The premolars and molars are specialized for ____.
2. The enzyme present in salvia is called __________.
3. The oesophagous is about _________ long.
4. The outer most opening of stomach is called _____.
5. Lipase is a ________ digesting enzyme.
6. Chyme is turned into a watery emulsion called___.
7. Secretin is hormone produced by _____________.
8. The bilirubin is produced by the breakdown of ___ in liver.
9. *Salmonella* is a bacterium cause disease _________.
10. The enzyme trypsinogen is changed into trypsin by______.

Section-II Short Questions.

1. Describe steps of swallowing.
2. Write the name of different layers of stomach.
3. List the enzymes of digestive system.
4. What are the hormones of digestive tract and their brief role?
5. What are the functions of bile?
6. Why some digestive enzymes are secreted in inactive form?
7. What are the symptoms and treatment of bulimia nervosa?
8. Write the aetiology of food poisoning, dyspepsia and obesity?

Section-III Extensive Questions.

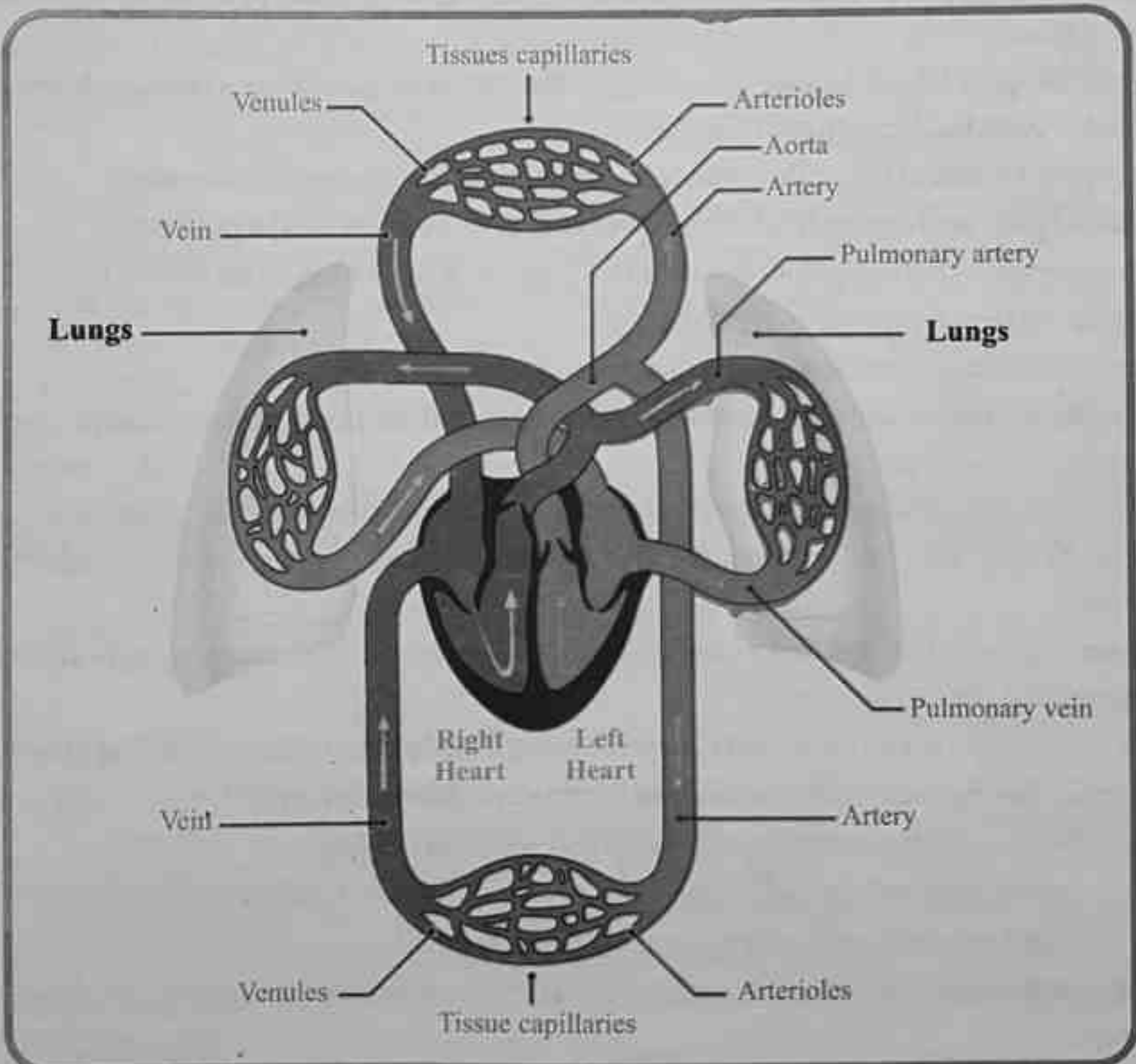
1. What is the role of oral cavity in digestion of food?
2. Describe the structure of stomach?
3. Describe the structure of small intestine?
4. Explain the function of stomach?
5. Describe the structure and function of large intestine?
6. Explain the role of liver and pancreas in digestion?
7. Describe the importance of duodenum in digestive tract?

UNIT 12

CIRCULATION

Major Concepts

12.1 Blood Circulatory System of Man
12.2 Human Heart
12.3 Blood Vessels
12.4 Blood Pressure and its Measurement
12.5 Cardiovascular Disorders
12.6 Lymphatic System of Man



Students Learning Outcomes

On completion of this unit students will be able to:

- State the location of heart in the body and define the role of pericardium.
- Describe the structure of the walls of heart and rationalize the thickness of the walls of each chamber.
- Describe the flow of blood through heart as regulated by valves.
- State the phases of heart beat.
- Explain the role of SA node, AV node and purkinji fibers in controlling the heart beat.
- List the principles and uses of Electrocardiogram.
- Describe the detailed structure of arteries, veins and capillaries.
- Describe the role of arterioles in vasoconstriction and vasodilation.
- Describe the role of pre capillary sphincters in regulating the flow of blood through capillaries.
- Trace the path of the blood through the pulmonary and systemic circulation (coronary, hepatic-portal and renal portal circulation)
- Compare the rate of blood flow through arteries, capillaries, venules and veins.
- Define blood pressure and explain its periods of systolic and diastolic pressure.
- State the role of baroreceptors and volume receptors in regulating blood pressure.
- Define the term thrombus and embolus.
- Identify the factors causing atherosclerosis and arteriosclerosis.
- Categorize Angina pectoris, heart attack, and heart failure as the stages of cardiovascular disease development.
- State the congenital heart problem related to the malfunctioning of cardiac valves.
- Describe the principle of angiography, coronary bypass, angioplasty and open heart surgery.
- Define hypertension and describe the factors that regulate blood pressure and can lead to hypertension and hypotension.
- List the changes in life styles that can protect man from hypertension and cardiac problem.
- Describe the formation, composition and function of intercellular fluid.
- Describe the composition of intercellular fluid with that of lymph.
- State the structure and role of lymph capillaries, lymph vessels and lymph trunks.
- Describe the role of lymph vessels (lacteal) present in villi.
- Describe the function of lymph nodes and state the role of spleen as containing lymphoid tissue.

Introduction

All living cells require efficient supply of nutrients, oxygen, hormones etc. The cells must get rid of metabolic wastes like CO_2 and nitrogenous wastes. Small organisms meet their requirements of supply of nutrients and oxygen and removal of waste products, simply by means of diffusion. Tiny animals have small size and large surface area so this process of diffusion is sufficient to meet their required transport of substances.

The larger and active animals like human cannot rely on diffusion alone. Therefore these animals must need an efficient transport system.

This chapter deals with human transport system and its components i.e., Heart, blood, blood vessels and blood pressure and cardiovascular disorders.

Tit bits

The study of diseases of cardiovascular system is called angiology.

12.1 Blood Circulatory System of Man

Human blood circulatory system is composed of following parts i.e., a muscular pumping organ called heart, a system of interconnecting tubes called blood vessels and a circulatory fluid, the blood. The blood always remains in the vessels so the system is known as closed circulatory system.

12.2 Human Heart

The heart of an adult human has a mass of around 300 grams, and is about the size of our fist. It is the most powerful organ in the circulatory system. The heart lies in the thoracic cavity between the lungs, slightly towards left, enclosed within the rib cage, with the sternum in front and vertebral column behind. It is surrounded by a double layered **pericardium.** A pericardial fluid is secreted in between these two layers. It lubricates and reduces the friction between the heart walls and surrounding tissues during the beating of heart.

Do you know?

Dr. Christen Barnard carried out the first heart transplant in 1967. The recipient, Louis Washkansky only lived for 18 days after transplant but now most of heart transplant patients are expected to survive for the rest of their life.

Tit bits

Cardio-logy from Greek Kardia, "Heart" and logia "study" is a branch of medicine dealing with disorders of heart as well as parts of circulatory system.

Structure of Human Heart

The heart is conical in shape and dark red in colour. The heart has four chambers, a **left and right atrium** at the top, and a **left and right ventricle** beneath. The right side is completely separated from the left side by a **septum.** The walls of heart are made almost entirely of a special kind of muscles called cardiac muscles. It is the regular contraction and relaxation of these muscles which produces the pumping movement of the heart called **heart beat**.

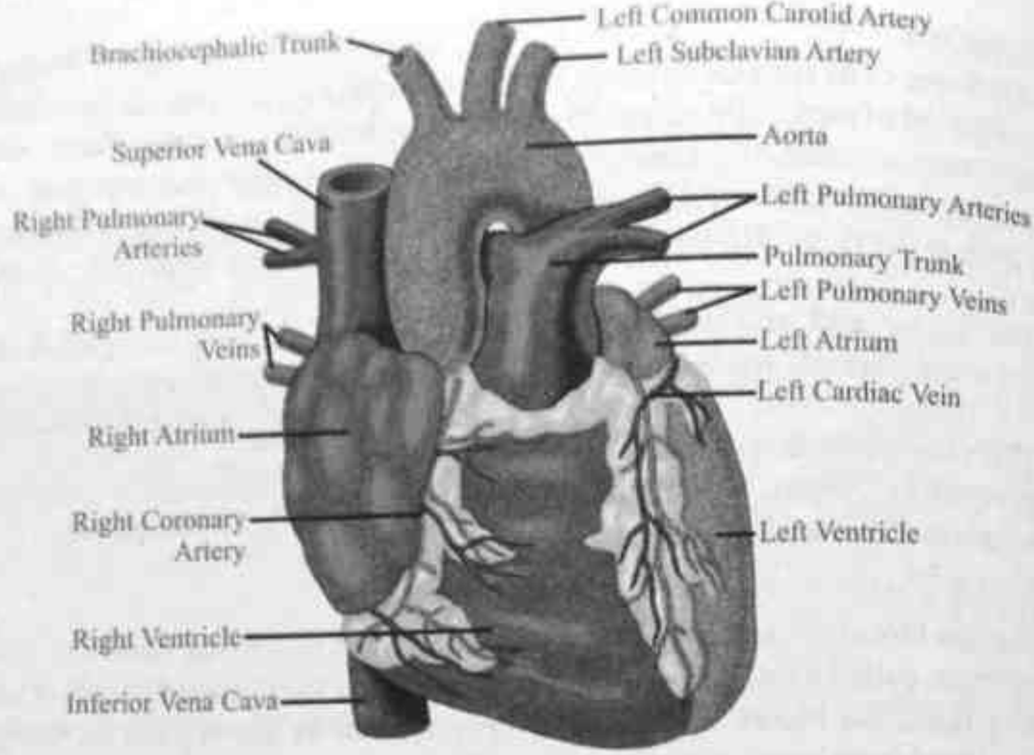


Fig. 12.1 External Structure of Heart

The **atria** on each side of the heart are separated from the **ventricles** by valves. These are atrioventricular valves (AV valves). The one on the left is often known as

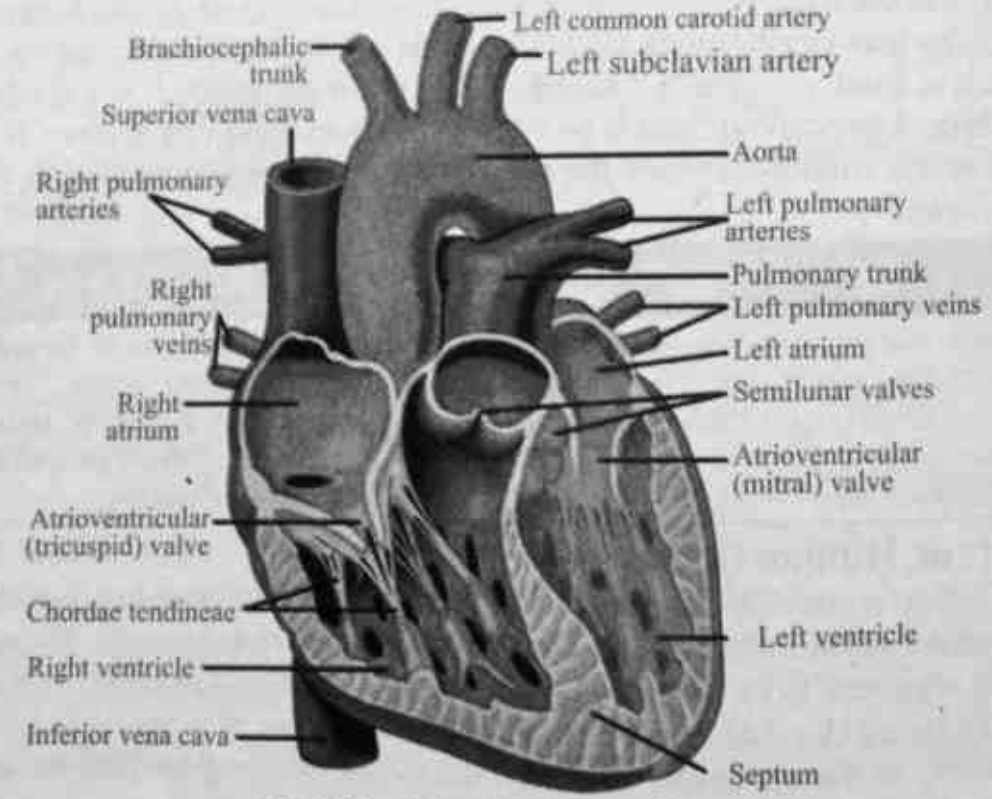


Fig. 12.2 Internal structure of heart

mitral valve, or alternatively the **bicuspid valve** because it has two flaps. The one on the right side is called **tricuspid valve.** The valves control one way flow of blood i.e. from atria to ventricles but prevent back ward flow.

The **semilunar valves** guard the emergence of pulmonary arch and systemic aorta. These valves also prevent backward flow of blood. On the outside of heart blood vessels can be seen. These are called **coronary arteries** which deliver oxygenated blood itself to the heart walls.

The heart wall is formed of three layers:

Epicardium: outer most, **Myocardium**, middle, **endocardium**, innermost. The epicardium is thin and comprising of smooth outer surface of heart. The myocardium is thick and composed of cardiac muscle cells. The endocardium consists of simple squamous epithelium.

> **Tit bits**
>
> *Heart block is a disease or inherited condition that causes a fault within the natural pace maker of the heart, due to some kind of obstruction or block in the electrical conduction system of heart.*

12.2.1 Heart Beat and its Control (cardiac cycle)

Adult human heart beats around 72 times per minute. One heart beat is called cardiac cycle. A cardiac cycle is a sequence of events which takes place in the heart during one heartbeat. First the atria contract; this is called **atrial systole**. As a result of this contraction blood is forced into the ventricles through atrio-ventricular valve now the ventricles contracts. This stage is called **ventricular systole.** The walls of ventricles are thicker and stronger than atrial walls, so they can produce much greater force. The blood is squeezed up into the aorta from the left ventricle and the pulmonary artery arises from the right ventricle. The

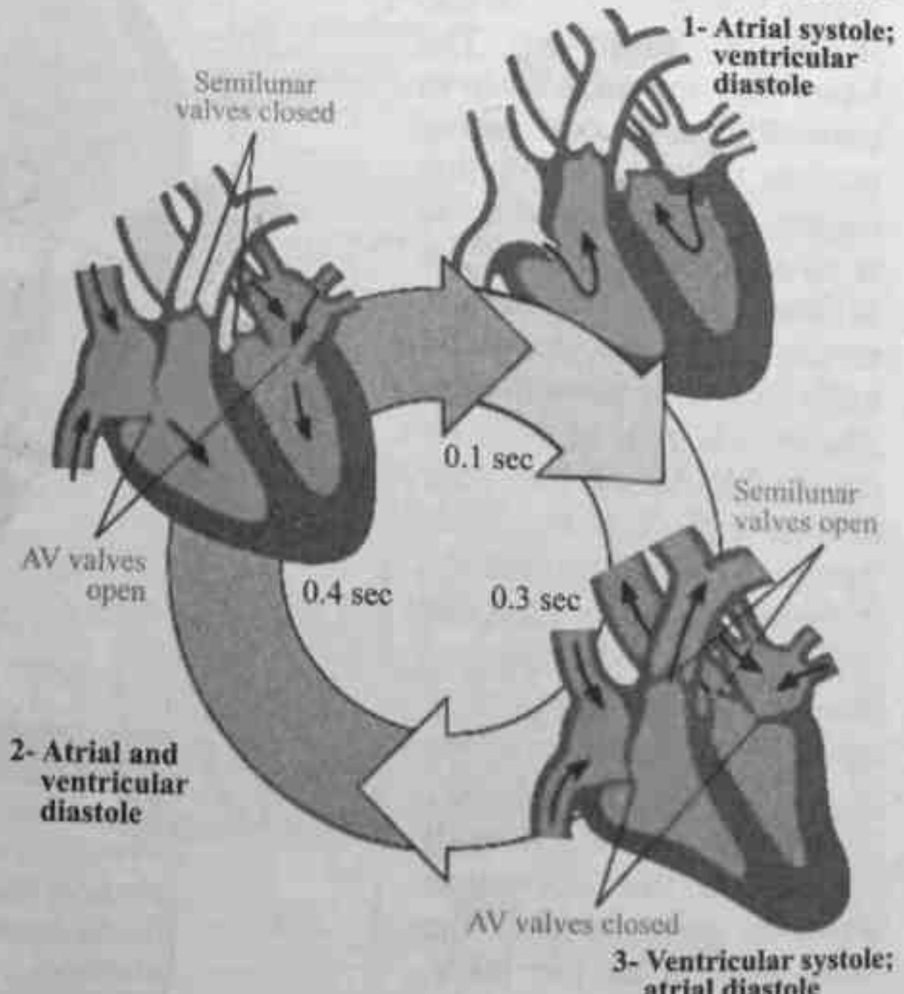


Fig. 12.3 Cardiac cycle

pressure of the blood in the ventricles pushes upward on the atrioventricular valves, pushing them shut. So if the valves are working properly no blood can go backwards into the atria. Next the muscles in the atria and ventricles relax. This is called **diastole.**

> **Do you know?**
>
> ***Cardiac output:*** *The volume of blood leaving the left ventricle is known as stroke volume.*
>
> *Cardiac output is the volume of blood leaving the left ventricle per minute so cardiac output = stroke volume x heart rate.*

12.2.2 Conducting System of the Heart

The cardiac muscles are **myogenic.** This means that these muscles contract and relax naturally. Heart does not need to receive impulses from a nerve to make it contract. If heart is kept in warm oxygenated solution containing nutrient's, the heart muscles will contract and relax rhythmically by themselves. However the individual heart muscle cells can not be allowed to contract at their own natural rhythms because if so the part of heart would contract out of sequence with other parts, the cardiac cycle would become abnormal and the heart would stop. The heart has its own built in controlling and coordinating system which prevent this happening. The cardiac cycle is initiated in a special patch of muscles in the wall of right atrium called the **sinoatrial node (SAN) or pace maker.** The muscle cells of SAN set the rhythm for all the other cardiac muscle cells. Their natural rhythm of contraction is slightly faster than the rest of the heart's electrical activity, which spreads out rapidly over the whole of the atrial walls. The cardiac muscle in the atrial wall respond to this excitation wave by contracting as the same rhythm as the SAN. Thus all the muscles in both

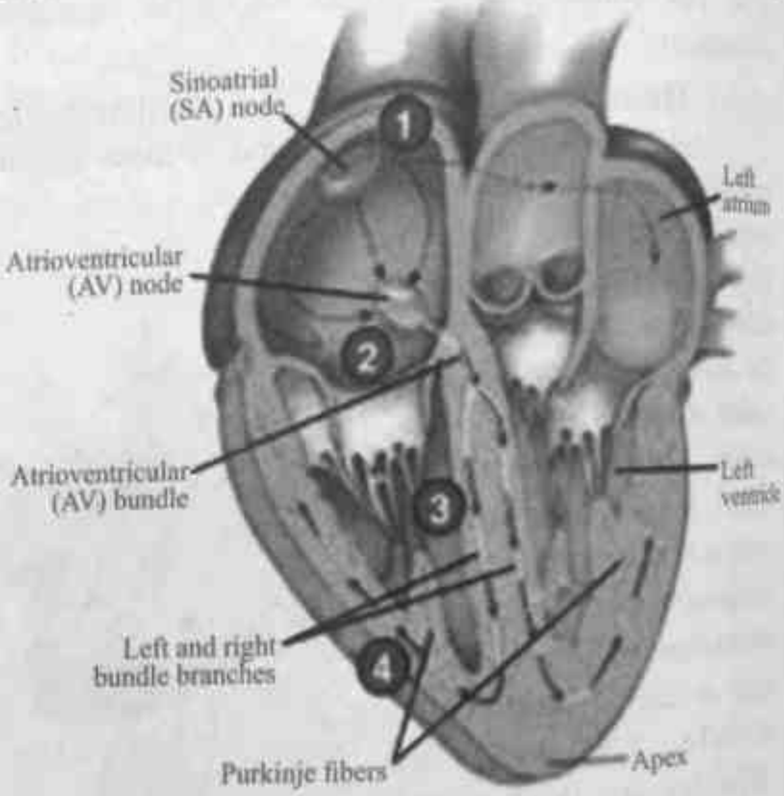


Fig. 12.4 SA node AV node

> **Tit bits**
>
> *The sinoatrial node was first discovered by a young medical student Martin Flack in the heart of mole, A small mammal.*

atria contract almost simultaneously.

As we know the muscles of ventricles do not contract until after the muscle of atria contract. This delay is caused by a feature of heart that briefly delays the excitation waves in its passage from atria to ventricles.

There is a band of fibers between the atria and ventricles which does not conduct the excitation wave. Thus as the wave spread out from the SAN over the atrial walls, it cannot pass into the ventricle walls. The only route is a patch of conducting fibers situated in the septum, known as atrio-ventricular node (AVN). The AVN picks up the excitation wave as it spreads across the atria. Besides, there is a bundle of nerve fibers called atrioventricular bundle (AV) or "Bundle of His" arising from AV Node, it pass through the septum in between the ventricles and divides into right and left bundle branches. Numerous conducting fibers called "Purkinje Fibres" arise from the branches and spread over the ventricles.

12.2.3 Electrocardiogram

The electrocardiogram (ECG) also known as EKG. It is a non invasive device that measures and records the electric activity of the heart over a period of time using electrodes placed on the skin. These electrodes detect the tiny electrical changes on the skin that arise from the heart muscles that is electrophysiological pattern of depolarization and repolarization during each heartbeat.

Tit bits

An elctrocardiograph is a machine that is used to perform electrocardiography and produces the electrocardiogram.

The first part of the wave called "P" wave is a small increase in the voltage of about 0.1 mV that corresponds to the depolarization of the atrial systole. The next part of ECG is the "QRS" complex which features a small drop in voltage (Q) a large voltage peak (R) and other small drop in voltage (S). The "QRS" complex corresponds to the depolarization of the ventricle during ventricle systole. The atria also repolarize during the "QRS" complex but have almost no effect on the ECG because they are quite smaller than ventriclular waves.

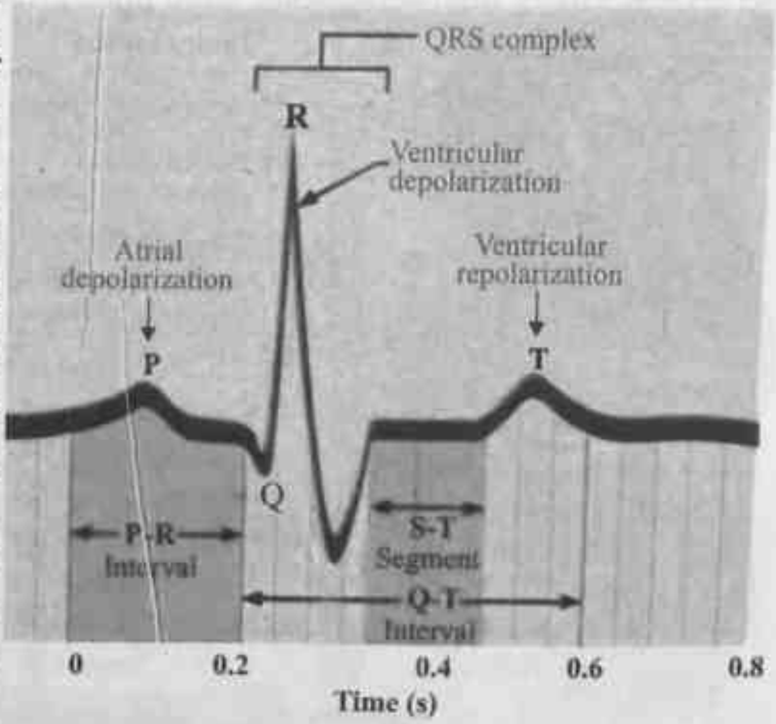


Fig. 12.5 ECG

The final part of ECG wave is the "T" wave, a small peak that allows the QRS complex occurs just prior to ventricular contraction. The "T" wave represents the ventricle repolarization during the relaxation phase of the cardiac cycle.

The overall goal of performing electrocardiography is to obtain information about the function of heart e.g., suspected myocardial infarction, suspected embolism, increase in size of heart, to access the severity of electrolytes abnormalities etc.

> **Do you know?**
>
> *Sinus bradycardia is a sinus rhythm with a rate that is lower than normal. In humans bradycardia is generally defined to be a rate of under 60 beat per minute, while sinus tachycardia is a sinus rhythm with a elevated rate of impulses usually greater than 100 per minute.*

12.3 Blood Vessels

There are three major types of blood vessels i.e. arteries, veins and capillaries. **Arteries** always carry blood away from heart. All arteries carry oxygenated except pulmonary arteries. The largest artery **(aorta)** divides into smaller one and these continue to divide to form much smaller vessels called **arterioles**. These in turn divide further into smaller vessels called **capillaries.** These capillaries then join up with each other to form **venule** and these finally merge to form **veins.** These bring the blood back to heart. All veins bring deoxygenated blood except pulmonary veins. Veins unite to form venae cavae.

> **Tit bits**
>
> *The aorta is the largest artery while vena cava is the largest vein in the body.*

Arteries: Greek arteria meaning wind pipe. Arteries are

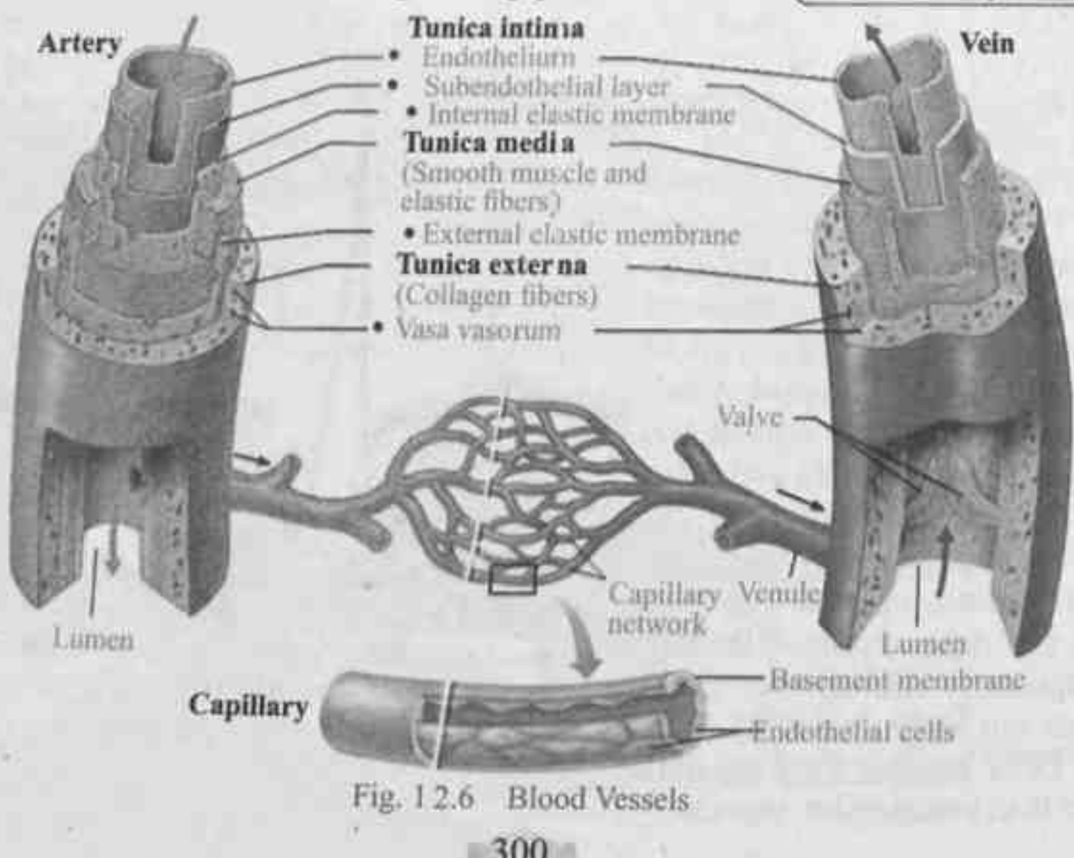


Fig. 12.6 Blood Vessels

thick walled vessels consisting of three layers. The outer layer of an artery is known as **tunica externa** and is composed of connective tissues made up of collagen fibers. Inside this layer is **tunica media** which is made up of smooth muscle cells and elastic tissue. The innermost layer which is in direct contact with the flow of blood, is the **tunica intima.** This layer is made up of epithelial cells.

Capillaries: These are the smallest and thinnest of blood vessels in the body. The intimate relationship between the circulatory system and the tissues is achieved at the level of capillaries. The function of capillaries is to carry blood as close as possible to all cells allowing rapid transfer of substances between cells of the body. Human capillary is approximately 7 to 9 μm in diameter almost same size as a

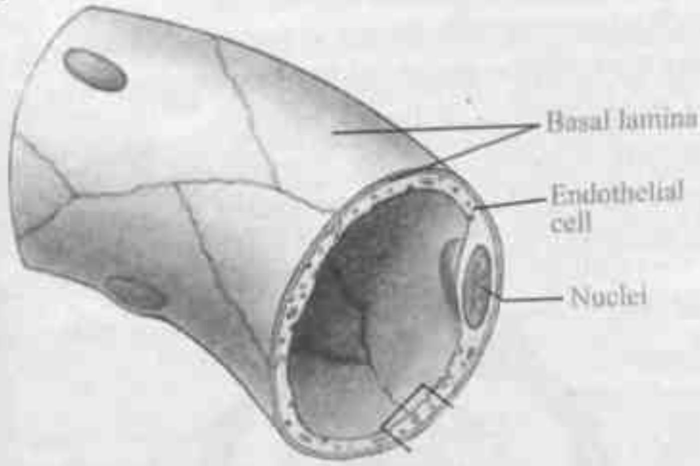


Fig. 12.7 Capillary

red blood cells, which can, therefore, only pass along the capillary in single file. Moreover the walls of capillaries are extremely thin, made up of a single layer of endothelial cells. This thinness of capillary walls helps to speed up the exchange rate of materials with the tissues.

Veins: Veins are the blood vessels that bring blood back towards heart. Most veins carry deoxygenated blood except the pulmonary and umbilical veins. Veins are less thick and less elastic than arteries. Moreover veins have relatively larger lumens than arteries.

A vein consist of three main layers. The outer thicker layer made up of connective tissue called the tunica externa or tunica adventitia. The middle layer is called tunica media and is composed of smooth muscle. This layer is quite thinner than arteries. The inner most layer is called tunica intima.

Tit bits

Cornea and cartilage lack capillaries. Therefore these structures are slow to heal if injured.

Tit bits

Veins are called capacitance vessels because most of blood volume (60%) is contained with in veins.

Tit bits

The veins appear blue because the subcutaneous fat absorb low frequency of light and reflect blue light.

Cardiac veins: *The vessels that remove deoxygenated blood from the heart muscles.*

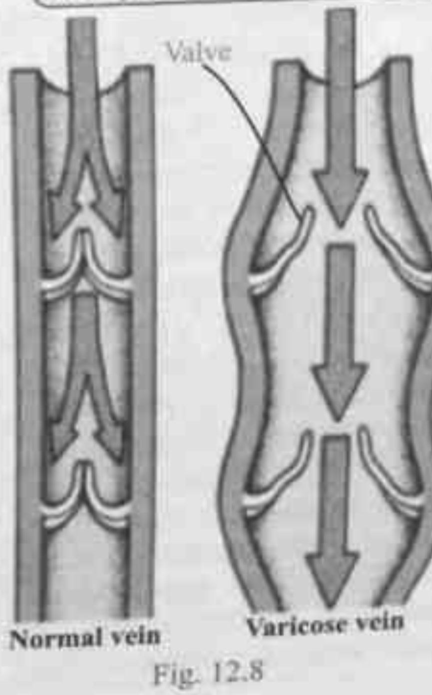


Fig. 12.8

The largest vein in human body is vena cava which enters the right atrium of heart from above and below.

The venules are small veins that collect blood from capillaries which then drai into veins.

Valves in veins: Veins mostly contain valves which prevent back-ward flow of bloo These valves are present in larger veins having diameter greater than 2mm. Howeve these valves are needed only in lower part of the body such as veins of hind limbs an abdomen, without these valves the flow of blood towards heart is very slow and difficult.

12.3.1 Role of arterioles in vasodilation and vasoconstriction

Vasodilation means widening of blood vessels as a result, blood flow increase due to decrease in vascular resistance (Due to increase of diameter of vessel.)

Vasoconstriction is the narrowing of blood vessels to decrease, blood flow due to increase in vascular resistance (Due to decrease in diameter of vessel).

The vasoconstriction and vasodilation normally occur as per need of the body e.g. to regulate body temperature during hot and cold or in situation of emergency like flow of blood from injury or during emotional situations e.g., sadness, rage etc.

Vasodilation and vasoconstriction is controlled by hormones. However thick smooth muscle layer in arterioles make this possible. The arterioles usually have large number of smooth muscles to perform this task.

12.3.2 Role of Pre-capillary sphincter in regulating the flow of blood through capillaries

A pre-capillary sphincter is a band of smooth muscle that adjust blood flow into capillaries. The pre capillary sphincter is located at a point where each of the capillaries originates from the arteriole. The sphincter can open and close the entrance to the capillary. Sphincter is unable to contract when blood flows into capillary bed at high pressure, then the fluid from capillaries pass into interstitial space and edema may result.

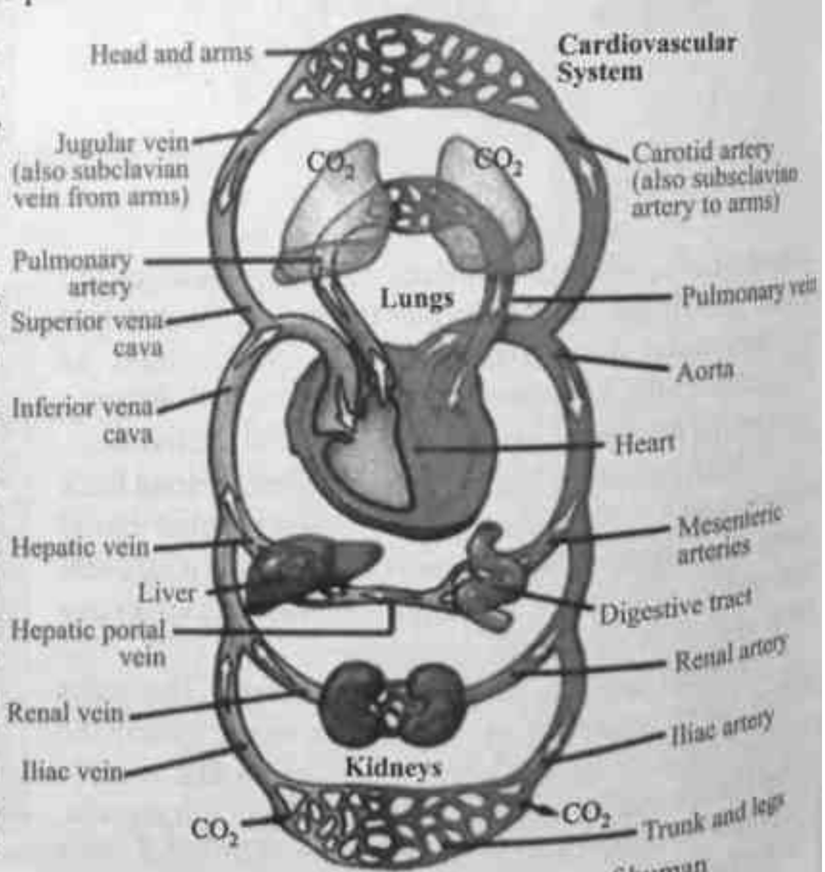


Fig. 12.9 Cardio-vascular system of human

12.3.3 Vascular Pathway

The blood vascular system may be divided into two parts i.e. pulmonary circulation and systemic circulation.

Pulmonary circulation:

The pulmonary circulation is also called pulmonary circuit. This portion of blood circulatory system carries deoxygenated blood away from the right ventricle of heart to lungs and returns oxygenated blood to left atrium and then into the left ventricle of the heart. The deoxygenated blood leaves the heart through pulmonary arteries while oxygenated blood enters into left afrium through pulmonary veins.

Systemic circulation:

The systemic circulation is the portion of the blood vascular system which transports, oxygenated blood away from the heart through the aorta from the left ventricle. This oxygenated blood is transported to all parts of body including heart muscles but excluding lungs. The left atrium is receiving and left ventricle is pumping chambers for systemic circulation. The right atrium is the receiving chamber of systemic circulation. It receives deoxygenated blood through inferior and superior venae cavae.

> **Tit bits**
>
> *Portal hypertension is a condition in which the blood pressure of the portals system is too high which may cause cirrhosis of liver.*

Coronary circulation:

The circulation of blood into the blood vessels of heart muscles i.e., myocardium is known as coronary circulation. Two coronary arteries originate from the left side of the heart at the beginning of aorta. There are two main coronary arteries i.e. left coronary which supplies oxygenated blood to left side of heart and right coronary artery which supplies oxygenated blood to the right side of heart. The deoxygenated blood is taken back to right atrium by cardiac veins.

> **Tit bits**
>
> *When the heart's natural pacemaker is defective then the rhythm of heart disturb. This may cause many problems and prove fatal. Therefore artificial pace maker is needed for regulating the heart's rhythm.*

Hepatic portal system:

The portal system is formed when a capillary bed pools into another capillary bed through veins without going through the heart. The some examples of the portal system are hepatic portal system and renal portal system in poikilotherms. The hepatic portal system is a system of veins related to digestive tract and its tributaries. It is also called the portal venous system. Hepatic portal system is responsible for directing blood from digestive tract to liver. So the substance absorbed in the small intestine travel first to the liver where these are metabolised and processed before sending towards the heart.

> **Tit bits**
>
> *The hepatic portal system is present in all vertebrates while renal portal system present only in poikilotherms vertebrates.*

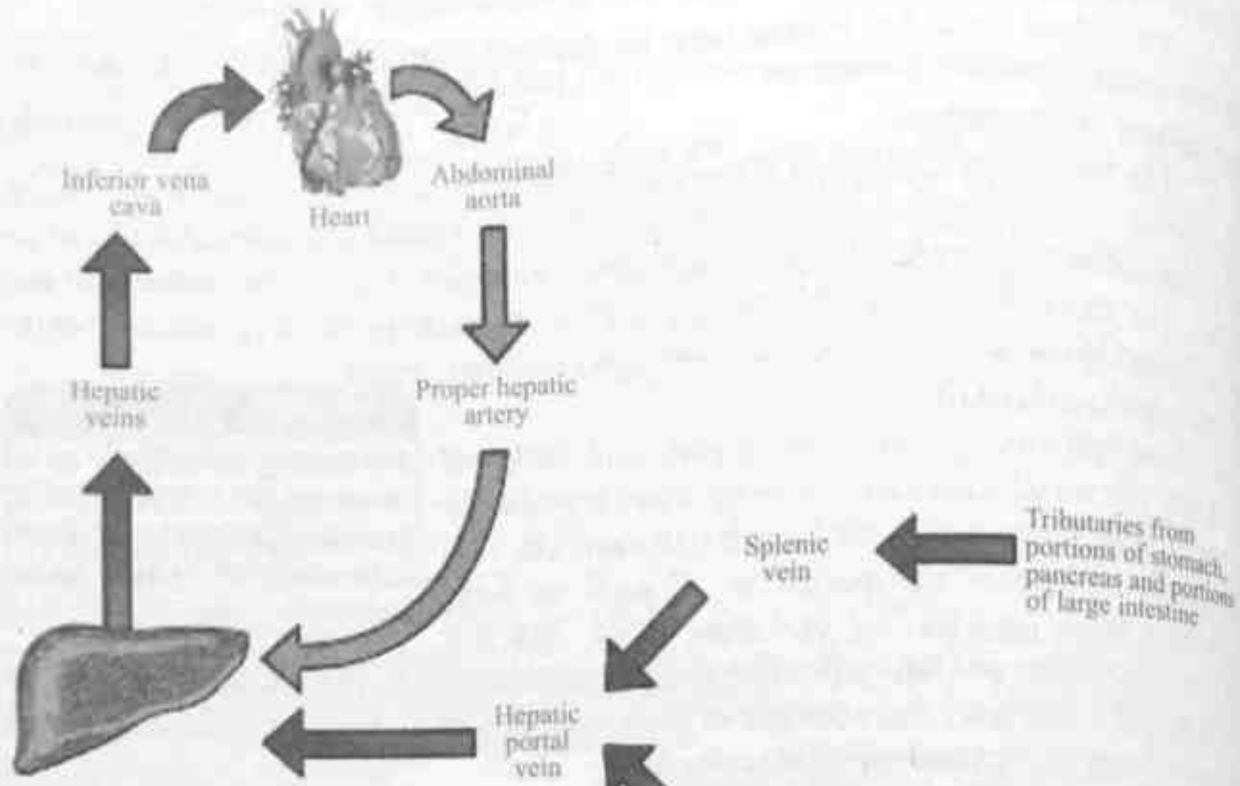


Fig. 12.10 Hepatic Portal Circulation

Renal circulation:

Renal circulation implies the circulation of blood to the kidney via renal artery for filtration and the collection of filtered blood towards heart. Renal arteries normally arise from the side of the abdominal aorta and supply blood to kidneys. The renal arteries carry large portion of total blood flow to the kidneys. Up to one third of total cardiac output can pass through the renal arteries to be filtered by kidneys.

Rate of blood flow in blood vessels:

Blood is circulated around the body through blood vessels by the pumping action of the heart. The rate of blood flow varies greatly in different blood vessels and tissues. It is high in larger vessels and decreases with the division of blood vessels and lowest rate is observed in capillaries.

> **Tit bits**
>
> *Liver has the most abundant blood supply with approximate blood flow of 1350ml/min. kidneys and brains are second and third most supplied organs with 1100 and 700 ml/min respectively.*

12.4 Blood pressure

The term blood pressure refers to the force exerted by the blood on the walls of blood vessels as it passes through them. Blood pressure is most commonly measured via a **sphygmomanometer** in which the height of a column of mercury reflects the circulatory pressure. There are two different pressures which are commonly measured, systolic pressure and diastolic pressure. The **systolic pressure** is the maximum pressure produced in the left ventricle during systole. The **diastolic pressure** is the pressure in the aorta at the end of diastole.

> **Tit bits**
>
> *Baro reflex is one of the blood homeostatic mechanisms that helps to maintain blood pressure.*

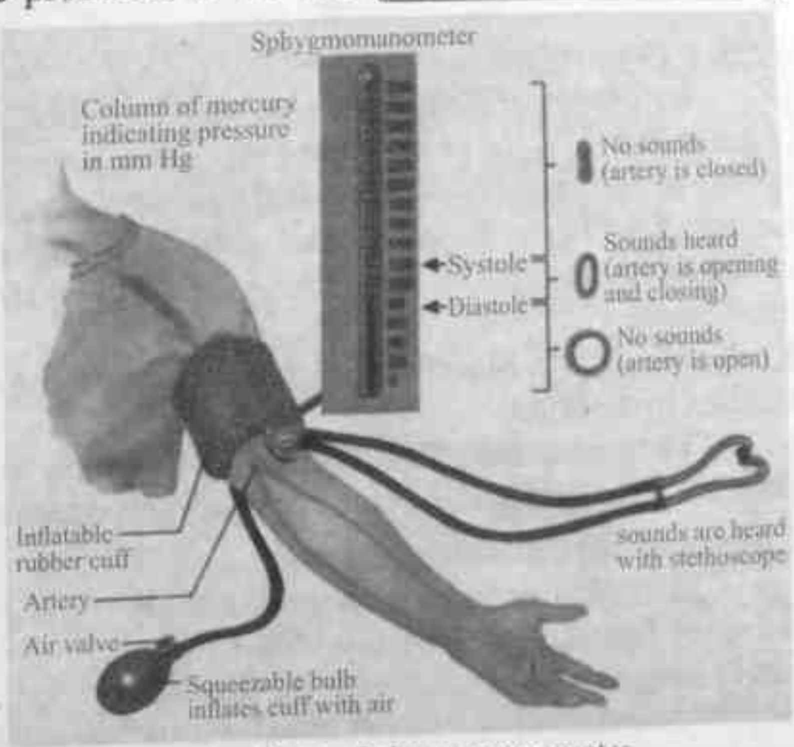


Fig. 12.11 Sphygmomanometer

Baroreceptors:

The blood vessels of vertebrates posses baroreceptors which sense the blood pressure. Then relay the information to the brain so that proper blood pressure can be maintained. These receptors are also called as **pressure receptors.**

On the bases of blood vessel baroreceptors can be divided into two types. **High pressure arterial baroreceptor** and **low pressure baroreceptors** also known as cardiopulmonary or volume receptors.

High Pressure Arterial Baroreceptors:

These receptors are located in the walls of aorta and carotid arteries. These receptors sense the blood pressure and convey the information to the nervous system as per need of the body.

Low Pressure Baroreceptors: (volume receptors)

These receptors are located in atria of the heart, carotid arteries and pulmonary vessels. When low pressure is detected the signal is transmitted by these receptors to the hypothalamus in the brain. The hypothamus increases the production of vasopressin which cause water retention in blood. This increases the blood volume as a result blood pressure aiso increases.

Comparison of the rate of blood flow through arteries arterioles, capillaries, venules and veins:

The rate of blood flow varies in different blood vessels. In arteries blood flow is highest as it is pushed out of heart. In adult human, the rate of blood flow in blood vessels at rest (cardiac out put) is about 5 liters/min.

In capillaries blood pressure is lowest while in veins blood pressure is still low as compared to arteries.

12.5 Cardiovascular Disorders

The disease of heart and blood vessels are known as cardiovascular disorders (CVD). Some examples of CVD are.

Do you know?

Thrombus is formed, from the platelets, fibrinogen, entrapped RBC and WBC mostly.

12.5.1 Thrombus

A thrombus is a blood clot that is formed in the blood vessel or in the heart during life and remain there. A thrombus can even block blood flow through a vessel or it can break off from the vessel wall and carried through the circulatory system. The formation of thrombus is called thrombosis.

Tit bits

Up to 90% of cardio vascular diseases may be prevented if established risk factors are avoided.

Embolus: It is a blood clot that travels from the site where it is formed, to another location in the body.

Thromboembolism is a collective term for the formation of thrombus and embolus. Which is leading cause of death in western civilization.

Causes of thromboembolism:

Infection or injury in endothelial lining of blood vessels, slow blood flow due to long period of inactivity, the disease like pneumonia, tuberculosis and emphysema.

Effect of thrombosis: Hypertension due to blockage of blood vessels either partly or completely. It blocks supply of oxygen which result in damage, destruction or even death of tissue (necrosis) in that area.

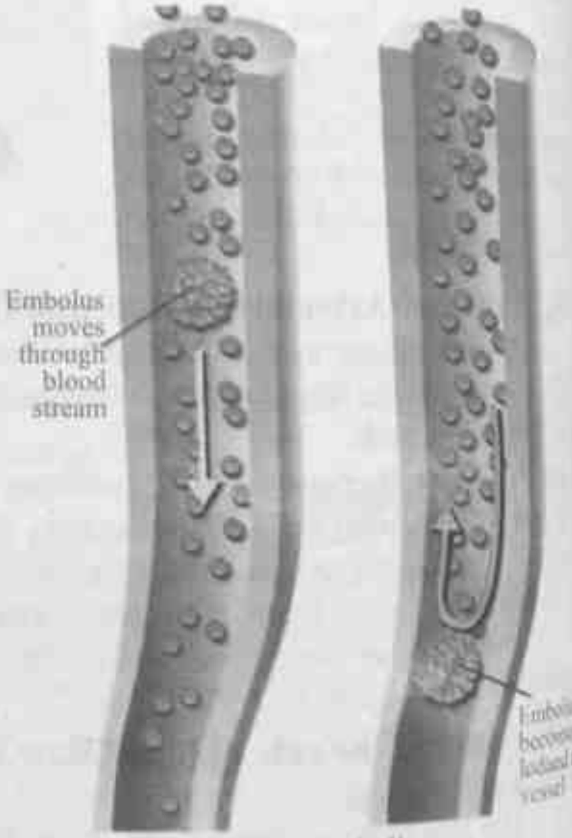


Fig. 12.12 Embolism

12.5.2 Atherosclerosis: (Gk. Athere; Porridge; skeleroe: Hardening)

It is storage of fat deposits on the inside wall of artery. Atherosclerosis is the co-existing antheroma and arteriosclerosis.

The deposition of hard yellow fatty masses called **plaques**, containing large quantities of cholesterol in the inner most layer (intima) of the arteries is called **atheroma.**

Arteriosclerosis: It is degenerative arterial change associated with advancing growing age primarily a thickening of middle layer of arteries. It causes the arterial lining much rougher than normal. This roughening tends to promote thrombus formation and lead to embolism. It also causes narrowing of blood vessels due to deposition of plaque which obstructs the flow of blood. Ca ions also deposit in the plaque, which loses (weakens) their elasticity and easily gets ruptured.

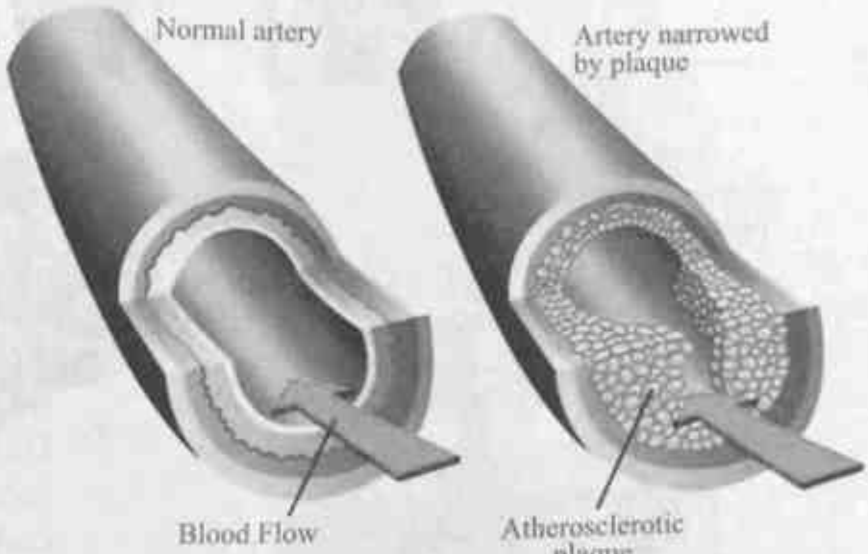


Fig. 12.13 Atherosclerosis

Causes of atherosclerosis:
Hypertension, smoking, hyper lipidemia, diabetes mellitus, lack of exercise and obesity.

Prevention: Do exercise regularly, avoid smoking, use of low cholesterol diet.

Angina Pectoris: If a coronary artery become partially blocked, the individual may suffer from angina pectoris (i.e., chest pain along with pain in the left arm). Angina is an alarming signal that heart is not receiving sufficient supply of oxygen and in future heart attack may occur. **Nitroglycerine** mostly helps to relieve the pain in angina pectoris, because this drug dilates the blocked blood vessels.

12.5.3 Heart Attack

Heart attack is the sudden death of a part of the heart muscle without warning due to sudden reduction of blood supply.

Heart attack mostly occurs when atheorsclerosis reach a critical level and damage large portion of heart or some time a blood clot may causes blockage of blood supply in coronary vessels.

The above factors cause death of a part of heart and the whole process is called myocardial infarction (Myo; muscle, cardium; heart, infarction; death due to lack of

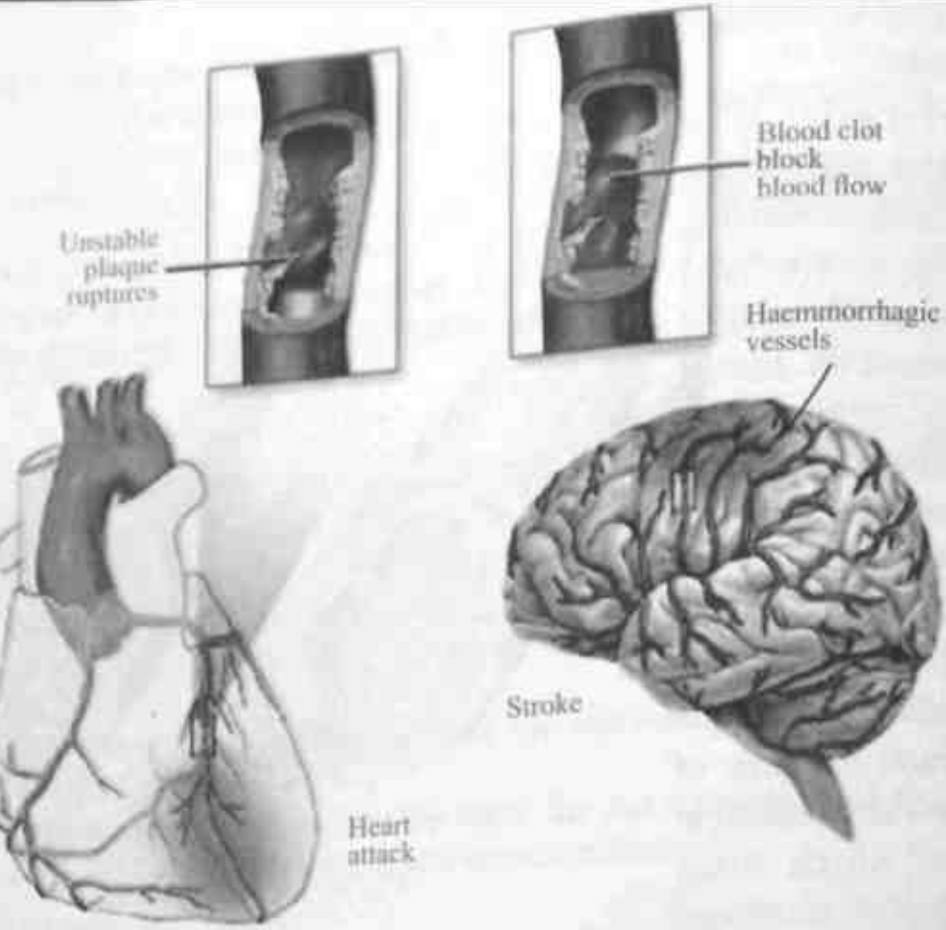


Fig. 12.14 Heart Attack and Stroke

oxygen). Myocardial infarction occurs mostly in individual over 45 year of age. Each year about more than one million people die due to heart attack. Males are more likely to suffer heart attack than females and also smokers than non-smokers.

Heart Failure: It is a clinical syndrome resulting from deficient cardiac volume, relative to body need, with inability of the cardiac output to keep pace with the venous return i.e, heart is unable to pump all the blood coming to it.

Congestive heart problem: It is abnormal function of cardiac valves. **Valvular stenosis** (Narrowing of heart valves due to scarring of its cusps) reduces the diameter of the valve orifice. Severe destruction of valve apparatus may cause valve ring dilation, the **chordiae tendinae** become thicken and shorten, this results in regurgitation of blood through the valve when it is incompletely closed.

12.5.4 Patent Ductus Arteriosus: (PDA)

It is disease of child hood(infant). In fetus, ductus arteriosus is a blood vessel which links the pulmonary artery with aorta. Just after birth when the baby takes its first breath, the lungs become functional and the placenta is cut off, the ductus arteriosus become closed.

Sometimes it fails to do so. This causes **blue babies** due to mixing of oxygenated and deoxygenated blood.

The symptoms include high heart beat, shortness of breath, respiratory problems etc. The causes are usually unknown but may be due to preterm birth, chromosomal abnormalities and this disease is treated by surgical procedure. Untreated PDA may lead to heart failure and death.

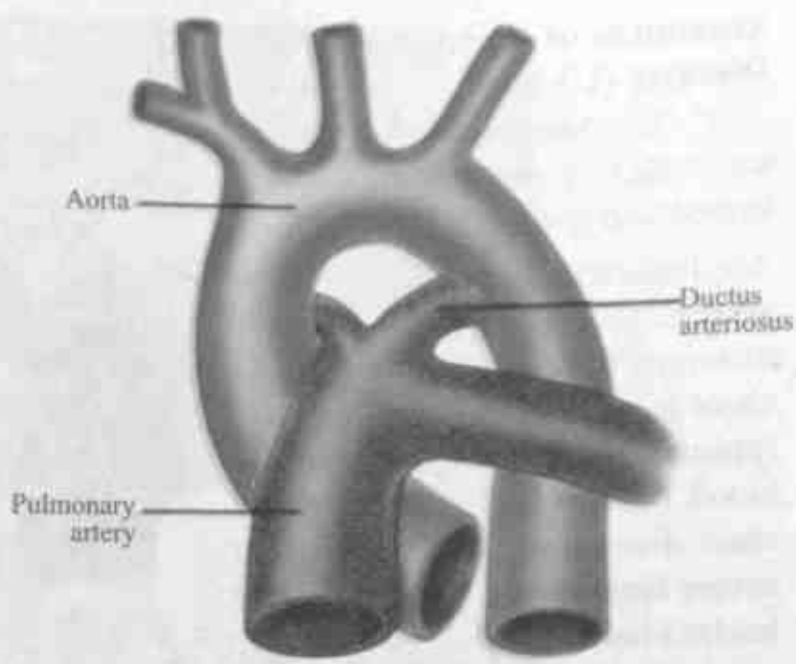


Fig. 12.15 PDA

Do you know?

PDA is usually diagnosed using non-invasive technique like echocardiography.

Angiography: It is a test in which dyes that can be seen by x-rays are injected into blood vessels (either arteries or veins) and are examined by x-rays. The resulting pictures are called angiograms. The angiograms are used to diagnose the narrowing or the blockages in vessels anywhere in the body.

The angiography can also be used to find places where arteries and veins are bulging or ballooning. These spots are called aneurysms and if this is not treated can cause death when these vessels rupture.

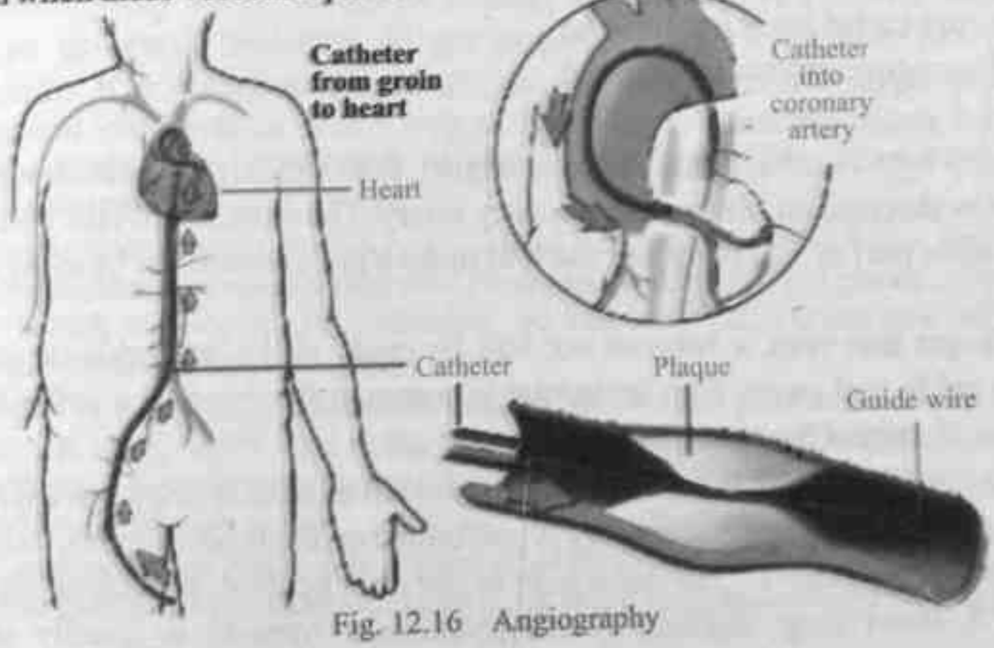


Fig. 12.16 Angiography

Treatment of Cardiovascular Diseases (CVD):

The cardiovascular diseases are treated by angioplasty, coronary bypass and open heart surgery.

Angioplasty: Sometimes our heart arteries may become blocked and narrowed from a buildup of cholesterol, cells or other substances (plaque). If it happens, it can reduce blood flow to our heart and cause chest discomfort. The complete or severe blockage of blood flow may lead to a heart attack.

Angioplasty opens blocked arteries and restores normal blood flow to our heart muscle. It is not major surgery. It is done by threading a **catheter** (thin tube) through a small puncture in a leg or arm artery to the heart. The blocked artery is opened by inflating a tiny balloon in it which forces the blood vessel to widen. A metallic ring called **stent** may also be inserted to restore and maintain blood flow.

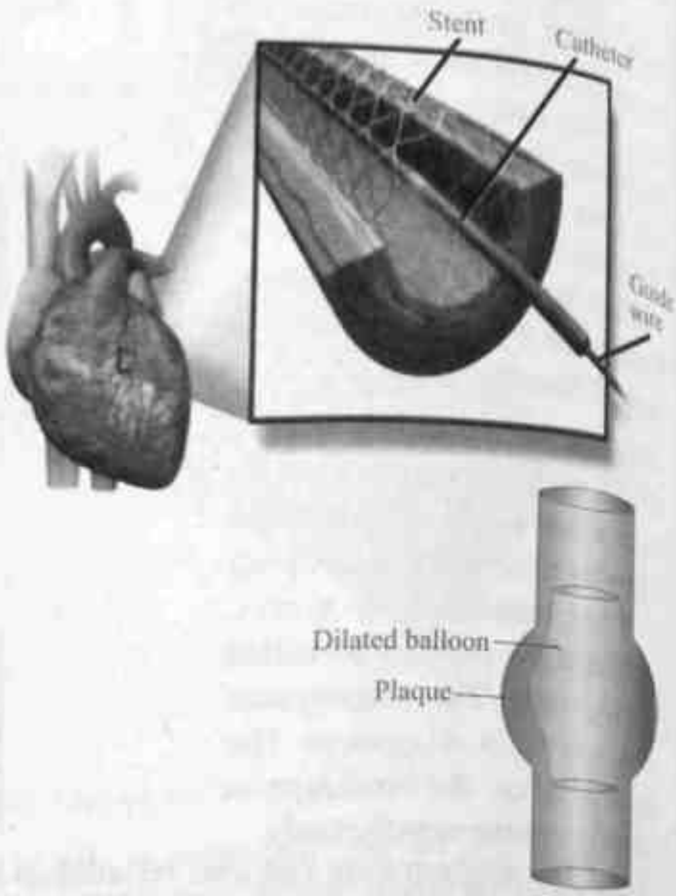


Fig 12.17 Stent in Coronary Artery

Coronary bypass: A coronary bypass surgery, is a surgical procedure to restore normal blood flow through an obstructed coronary artery. The doctor will take a vein or artery from another part of the body and use it to make a graft around the blocked area in your artery.

To get this vein, a surgical cut will be made along the inside of patients leg, between ankle and groin. This technique is common for those who suffer from severe occlusion of parts of the coronary arteries.

Open heart surgery: It is an old therapy and is not advised now a days. It is a surgery, in which the chest is opened and surgery is performed on the heart muscles, valves, arteries or other heart structures. The heart may or may not opened, depending on the type of surgery. A heart lung machine (cardiopulmonary bypass) is usually used during

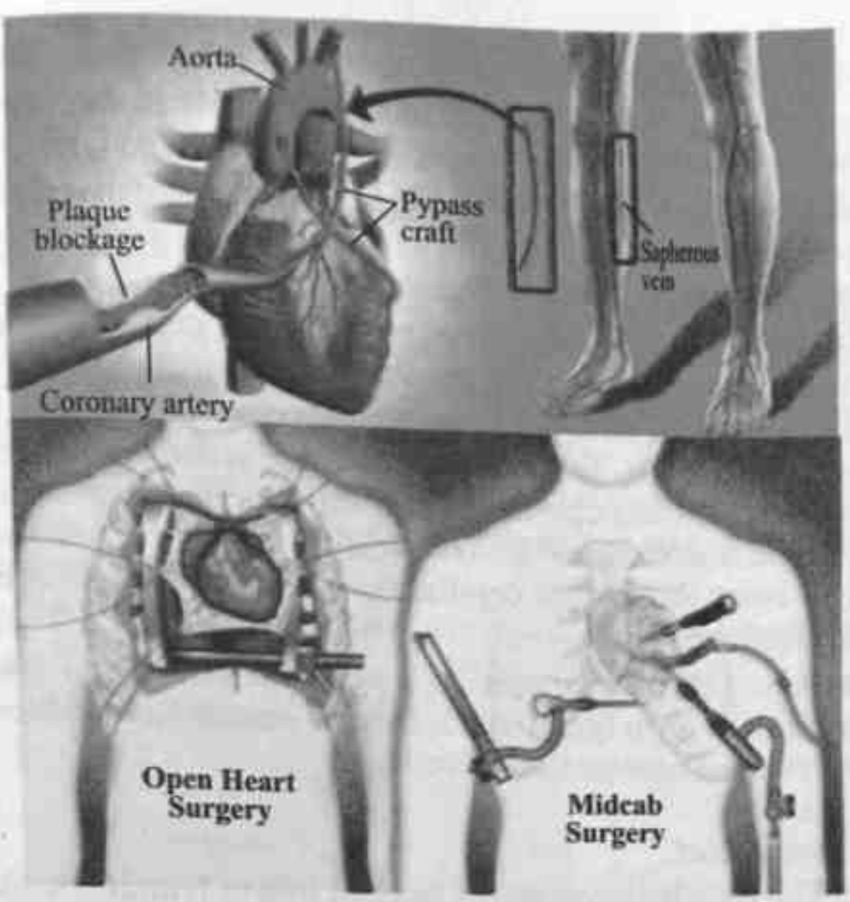


Fig. 12.18 Heart Surgery

conventional coronary artery bypass graft(CABG) surgery. After completion of surgery and the heart beat is started and provides blood and oxygen to the body the chest is again closed. There are some new surgical procedures being performed that are done in which the heart continuously beats termed as **beating heart surgery** (smaller incisions in sternum) or minimal invasive direct coronary artery bypass (MIDCAB).

Hypertension: It is called mother of all physiological diseases. Hypertension is a chronic medical condition in which a person suffers persistently from high blood pressure. i.e., more than 140/90 mm of Hg, at least two different reading apart is considered hypertension.

Factors regulating blood pressure are: Heart beat rate, stroke volume, resistance to blood flow by the blood vessels, vasomotor center in the medulla and power of heart beat. The factors which can lead to hypertension are less exercise, excess use of alcohol, ageing and genetical i.e., family history.

Hypotension: It is opposite to hypertension i.e, (**low blood pressure**). It is considered as physiological state, rather than a disease, not always but mostly due to shocks. The initial symptoms of hypotension is dizziness, fainting and seizures, chest pain, shortness of breath and headache may occur.

The most common cause is less volume of blood flow through body. It also occur in disease like Parkinson's, diabetes, syphilis, or some time excessive sweating and less fluid intake.

12.6 Lymphatic System in Human

The lymphatic system is neither closed circulatory system nor does it have pump, comprises of lymph capillaries, lymph vessels, lymph nodes and lymph.

Lymph: It is colorless fluid with in lymphatic vessels, that is derived form blood vessels (Blood plasma) and resembles to plasma in composition, contains WBC (no RBC), contains large protein, which ultimately returns to the blood.

Lymph Capillaries: These are small blind ended tubes occur in almost all tissues of all organs. They have no opening at the end, residing in interstitial regions.

They unite and merge with the large lymph vessels. Their wall consist of only a single layer of endothelial cells. The intercellular space in their wall are longer than those of the capillaries. Therefore more permeable for substances in intercellular fluid. As they are blind ended in the tissues, thus the lymph is forced by the pressure created in the interstitial fluid to enter the lymph capillaries. The lymph capillaries in the villi of intestine are called Lacteals.

Lymphatic Vessels: Lymphatic capillaries unite to form larger lymphatic vessels, which ultimately unite to form lymph duct. Lymph vessels have valves, which prevent backward flow of lymph. There are two main ducts.

i) Thoracic duct

ii) Right lymphatic duct.

Thoracic duct: The lymphatic vessels of the legs join to lymph vessels of alimentary canal and then to form the thoracic duct which empties lymph into the left subclavian.

Right Lymphatic duct: It drains lymph from the right anterior parts of the body and finally enters into the right branchiocephalic vein.

Lymph nodes: These are aggregations of lymphoid tissues having lympocytes which are small, rounded, oval or bean shaped structures, consist of lymphocytes, connective tissues and lymph vessel.

Location: In neck region, abdomen, armpit, groin, elbow and knee joint. etc.

Functions of Lymph nodes

i) Produce lymphocytes and antibodies for the defense of the body

ii) They also filter lymph (make germ free)

iii) Destroy worn out RBCs.

Lymph Masses

There are many lymphoid masses present in the wall of digestive tract in the mucosa and submusoca. The larger masses are spleen, thymus, tonsils and adenoids are all lymphoid aggregation which functions to produce lymphocytes.

Flow of Lymph in lymph vessels

The circulation of lymph is brought about by:

- Contractility of lymph vessels.

Activity of skeletal muscles, during general body movement and massage or physiotherapy.

- Movement of visceral organs.

Breathing movement

- The valve present in the wall of lymph vessels, which permit the lymph flow is only one direction i.e., towards hearts.
- The lymph from lymph duct poured into the subclavian veins.

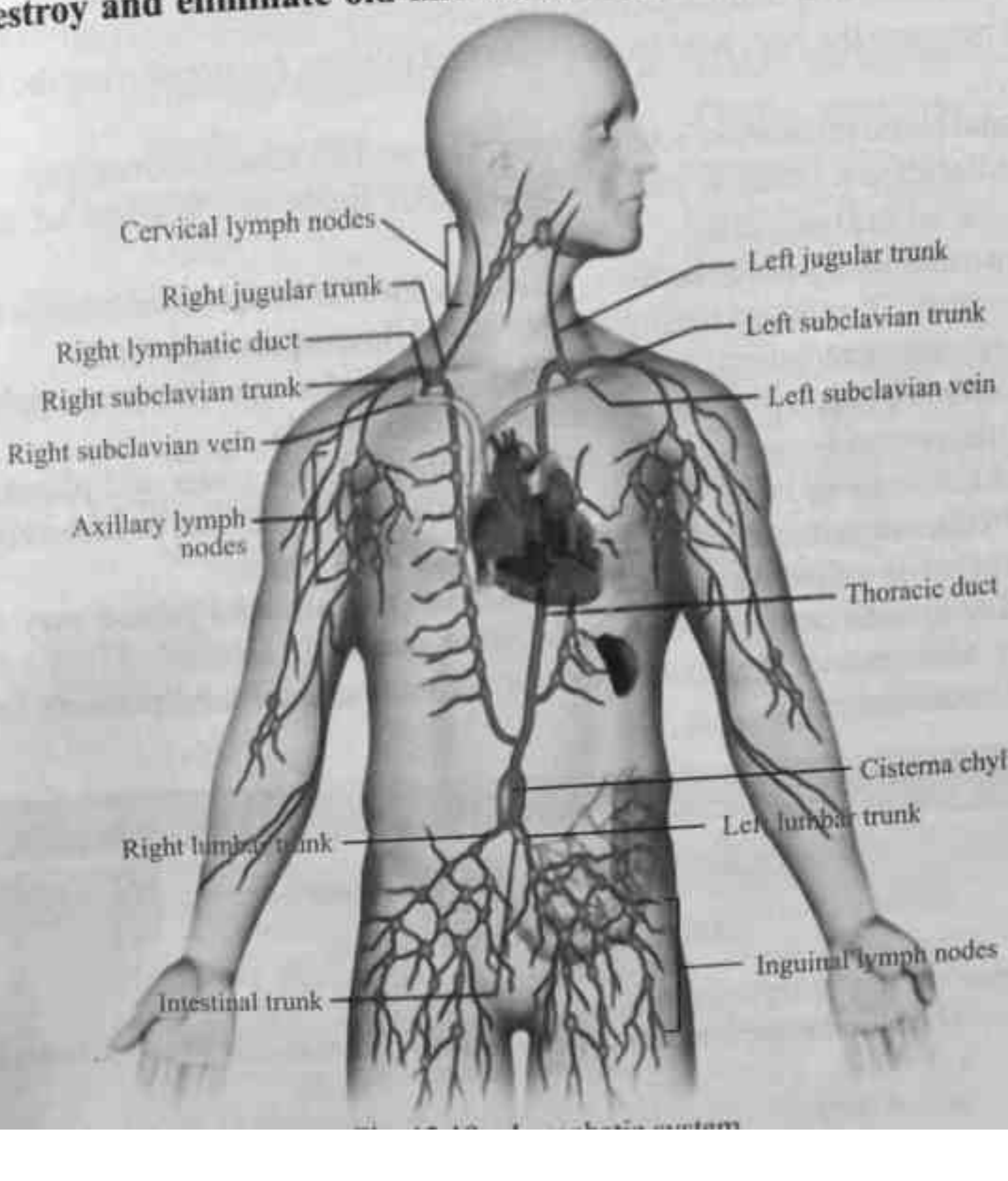
Function of lymphatic system:

Control tissue fluid: About 3 liters fluid leaves the blood capillaries in an adult person per day. This fluid and its proteins and many other substances from the cell are returned by lymph back into the blood, and thus tissues do not face the problem of excess fluid in their intercellular space.

Transport of fatty acid and glycerol: by lacteal at villus level of ileum.

Production of lymphocytes by lymph nodes and thymus which destroy the bacteria, thus helps in defense.

Destroy and eliminate old and worn out RBC In lymph nodes especially in spleen.



SUMMARY

- The blood vascular system transport nutrients, gases, water, nitrogen containing wastes, hormones, blood cells and other substances to and from the cells of our bodies, help to destroy foreign bodies, maintain pH and body temperature.
- One contraction and relaxation of heart is called a cardiac cycle. The contraction is called systole and relaxation is called diastole.
- The sinu-atrial node (SA node) or pace maker is the impulse generating group of tissue located in right atrium or auricle of the heart.
- Electrocardiogram (ECG) is an instrument used for recording the electrical activity of heart, to know it working normally or not.
- Heart muscles contract rhythmically without external stimulation. They are myogenic.
- Heart is surrounded by double membrane known as pericardium. A pericardial fluid is secreted between the two, help to lubricate and prevent friction during the beating of heart.
- The normal blood pressure of adult human is about 120/80 mm of mercury.
- The capillaries are thinnest blood vessels, thus helps in exchange of substances between blood and body cells.
- Certain nerve endings act as sensors, which are located in our blood vessels known as Baroreceptors. They detect the pressure of blood flowing through them.
- Angina is a severe radiating chest pain due to lack of blood and oxygen supply to heart muscle, often due to obstruction of coronary blood vessels.
- Lymphatic system (vessels) act as drainage channels for water and plasma protein that have leaked away from blood at capillaries bed and that must be delivered back to blood circulation, without which death can occur in 24 hours.
- Hypertension is called as silent killer, because the affected person may show no outward symptoms until a stroke or heart attack occurs.
- Mercury Manometers are being used for measuring the blood pressure known as sphygmomanometer.

EXERCISE

Section I: Objective Questions

Multiple Choice Questions

A. Choose the best correct answer.

1. The blood vessel that transports blood from body cells toward heart is
   (a) Vein (b) Venule
   (c) Artery (d) Arteriole

2. Which layer in arteries can withstand higher blood pressure during ventricular systole?
   (a) Outer layer (b) Middle layer
   (c) Inner layer (d) All these
3. The arteries divide into smaller vessels called
   (a) Arterioles (b) Capillaries
   (c) Venules (d) Veins
4. Artherosclerosis is mainly because of deposition' of which of the following.
   (a) High level of cholesterol (b) Low level of cholesterol
   (c) High level of phospholipids (d) Low level of phospholipids
5. Blockage of blood vessel in the heart by an embolus causes necrosis or damage to portion of heart muscles is called
   (a) Thromboembolism (b) Myocrdial infarction
   (c) Stroke (d) Cardiac arrest
6. Congestive heart failure is because of retention of blood in
   (a) Lungs (b) Heart
   (c) Liver (d) Both lungs and heart
7. The lymph vessels empty in
   (a) Arteries (b) Arterioles
   (c) Veins (d) Capillaries
8. Lymph nodes are not present in which of the following region in humans.
   (a) Neck region (b) Axilla
   (c) Groins (d) Stomach
9. The blood is filtered at
   (a) Lymph nodes (b) Spleen
   (c) Liver (d) Bone marrow

B. Fill the blanks

1. The arteries which carry blood towards heart muscles are called_____.
2. The valve between right auricle and right ventricle is called_____.
3. The aorta is the largest _____ of the body.
4. One complete heart beat completes in about_____ seconds.
5. The high blood pressure is also called_____.
6. The fluid of lymphatic system is called_____.

7. The largest veins are inferior and_____ venae cavae.
8. Stents are used to keep the artery_____.
9. The veins brings blood back to ______.
10. The formation of clotted blood mass is called_____.

Section II: Short Questions

1. How hepatic portal system is important to maintain blood composition?
2. What is pulmonary circulation?
3. Write the uses of electrocardiography.
4. Write a note on thrombosis.
5. What are the main functions of lymphatic system?
6. What is the role of SA node and AV node in heart function?
7. How cardiovascular diseases can be prevented?
8. Write the names of different valves of heart.
9. Define artery, vein and capillary.
10. Differentiate pulmonary circulation and systemic circulation.

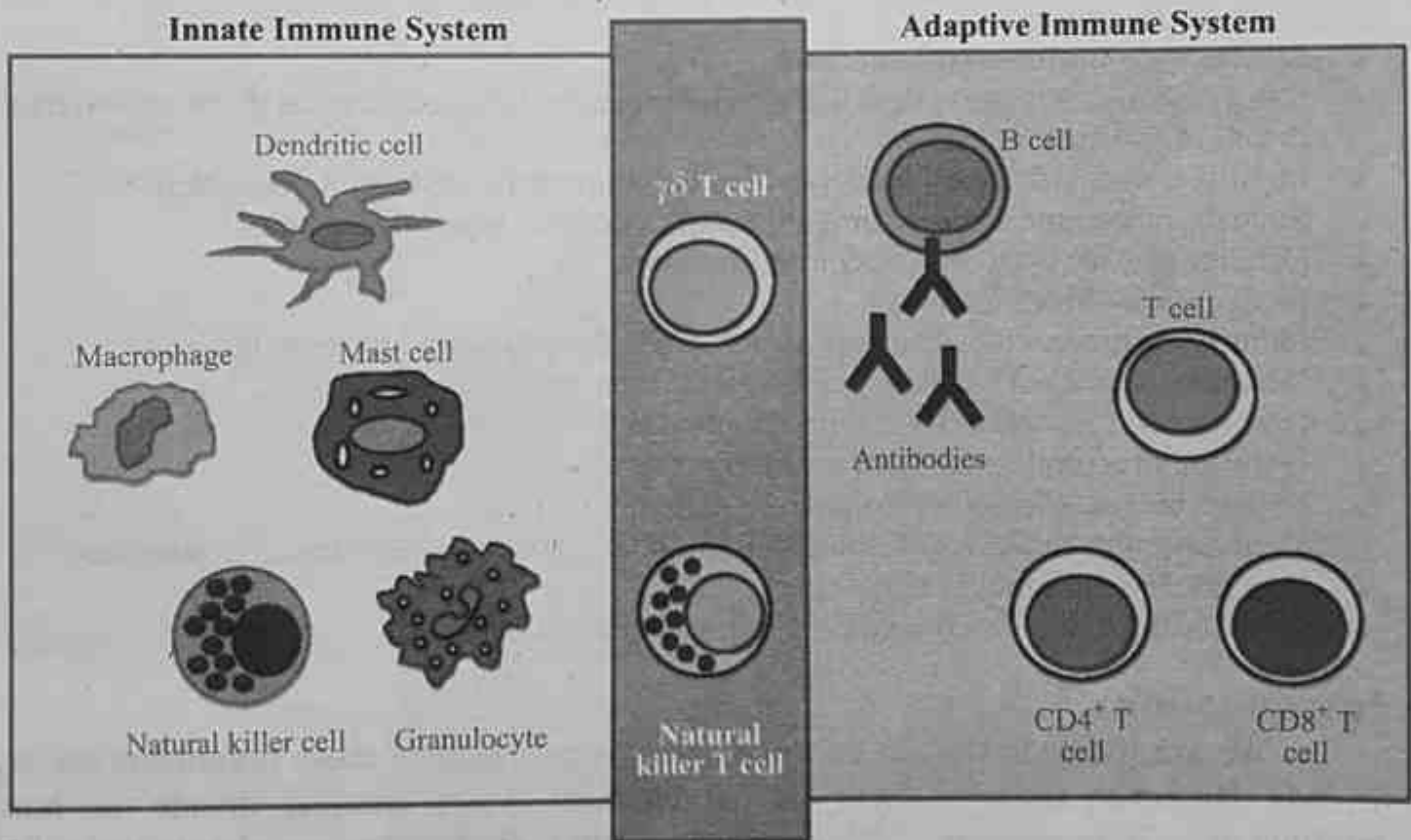
Section III: Extensive Questions.

1. Describe the external structure of human heart
2. Illustrate the internal structure of human heart.
3. Describe cardiac cycle in detail.
4. Explain the hypertension and hypotension.
5. Describe the structure of blood vessels.
6. Write a detailed note on hypertension.
7. Explain lymphatic system of man.

UNIT 13 IMMUNITY

Major Concepts

13.1 First Line of Defence.
13.2 Second Line of Defence (non specific defence)
13.3 Third Line of Defence (The specific defence)



Students Learning Outcomes

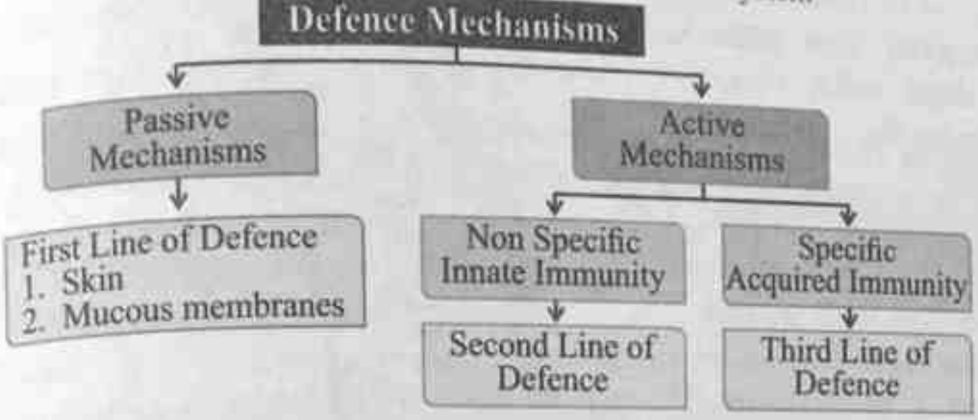
On completion of this unit students will be able to:

- Describe the structural features of human skin that make it impenetrable barrier against invasion by microbes.
- Explain how oil and sweat glands within the epidermis inhibit the growth and also kill microorganisms.
- Recognize the role of the acids and enzymes of the digestive tract in killing the bacteria present in food.
- State the role of the ciliated epithelium of nasal cavity and of the mucous of the bronchi and bronchioles in trapping air borne microorganisms.
- Describe the role of macrophages and neutrophils in killing bacteria.
- Explain how natural killer cells kill the cells that are infected by microbes and also kill cancer cells.
- State how the proteins of the compliment system kill bacteria and how the interferons inhibit the ability of viruses to infect cells.
- State the events of the inflammatory response as one of the most generalized nonspecific defenses.
- Outline the release of pyrogens by microbes and their effect on hypothalamus to boost the body's temperature.
- List the ways the fever kills microbes.
- Categorize the immune system that provides specific defense and act as the most powerful means of resisting infection.
- Identify monocytes, T-cells and B-cells as the components of the immune system.
- State the inborn and acquired immunity as the two basic types of immunity.
- Differentiate the two types of acquired immunity
- (active and passive immunity).
- Identify the process of vaccination as a means to develop active acquired immunity.
- Describe the roles of T-cells in cell-mediated immunity.
- Describe the role of B-cells in antibody-mediated immunity.
- Draw the structural model of an antibody molecule.
- Explain the role of memory cells in long-term immunity.
- Define allergies and correlate the symptoms of allergies with the release of histamines.
- Describe the autoimmune disease.
- Describe the role of T-cells and B-cells in transplant rejection.

Introduction

We are living in the sea of micro-organisms. Most of these organisms are our friends. However, some of them are our enemies. These enemies invade our body continuously. To counter attack these invaders, our body has developed a system called **immune system.** The immune system consists of many biological structures and processes within an organism that protects against diseases. This ability of an organism to combat diseases and pathogen is called **immunity.** The study of immunity is called **immunology.** In this chapter we will discuss three lines of defence of immune system.

Table 13.1 Lines of defence of immune system



13.1 First Line of Defence (Layered Defence)

The first line of defence is non specific and part of innate immunity (present naturally at the time of birth). It is the best defence as it keeps pathogens out of the body. It consists of following parts.

> **Tit bits**
>
> *The word skin is derived from Latin word "cutis" In mammals it is the largest organ of the body. It has many functions like protection, sensation, heat regulation, control of evaporation, excretion etc.*

13.1.1 Skin

Skin is the largest organ of the vertebrate body accounting for 15% of an adult human's total weight. The skin not only defends the body by providing nearly impermeable barrier but also reinforces this defence through chemical weapons on the surface.

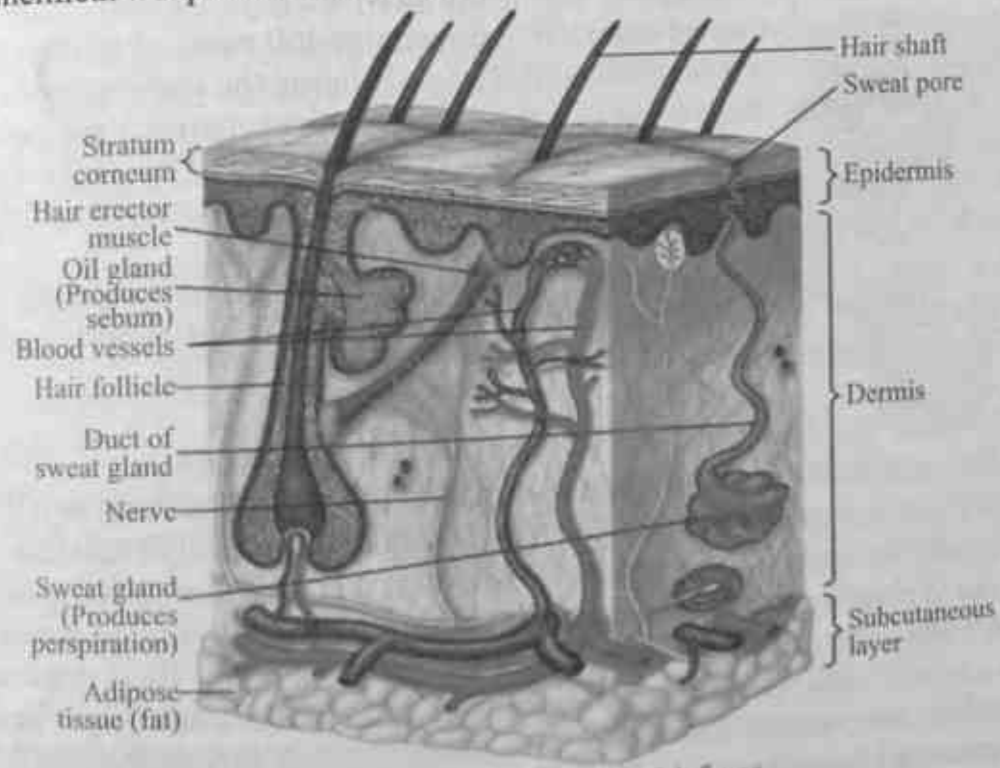


Fig. 13.1 Skin as first line of defence

The skin contains **keratinocytes** and also possesses dead cells, these become barrier for microbes to get entrance.

The dermis of skin produces oil from **sebaceous** glands and sweat from **sweat glands,** gives the skin surface a pH of 3 to 5. It is acidic enough to inhibit the growth of many micro-organisms. Sweat also contains the **lysozymes,** which digest bacterial cell wall. These also contain natural antibiotic (such as lactic acid).

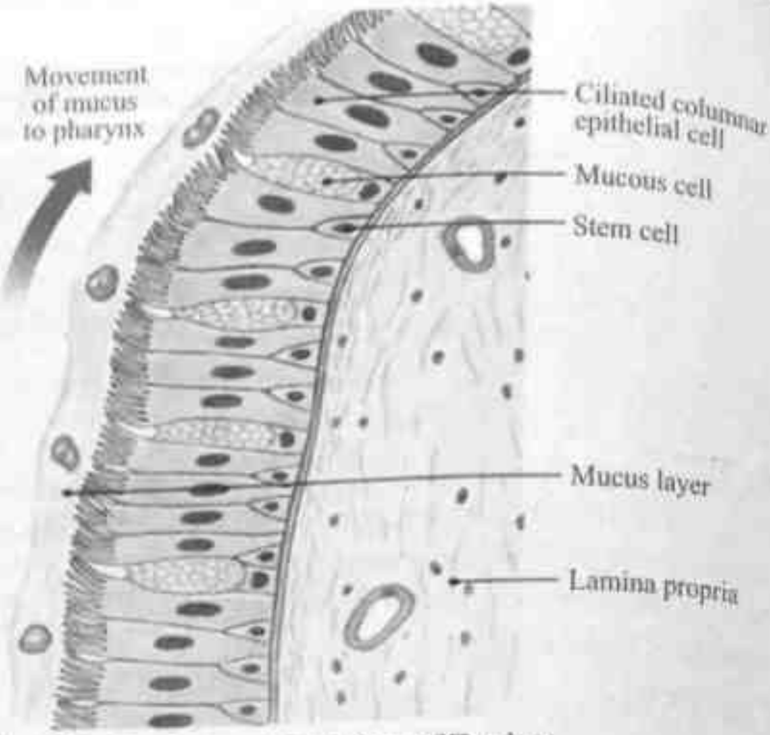


Fig. 13.2 Respiratory Epithelium of Trachea

13.1.2 Digestive and Respiratory tract

Both the digestive and respiratory tract open to the out side and their inner surfaces must also be protected by foreign invaders. Microbes are present in food but many are killed by saliva which also contains lysozyme and $NaHCO_3$. The very low pH of stomach due to HCl, enzymes of stomach and intestine kill most of microbes of food. Micro-organisms also present in inhaled air. The cells lining the respiratory tract secrete layer of sticky mucus that traps most of the micro-organisms before they can reach the warm moist lungs, which would provide ideal breeding ground for them. Other cells lining in these passages have **cilia** that continuously sweep the mucus towards the glottis. There it can be either swallowed or spit out.

Occasionally an infectious agent, called a pathogen will enter the digestive and respiratory system and body will use defence mechanisms such as vomiting, diarrhoea, coughing and sneezing to expel the pathogens.

13.2 Second Line of Defence: (non specific defence)

This line of defence is also a part of innate immune system. Although the surface defences of the vertebrate body are very effective but occasionally breached allowing invaders to enter the body. At this point the body uses a host of non-specific cellular and chemical devices to defend itself. This type of defence is referred as second line of defence. All these devices have one common property i.e., they respond to any microbial infection without pausing to determine the invader's identity. The cells and chemicals of second line of defence, defend the body to attack and kill the invaders.

The second line of defence consists of three types of mechanisms i.e., natural killer cells, inflammatory responses and temperature responses.

13.2.1 Killing cells of blood

Perhaps the most important of vertebrate body's non-specific defence are the white blood cells called leucocytes. These cells circulate through the body and attack invading microbes within tissue. There are three basic kinds of these cells and each kill invading micro-organism differently.

Do you know?

How neutrophil is different from lymphocytes, second line of defence and third line of defence.

Macrophages :

The macrophages (Big eaters) are large irregularly shaped cells that kill microbes by ingesting them through phagocytosis (like *Amoeba*).

They are found in organs such as lungs, liver, spleen, kidney and lymph nodes rather than remaining in the blood.

They leave the bone marrow and travel into the blood as monocytes, where they develop into macrophages. Once they leave the blood and settle in the organs, they remove any foreign matter found there.

The macrophages are long-lived cells. They play a crucial role in initiating immune response. They do not destroy pathogens completely but cut them up to display antigens that can be recognized by lymphocytes. Macrophages secrete some types of proteins which trigger maturation of monocytes. A protein interleukin-I stimulate the hypothalamus to raise body temperature, and other protein stimulate the specific response.

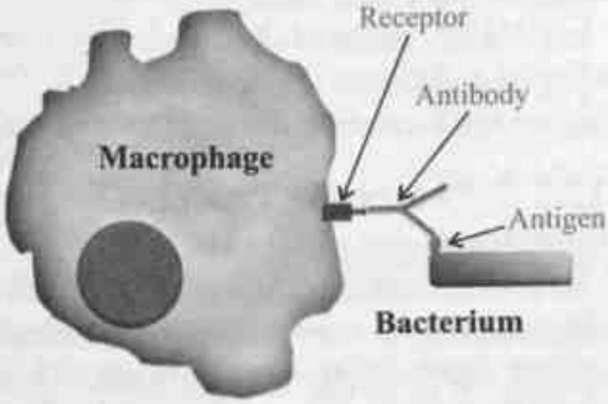


Fig. 13.3 Macrophage

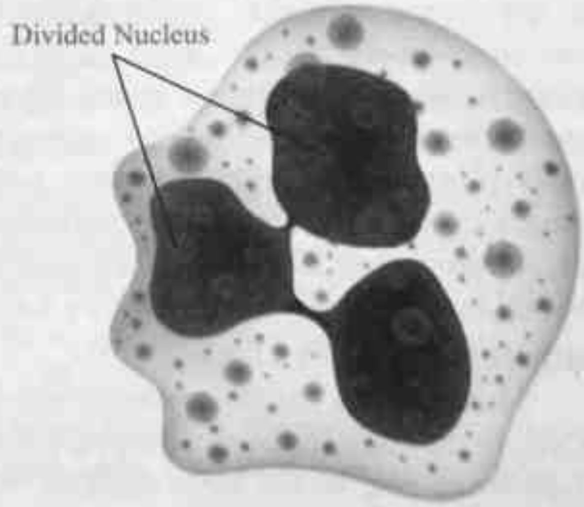


Fig. 13.4 Neutrophils

Neutrophils:

The neutrophils are types of white blood cells that, like macrophages destroy the pathogens by phagocytosis. In addition neutrophils release lysozyme, chemicals that kill other bacteria in the neighbourhood. Neutrophils have short life span, after killing and digesting some pathogens they die. Dead neutrophils are collected at the site of infection to form pus. Due to psuedopodial movement, their body squeeze and can enter all those parts of tissues where other WBC can not enter. These are most abundant types of WBCs in most mammals, about 40 to 70%.

Natural killer cells:

These cells do not attach invading microbes directly instead they kill cells of the body that have been infected. They do not phagocytose microbes but rather by creating a hole in the plasma membrane of target cell. Proteins called **perforins** are released from the membrane of the natural killer cells and inserted into membrane of target cell which then swell and bursts,by a protease (enzyme).

The natural killer cells cause very effective defence against cancer cells usually before the formation of malignant tumor.

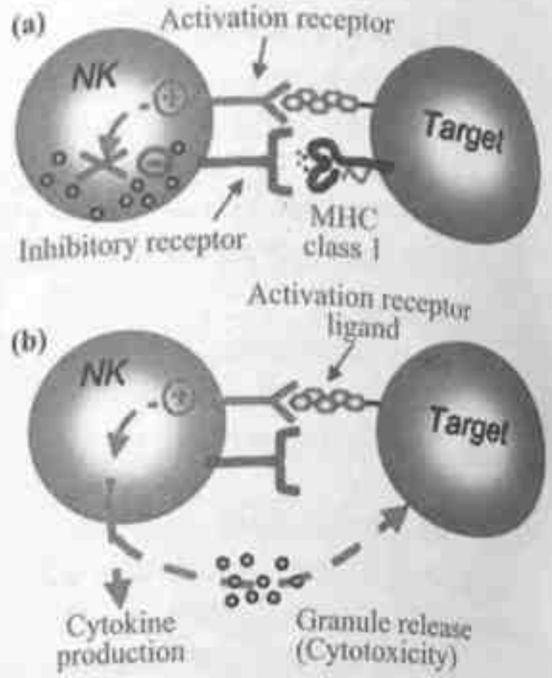


Fig. 13.5 Natural Killer Cell (NK)

Activity

Justify why the physicians prescribe antipyretic drugs, when fever is a nonspecific defence against microbial infection.

13.2.2 Protective Proteins (complement system)

The cellular defence of vertebrates are enhanced by a very effective chemical defence called the complement system. This system consists of approximately 20 to 30 different proteins formed in the liver, that circulate freely in the blood plasma. When these proteins encounter bacterial or fungal cells then these proteins form a membrane attack complex that inserts itself into the foreign cells (pathogen cells) plasma membrane forming a pore like natural killer cells. The water enters the foreign cell (pathogen cells) through this pore causing, the cell to swell and burst.

Tit bits

Aspirin reduce the degree of fever because aspirin impedes the formation of prostagladin from arachidonic acid. Drugs like aspirin that reduce fever are called antipyretic.

Interferons (IFNs):

These belong to cytokines (Protein in lymph cells). Interferons is another class of proteins that plays a key role in the body defence. There are three major categories of interferons. These are grouped into two types. Type I, alpha and beta while type II is gamma. These cells of the body synthesize alpha and beta interferons. These polypeptides act as messengers, that protect normal cells in the vicinity of infected cells from becoming infected. Though viruses are still able to penetrate the neighbouring cells. The **alpha and beta interferons** prevent viral replication and protein assembly in these cells. (Thus named interferons means interfere with viral replication inside body cell).

Activity

How antihistamine therapy is helpful to the patients of runny nose and skin rashes?

Gamma interferon is produced only by particular lymphocytes and natural killer cells. Gamma interferons defend against infection and cancer. These also activate other immune cells such as macrophages and natural killer cells.

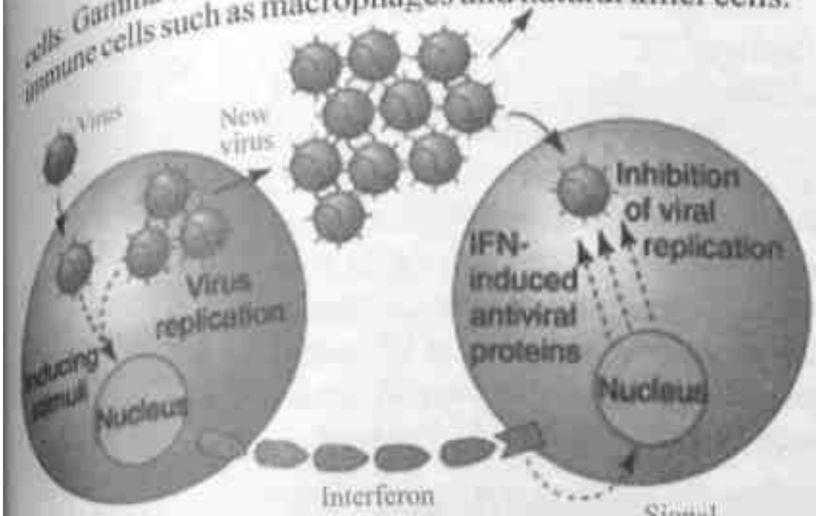


Fig. 13.6 Interferons

Tit bits

Invading bacteria and viruses are recognized as foreign because they contain molecules, which are different from any of our own molecule. These foreign molecules are known as antigens.

Inflammatory Responses:(means setting on fire)

The inflammatory response is a localized, nonspecific against infection. Infected or injured cells release chemical alarm signals, most notably **histamine and prostaglandins** (Produced from all nucleated cells). These chemicals promote the dilation of local blood vessels, which

Tit bits

Histamine secreted from basophils and mast cells which are a class of WBC. These cells are filled basophil granules found in number of tissues.

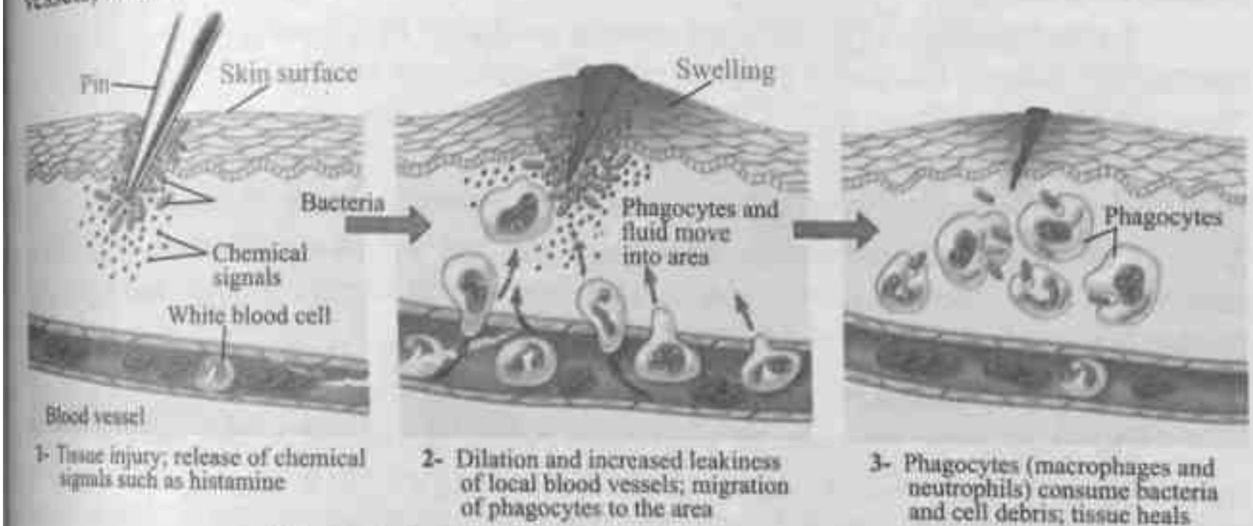


Fig. 13.7 Inflammatory Responses

increase the flow of blood at the site of infection or injury and causes the area to become warm, red, swollen and feel pain. They also increase the permeability of capillaries in the area producing **edema.** Phagocytes migrate from the

Activity

Search net to see the difference between two sub classes of monocytes.

blood to the extra cellular fluid where they can attack bacteria. The function of inflammation is to remove necrotic cells and to start rapair process and prevent spreading of infection.

13.2.4 Temperature Responses

Macrophages that encounter invading microbes release a regulatory molecule called interleukin-1 which is carried by blood to the brain. **Interleukin-1** and other **pyrogens** (Greek Pyr=fire) such as bacterial endotoxins cause neurons in the hypothalamus to raise the body temperature several degrees above the normal value of 37°C (98.6°F). The elevated temperature thus results is called fever. Fever contributes to the body's defence by stimulating phagocytosis and causing the liver and spleen to store iron, reducing blood level of iron which bacteria need in large amount to grow. However very high fever is harmful because excessive heat may denature critical enzymes and proteins of body. Therefore, the patient is given antipyretic drugs.

13.3 Third Line of Defence: (The specific defence)

Many of us contract some sort of infection in our child hood, small pox for example, is an illness that many of us experience before we reach our teens. It is a disease of childhood as most of us contract it in childhood stage and never catch it again. Once you have had the disease, you are usually immune to it. The specific immune defence mechanism provides such immunity.

An antigen is a molecule capable of inducing an immune response in the host. These are usually foreign bodies but sometimes these are part of host itself in an autoimmune disease.

An antibody is a "Y" shaped protein produced by plasma cells to destroy or neutralize antigens. These are attached on pathogens and secreted by B. lymphocytes. The third line of defence is specific and most effective consists of two types.

1. **Humoral immunity,** mediated by macromolecules found in the extra cellular fluids such as antibodies, complement proteins and certain antimicrobial peptides.
2. **Cell mediated immunity:** This type does not involve antibodies; but rather involve the activation of phagocytes, antigen specific cytotoxic T- Lymphocytes and release of various cytokines in response to antigens.

13.3.1 Role of Monocytes in Third Line of Defence

The monocytes are types of leukocytes (white blood cells), they are the largest type of leukocytes. As part of vertebrate innate immune system (discussed in second line of defence), monocytes also influence the process of adaptive immunity. There are at least two sub classes of monocytes in human blood.

I) **Dendritic cells:-** These are antigen presenting cells, mark out foreign bodies to be destroyed by lymphocytes.

ii) **Macrophage:-** These are large phagocytic cells.

13.3.2 Role of T-Cells in Third Line of Defence: (cell mediated immunity)

T-Cells or T. Lymphocytes are a type of lymphocytes (a type of WBC) that play a central role in cell mediated immunity. T-cell can be distinguished from other lymphocytes such as B-Cells and natural killer cells by the presence of a T-Cell receptor on the cell surface. They are called T-Cells because they mature in the **thymus** from thymocytes, an endocrine gland in chest (some are synthesized in tonsils also).

Tit bits

The primary response is slow because at this stage there are very few B-cells that are specific to antigen.

Activation of T-Cells: When infection occurs the T-cells detect particular antigen of invading micro-organism by engulfing it. The T-Cells display these antigen on their surface with the help of their own protein known as **Major Histocompatibility Complex** (MHC). In this way, macrophages become **antigen presenting cells (APCs)**. At the same time macrophages release **interleukin 1** that stimulates helper T-Cells and attracts them towards displayed antigen. The helper T-Cells have receptor by which they bind with specific antigen present on APC. The receptor on surface of T-Cells are called T-cell receptor (TCR). The T-cell also stimulated by interleukin to secrete another protein called **interleukin 2** which

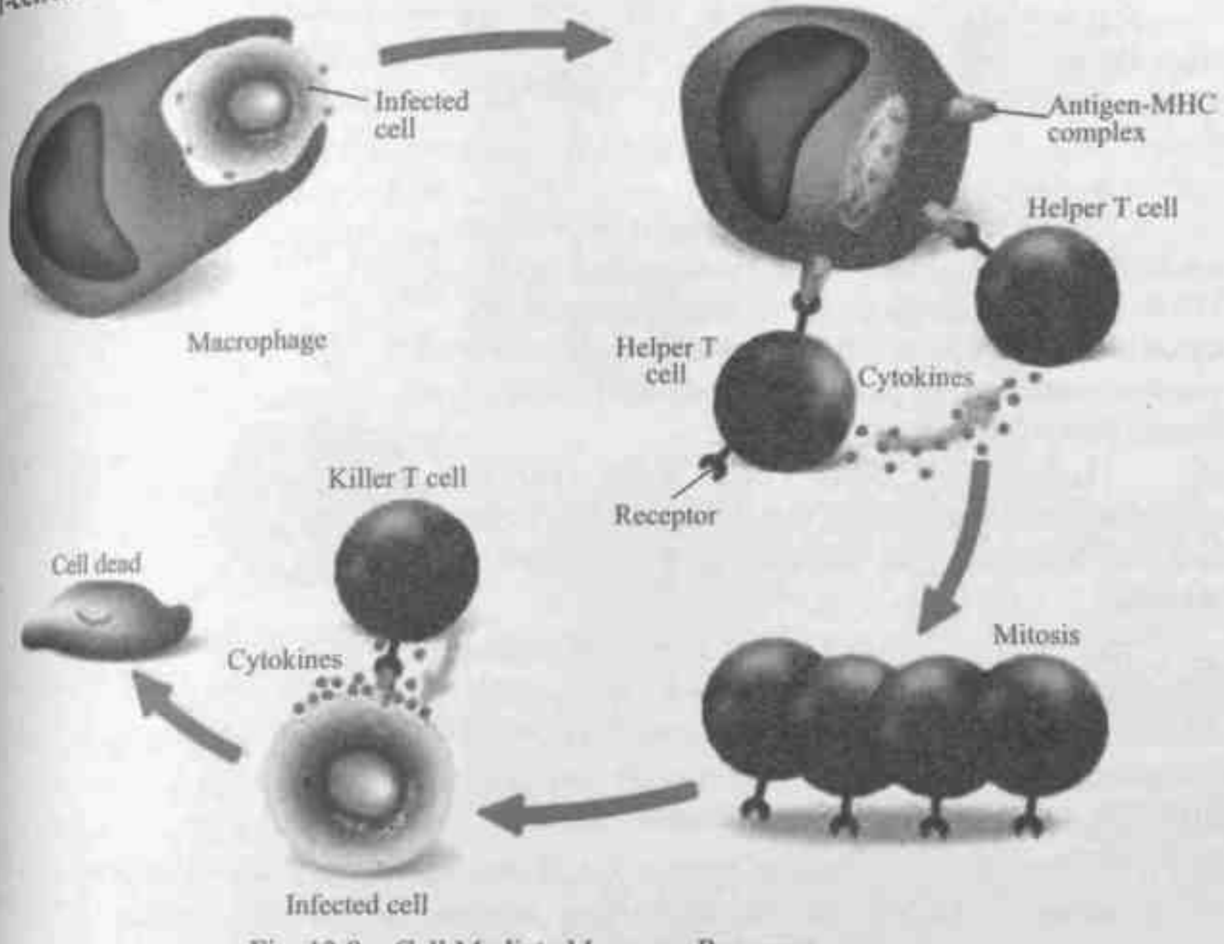


Fig. 13.8 Cell Mediated Immune Response

is not only responsible for division of helper cells but also proliferates certain cytotoxic T- cells and B cells. There are millions of different T-cells, as each type of T-cells respond to a specific type of antigen. This type of immunity is called cell mediated immunity.

Types of T-Cells: The T-lymphocytes are of two types i.e., **CD8** (cluster of differentiation) as they have surface marker CD8, include cytotoxic T-cells and suppressor T-Cells. The other group is helper T-Cells also called **CD4** cells due to presence of surface marker CD4. On activation, the T-Cells divide and produce 4 types of cells, these four types of cell play vital role in cell mediated immune response. The four types of cells produced by T-cells are as follow.

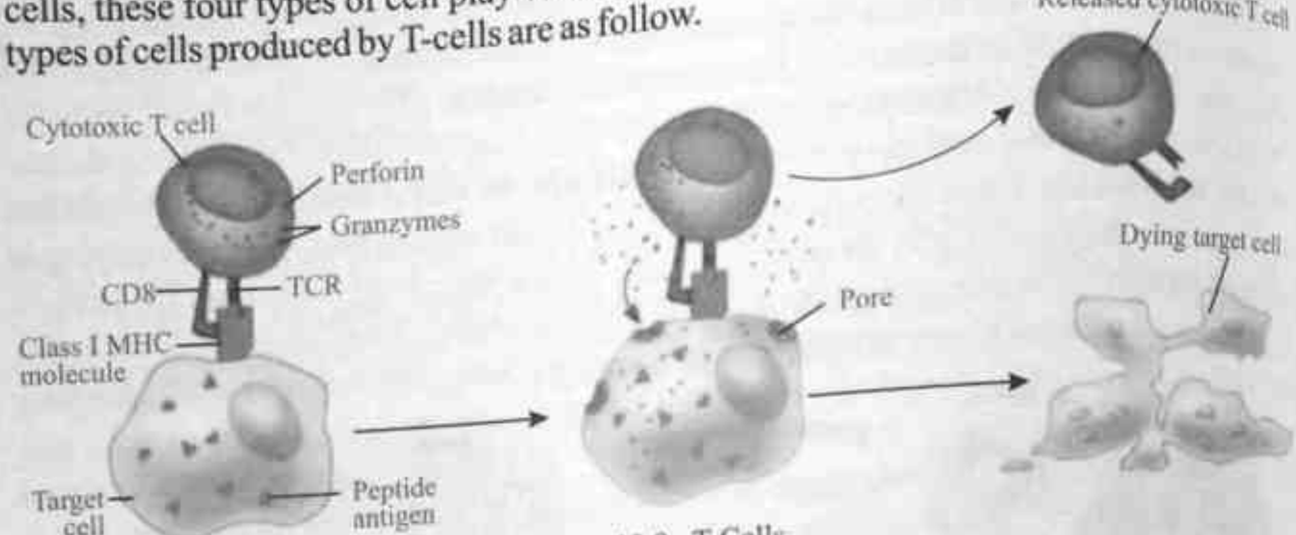


Fig. 13.9 T-Cells

a. **Cytotoxic T-Cells:** These cells produce a toxin called **cytotoxin.** This destroy pathogen's DNA and perforin protein is also produced by cytotoxic T-cells. The perforin creates hole in the plasma membrane of pathogen as a result pathogen breaks down into pieces.

b. **Helper T-Cells:** These cells secrete cytokines which stimulate the division of B-Cells and T-Cells to increase defense against pathogenic attacks.

c. **Suppressor T-cells:** After the successful removal of infection the suppressor T-Cells secrete certain proteins that inhibit further proliferation of T-Cells, Thus immune response is blocked therefore, the cells are called suppressor T-Cells.

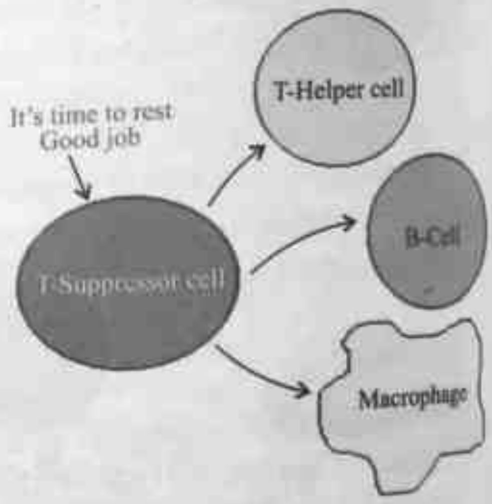


Fig. 13.10 Binary Fission

d. **Memory T-Cells:** This type of T-cells remain inactive for many years after the initial exposure to antigen. However they become active very quickly during the secondary response to antigen and fight against pathogen.

13.3.3 Role of B-Cells in Third Line of Defence "Humoral immunity" or Antibody Mediated immune response.

The antibodies are small glycoprotein molecules.

B-lymphocytes secrete antibodies, which destroy bacterial pathogens. B-lymphocytes are so called because they develop in the bone marrow and first discovered in the bursa of intestines of birds.

As mentioned earlier in this chapter that antigens are foreign molecules because they are different from any of our own molecules. We have a huge number of B-lymphocytes in our blood each one of them recognizes and responds to one particular antigen. The B-lymphocytes respond by producing antibodies.

Activation of B-Lymphocytes

Most B lymphocytes will spend all their lives without anything happening to them at all because they never meet their particular antigen. But a B-lymplcyte does encounter an antigen which binds to the receptors on its cell surface membrane, it is triggered into action. After encountering its specific antigen, the B-lymphoeyte is stimulated to divide repeatedly by mitosis. Some of these cells differentiate into **plasma cells.** These cells have the ability to produce very large number of antibody molecule in very less time (2000 antibody molecules per second). These antibodies bind with antigens and destroy them.

Other cells produced as a result of mitosis do not secrete antibody, instead they remain as **memory cells**. These cells live for long time and remain circulating in the blood, they are capable of responding very quickly if the same type of antigen enters the body again.

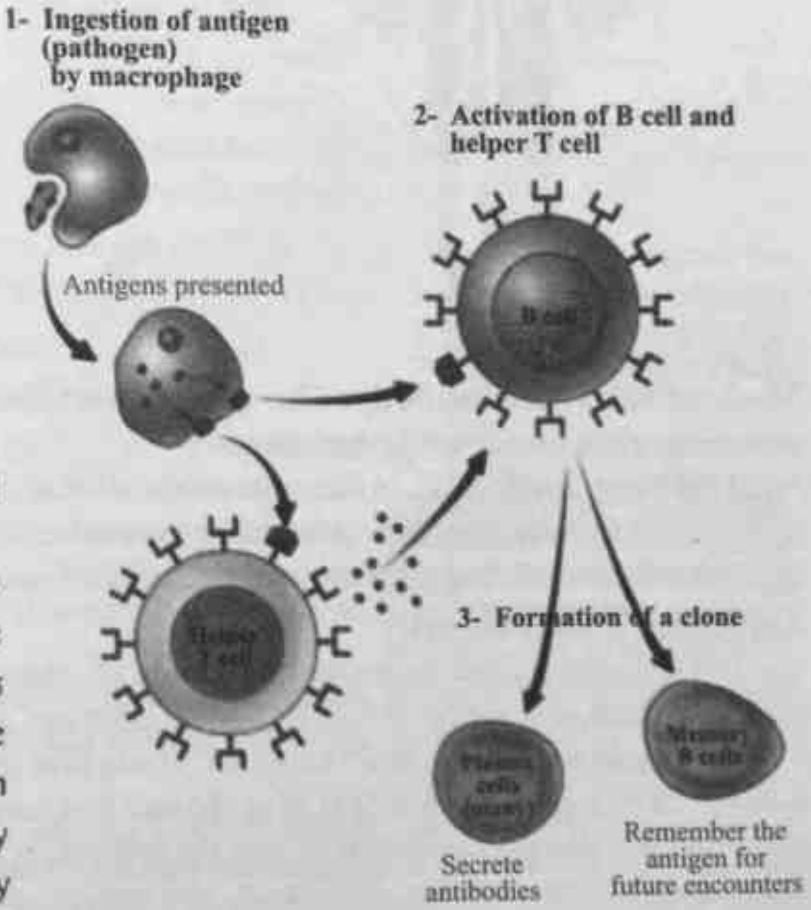


Fig. 13.11 Antibody mediated response

Structure of Antibody:

Antibodies are all globular glycoproteins and form the group of plasma proteins called **immunoglobulins.**

The basic molecule common to all antibodies consisting of four polypeptides chains two **long (heavy) chains** and two **short (light) chains. Disulphide bridge,** hold the chains together. Each molecule has two identical antigen binding sites which are formed by both heavy and light chains. The sequence of amino acids in these regions make the specific three dimensional shape which binds to just one type of antigen. This is the variable region which is different on each type of antibody molecule produced. The hinge region gives the flexibility for the antibody molecule to bind around the antigen.

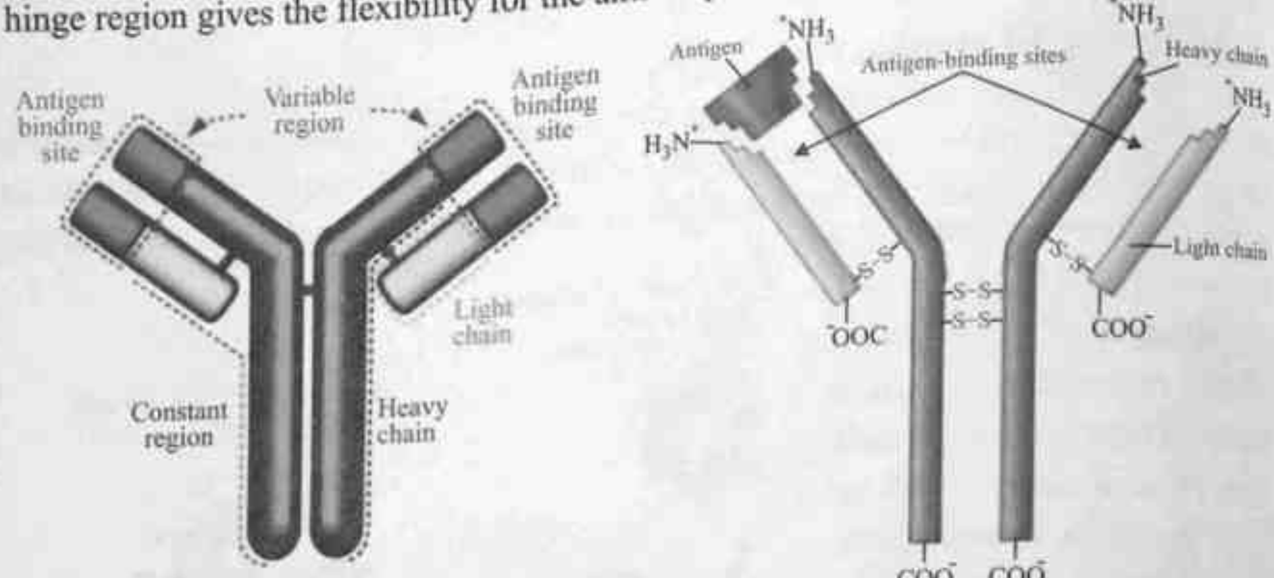


Fig. 13.12 Antibodies

Mode of action of antibody: There are different modes of action of antibodies, some important modes are given below.

Neutralizing antibody: In this type of mode of action of antibody, an antibody that defend a cell from an antigen or infection by neutralizing any effect it has biologically. An example of a neutralizing antibody in diphtheria antitoxin.

Activation Complement:

The complement proteins are group of plasma protein, which are made by liver. These proteins are activated by an antigen antibody complex. These proteins usually cluster together to form a pore or channel that insert into a microbe plasma membrane to lyse the cell. Some of these complement proteins can cause chemotaxis and inflammation. Due to these activities number of white blood cells increase at the site of infection.

> **Do you know?**
> *There are 5 classes of antibodies i.e. immunoglobulin IgG, IgM, IgD, IgA and IgE.*

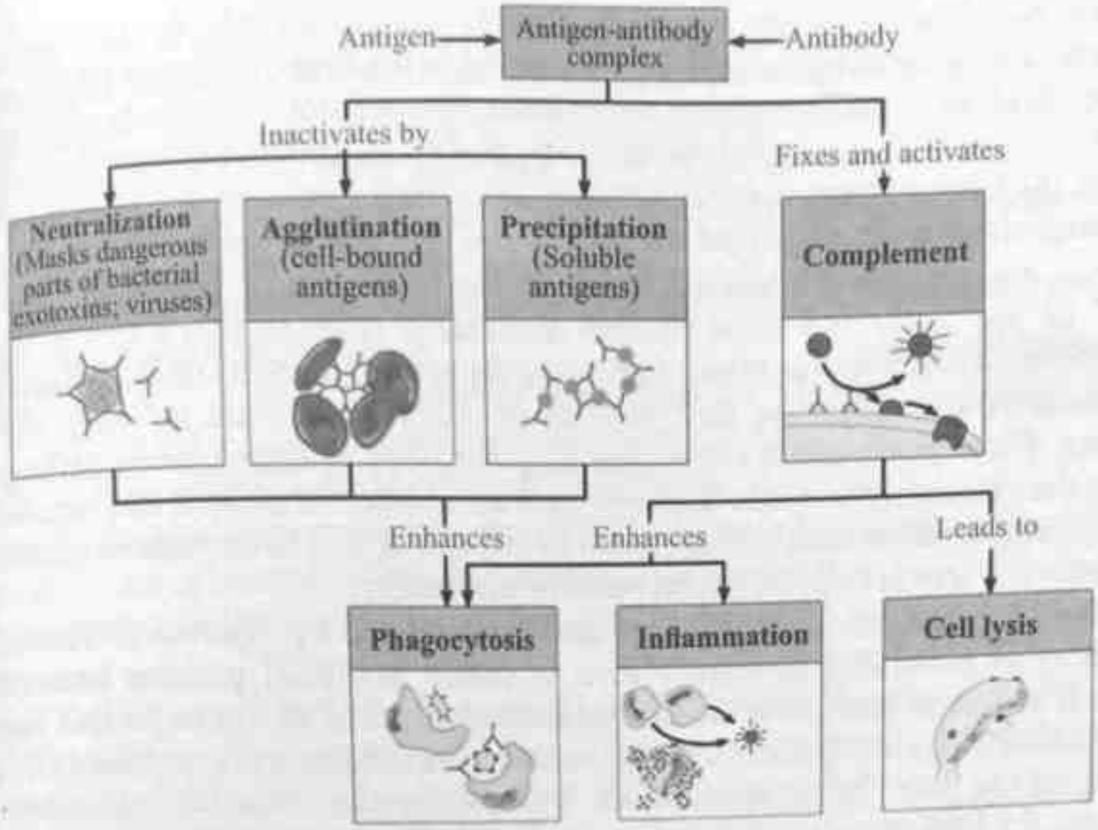


Fig. 13.13 Mode of action of antibody

Precipitating antigens: When antibodies bind to some free antigen, cause the antigen to precipitate out of solution, thus phagocytic cells can easily ingest them.

Facilitating phagocytosis: When antigen antibody complex is formed it signals the phagocytic cells to attack. This complex binds to the surface of macrophages, it facilitates phagocytosis.

Activity

Do you know what are auto grafts ?

13.3.4 Inborn and Acquired Immunity

As discussed in the early part of this chapter that inborn (innate) immunity is non specific and makes the first and second line of defence. On the other hand the acquired (adaptive) immunity is highly specific and develops in reaction of antigens. However, it takes several days to become fully functional.

Tit bits

Organ transplant is a medical procedure in which an organ is removed from donor body and placed in the body of recipient to replace a damaged or missing organ.

Types of acquired or Induced immunity: Acquired immunity may be active or passive and either type may be acquired naturally or artificially.

Active immunity: It is a kind of immunity which develops after contracting pathogen inside the body. The body has been stimulated to make a particular type of antibody and can produce these same ones more quickly in large quantity, if it is exposed to same pathogen again. The immunity has developed naturally, is called as **natural active**

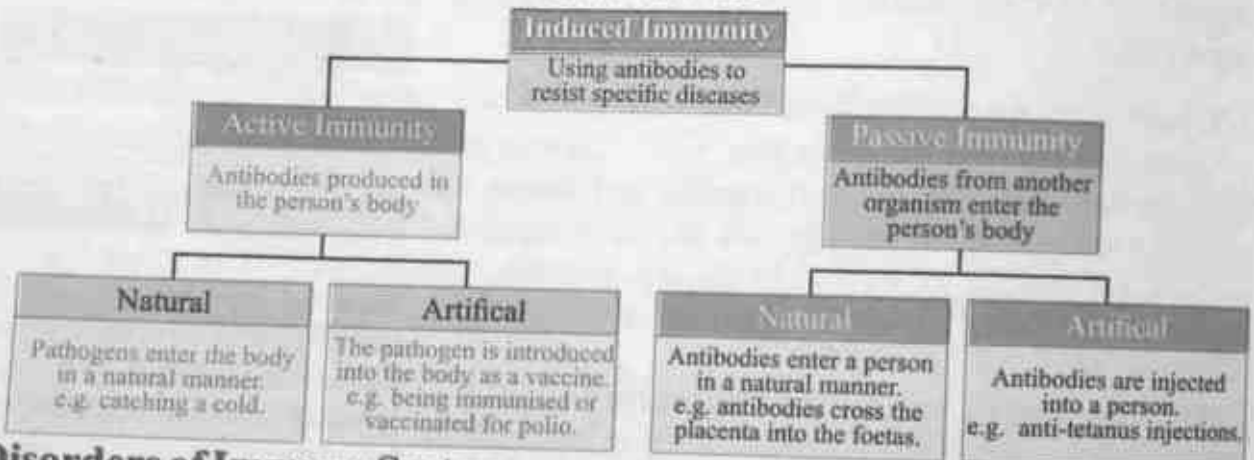
Another way in which active immunity can develop is by vaccination. This involves injecting the antigen into body. It may be in the form of viruses which have been made harmless, or as an inactivated toxin from a bacterium. The body responds in the same way as it would, if invaded by the living pathogen, producing memory cells which will make the person immune to the disease that is they may ever encounter it. This way of acquiring active immunity is not natural. So it is called **artificial active immunity.**

Passive immunity: It is observed that a young baby's immune system takes time to develop. In the uterus the fetus obtains antibodies from mother's blood, across the placenta. After birth, it will continue to receive them from mothers milk. **Colostrum,** thin yellow milk produced in the first few days after birth. This is especially rich in antibodies. These ready made antibodies help the baby to fight against pathogens. The baby has the immunity to same diseases as their mother because it has received ready made antibodies, rather than making them itself, this is said to be passive immunity as it occurs naturally so it is called **natural passive immunity.**

However passive immunity can also be provided by injections. This is not the natural way of providing immunity so it is called **artificial passive immunity.** For example if a person has cut or wound on its body, he/she needs to protect against the bacterium that cause tetanus. Tetanus is caused by the infection of bacterium *Clostridium tetani*. It is too late for a vaccination, because by the time their immune system responded, the bacterium would have multiplied and cause **fatal illness called tetanus.** Instead the person will be given an injection of antitoxin. The antitoxin will bind to the toxin produced by bacteria, rendering it harmless.

Passive immunity does not last as long as active immunity. No lymphocytes have been stimulated to produce clone of themselves, so no memory cells have been formed.

Flow Chart: 13.2



Disorders of Immune System

An autoimmune disorder is a condition arising from abnormal immune response to a normal body part. There are at least 80 types of autoimmune diseases. Nearly all body parts can be involved. Common symptoms include low grade fever, feeling tired, often symptoms appear and disappear. Some examples of autoimmune disorder are:

Allergies: Allergic diseases are number of disease conditions caused by hypersensitivity of the immune system to some thing (Allergens) in the environment that usually causes little or no problem in most people. These diseases **cause hay fever,** food allergies, atopic dermatitis, allergic asthma etc. **Symptoms** may include red eyes, an itchy rash, sneezing, runny nose, shortness of breath or swelling.

The cause of allergies are usually genetic and environmental factors like pollen, metals, food, insect stings, drugs etc.

Usually antihistamine is given to allergic patients because in allergic conditions histamine production increases.

Transplant rejections: Transplant rejections occur when transplanted tissue is rejected by the recipient's immune system, which destroy the transplant tissue. This happens when recipients cells may recognize the donor's organ's or tissue as being foreign. As a result the recipient immune system activates against transplant organ and destroys it.

Do you know?

Stress can affect the way our immune system works. It can lead to increased level of cortisol which can blunt immune system. While positive emotions and a healthy life style may boost our immunity. Sleep deprivation can also impact.

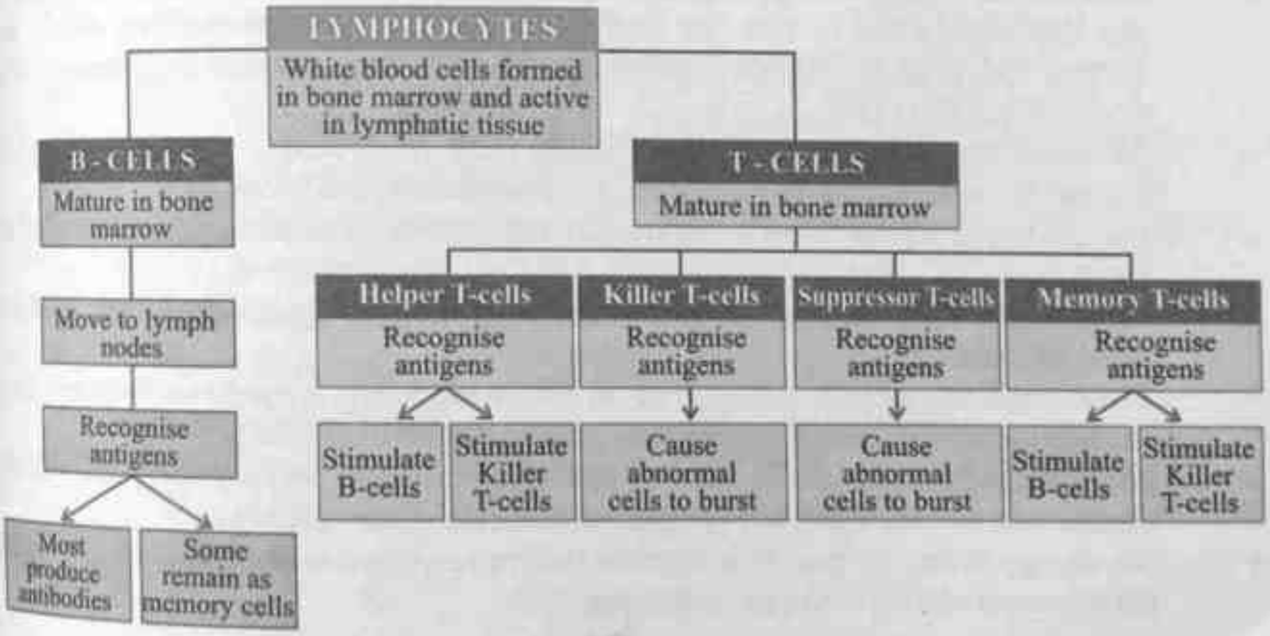
Role of T-Cells and B-Cells in transplant rejection

Rejection is an adaptive immune response via cellular immunity mediated by killer T-Cells. It induces apoptosis of T-Cells as well as humoral immunity mediated by activated B-Cells secreting antibody molecules. Although the action is joined with the components of innate immune response i.e., phagocytosis and soluble immune proteins. However different types of transplant tissues tend to favor different balances of rejection mechanisms.

Activity

Being too clean, can inhibit your immune system from functioning properly. Justify this statement by searching the information from different sources.

Flow chart 13.3 Different types of WBC



SUMMARY

- Defense system that had evolved to protect animals from invading pathogenic microorganisms and cancer is called as immune system and its study is called as immunology.
- The outermost layer of the vertebrate body, the skin, is the first barrier or first line of defense to penetration by microbes. Mucous membrane in the respiratory and digestive tracts is also important barriers that protect the body from invasion.
- The skin is the largest organ of the vertebrates and human body, accounting for 15% of an adult human's total body weight.
- The dermis of skin is 15 to 40 times thicker than the epidermis. It provides the structural support for the epidermis and the matrix for the many blood vessels, nerve endings, muscles, and other structures situated within skin.
- The body uses a host of nonspecific cellular and chemical devices to defend itself. We refer to this as second line of defense.
- The lymphatic system consists of network of lymphatic capillaries, ducts, nodes and lymphatic organs, and although it has other functions involved with circulation, it also stores cells and other agents used in the immune response.
- Macrophages are large eating cells, irregularly shaped cells that kill microbes by ingesting them through phagocytosis.
- Natural killer cells also known as "NK" do not attack invading microbes directly. Instead, they kill cells of the body that have been infected with viruses.
- The cellular defenses of vertebrates are enhanced by a very effective chemical defense called the complement system. This system consists of different proteins that circulate freely in the blood plasma.
- The inflammatory response is a localized, nonspecific response to infection.
- Interleukin-1 and other pyrogens such as bacterial endotoxins cause neurons in the hyphothalamus to rise the body's temperature several degrees above the normal value of 37 degree centigrade (98.6F). The elevated temperature that result is called fever.
- Antigens are large, complex molecules such as proteins; they are generally foreign to the body, usually present on the surface of pathogens.
- Lymphocytes called B-cells respond to antigens by producing proteins called as antibodies.
- The immune defense mechanisms of the body involve the actions of white blood cells, or leukocytes.
- The recognition of infectious agents in innate immunity is mediated by germ line-encoded receptors called pattern recognition receptors (PRRs).
- Each antibody molecule consists of two identical short polypeptides, called light chains, and two identical long polypeptides, called heavy chains.
- An allergy is an excessive or hypersensitive response of the immune system to harmless substance in the environment.

EXERCISE

Section I: Objective Question

Multiple choice Questions

A. Choose the correct answer.

1. Which of the following can not induce immunity?
   (a) Bacteria (b) Parasites
   (c) Virus (d) Worms
2. Skin is a ________ barrier.
   (a) Anatomical (b) Phagocytic
   (c) Physical (d) Inflammatory
3. Which among the following is anti-bacterial?
   (a) Interferon (b) hormone
   (c) Amylose (d) Protein
4. Which of the following is anti-viral?
   (a) Lysozyme (b) protein
   (c) Interferon (d) Hormone
5. Identify the phagocytic cells from the following combination.
   (a) Macrophage and Neutrophil (b) Macrophage and eosinophil
   (c) Lymphocyte and eosinophil (d) Eosinophil and neutrophil
6. Histamine is secreted by.
   (a) Epithelial cell (b) Red blood cells
   (c) Mast cells (d) White blood cells
7. Humoral immunity consists of:
   (a) Normal cells (b) Cytotoxic cells
   (c) Pathological cells (d) Immunoglobulin molecules
8. Which of the following secretes immunoglobulin.
   (a) T-lymphocyte (b) Macrophage
   (c) B-lymphocyte (d) Mast cells
9. Immunoglobulin are chemically.
   (a) Glycogens (b) Glycolipids
   (c) Glycoproteins (d) Lipoproteins
10. Colostrum is especially rich in.
    (a) Antibodies (b) Antigen
    (c) Sucrose (d) Histamine

B. Fill in the Blanks.

1. MHC is the abbreviation of __________.
2. The study of immunity is called __________.
3. Sweat from sweat glands gives the skin surface pH of __________.
4. Dead neutrophils after collected at the site of infection to form __________.
5. __________ is thin yellow milk produce in the first few days after child birth.
6. All antibodies are made of polypeptide __________.
7. Cytotoxic T-cells produces a type of toxin known as __________.
8. Tetanus is caused by a bacterium named __________.
9. The active immunity developed naturally is called __________.

Section II: Short Questions

1. How do macrophages destroy foreign cells?
2. How does complement system participate in defence against infection?
3. In what two ways do macrophages activate helper T cells? How do helper T cells stimulate the proliferation of cytotoxic T cells?
4. What are memory cells?
5. Define the terms T-cell, B-cell, antigens, antibodies, microbes, monocytes and vaccines.
6. Differentiate between antibody and cell mediated immune response.
7. Write the benefits of fever.
8. What are the major differences between innate and adaptive responses?
9. Write a note allergic diseases.
10. How and why might transplant be rejected?

Section III: Extensive Question

1. Explain second line of defence and discuss its types.
2. Write note on complement system.
3. Describe third line of defence.
4. What are different types of T-cells? Discuss.
5. Differentiate between active and passive immunity.
6. Write in detail diseases of immune system.
7. What is the role of B-cell in third line of defence?
8. Describe the structure of antibodies.
9. Describe protective proteins.
10. Explain on inflammatory and temperature responses.

Greek and Latin Roots in Biology

auto = self, e.g. autotroph [Greek]
bios = life, e.g. biology, biomass [Greek]
bis = twice, e.g. binary fission, bicuspid valve [Latin]
chloros = (pale) green, e.g. chlorophyll, [Greek]
chroma = colour, e.g. chromatopsia, chromosome [Greek]
dia = across, e.g. diaphragm, dialysis [Greek]
di = twice, e.g. dichromatic, diploid, dipeptide [Greek]
ektos = outside, e.g. ectoparasite [Greek]
epi = upon (above), e.g. epicotyl, epidermis [Greek]
exo = outside, e.g. excocytosis, exoskeleton [Greek]
haima = blood, e.g. haemoglobin, haemophilia [Greek]
heteros = other (different), e.g. heterozygous [Greek]
homos = same, e.g. homologous, homozygous [Greek]
hypo = under, e.g. hypocotyl, hypothermia [Greek]
inter = between, e.g. inter-cellular, intercosta [Latin]
intra = within, e.g. intra-cellular, intra-uterine [Latin]
kytos = vessel (a cell), e.g. cytoplasm, erythrocyte, leucocyte [Greek]
lipos = fat, e.g. lipase, lipid [Greek]
lysis = dissolution, e.g. dialysis, lysozyme [Greek]
mesos = middle, e.g. mesenteric, mesophyll [Greek]
meta = after (change), e.g. metamorphosis [Greek]
mikros = little, e.g. micropyle, microvilli [Greek]
morphe = form (shape), e.g. metamorphosis, morphology [Greek]
phagein = to eat, e.g. oesophagus, phagocyte [Greek]
phyllon = leaf, e.g. chlorophyll, mesophyll [Greek]
phyton = plant, e.g. phytoplankton, saprophyte [Greek]
polys = many, e.g. polypeptide, polysaccharide [Greek]
protos = first formed, e.g. protista, protoplasm [Greek]
rhiza = root, e.g. rhizoid, rhizome [Greek]
semi = half, e.g. semicircular canal, semilunar valves [Latin]
sub = under, e.g. sub-cutaneous, subclavian, subsoil [Latin]
sym-, syn = together, e.g. symbiosis, synapse [Greek]
tres = three, e.g. triceps brachii, tricuspid valve, tripeptide [Greek]
trophe = food, e.g. autotroph, trophic level [Greek]
unus = one, e.g. unicellular, unisexual [Latin]
vas = vessel, e.g. vascular bundle, vaso-dilation, vasodilator [Latin]
zoon = animal, e.g. zoology, zooplankton [Greek]

Glossary

A

Abscisic acid: Plant hormone that promotes stomatal closure, bud dormancy, and seed dormancy.

Abscission: The dropping of leaves, flowers, fruits, or other plant part due to hormonal action.

Absorption: In most animals, movement of nutrients, fluid, and ions across the gut lining and into the internal environment.

Accessory Pigment: Light-trapping pigment molecule; it contributes to photosynthesis by extending the range of usable wavelengths beyond those absorbed by the chlorophylls.

Acid: A substance that releases hydrogen ions when dissolved in water.

Acoelomate: of some of the invertebrates, having no fluid-filled cavity between the gut and body wall.

Activation energy: The minimum amount of collision energy necessary to drive reactant molecules to an activated state at which a given chemical reaction will proceed spontaneously.

Active site: A cleft in the surface of an enzyme molecule where a specific reaction is catalyzed, or made to proceed far faster than it would spontaneously.

Active transport: The solute is transported against its concentration gradient. An energy boost, as from ATP, activates the protein.

Adenine: A purine; a nitrogen-containing base in certain nucleotides.

Adipose tissue: A type of connective tissue having an abundance of fat-storing cells.

Aerobic respiration: The main pathway of ATP formation, for which oxygen is the final acceptor of electrons stripped from glucose or another organic compound.

AIDS: Short for acquired immunodeficiency syndrome.

Alcohol: An organic compound that has one or more hydroxyl groups (-OH) and readily dissolves in water. Sugars are examples.

Alcoholic fermentation: Anaerobic pathway of ATP formation. Pyruvate from glycolysis is degraded to acetaldehyde, which accepts electrons from NADH to form ethanol with a net yield of two ATP. NAD^+ is regenerated.

Amino acid: A small organic molecule with a hydrogen atom, an amino group, an acid group, and an R group bonded covalently to a central carbon atom; the subunit of polypeptide chains or protein.

Amphibians: A type of vertebrate somewhere between fishes and reptiles in body plain and reproductive mode, example salamanders, frogs and toads.

Anaerobic pathway: Metabolic pathway in which a substance other than oxygen serves as a final acceptor of electrons that have been stripped from substrates.

Angiosperm: A flowering plant.

Annual: A flowering plant that complete its life cycle in one growing season.

Anther: A pollen-bearing part of a stamen.

Antibiotic: One of many metabolic products of certain microorganisms that can kill their bacterial competitors for nutrients in soil.

Antibody: One of diverse array of antigen-binding receptors. Only B- WBC makes antibody molecules and position them their surface or secrete them.

Antigen: A molecular configuration that white blood cells recognize as foreign and that triggers an immune response. Most antigens are protein at the surface of pathogens or tumor cells.
Aorta: Main artery of systemic circulation; carries oxygenated blood away from the heart to all body regions expect the lungs.
Apical dominance: Inhibitory influence of a terminal bud on growth of lateral buds.
Apical Meristem: A mass of self–perpetuating cells responsible of primary growth at root and shoot tips.
Apoptosis: Of multicelled organisms, a program natural death of cell.
Archaebacteria: A kingdom of prokaryotes; methanogens, halophiles, and thermophiles.
Artery: A large-diameter, rapid-transport blood vessel with a thick, muscular wall, carrying away from heart.
Asexual Reproduction: Any of number of modes of reproduction by which offspring arise from a single parent and inherit the genes of that parent only.
Atmosphere: A volume of gases, airborne particles, and water vapor that envelops the earth.
Atom: A smaller particle unique to a given element; it has one or more positively charge protons, electrons, (except for hydrogen), neutrons.
Atomic number: The number of proton in a nucleus of each atom of an element; the number differ for each element.
ATP: Adenosine triphosphate. A nucleotide of adenine, ribose, and three phosphate groups that acts as an energy carrier.
Autoimmune response: Misdirected immune response in which lymphocytes mount and attack against normal body cells.
Autotroph: Organism that synthesizes its own organic compounds using carbon dioxide (as the carbon source) and energy from the physical environment (such as sunlight energy).
Auxin: A plant hormones that influences, growth such as stem elongation.

B

B- Lymphocyte: (B- cell) The only white blood cell that produces antibodies, then positions them at the cell surface or secretes them as weapons in immune responses.
Bacterial conjugation: Transfer of plasmid DNA from one bacterial cell to another.
Bacteriophage: Category of viruses that infect bacterial cells.
Basal body: A centriole which after giving rise from microtubules of a flagellum or cilium, remain attached to its base in the cytoplasm.
Base: Any substance that accepts hydrogen ions when dissolved in water.
Basophil: Fast-acting white blood cells that secretes histamine and any other substances to maintain an inflammatory response.
Biennial: A flowering plant that lives through two growing seasons.
Bilateral symmetry: Body plan in which the left and right halves of an animal are mirror-images of each other.
Binary fission: A mode of asexual reproduction; whole body into two parts of the same or different sizes.
Biogeochemical cycle: The movement of an element from the environment to organisms, then back to the environment.
Biological species concept: A species is one or more population of individuals that are interbreeding under natural conditions and producing fertile offspring and that are

reproductively isolated from other such populations. The concept applies only to sexually reproducing species.

Biomass: Combined weight of all organisms at a given tropic level in an ecosytstem.

Bipedalism: Habitually walking on two feet, as by birds and human.

Bird: The only vertebrate that produces feathers.

Blood: A fluid connective tissue composed of water, solutes, and formed elements (blood cells and platelet) it carries substances to and from cells and helps to maintain internal environment favorable for cells activities.

Blood pressure: Fluid pressure, generate by heart contractions, that circulates blood.

Bud: An undeveloped shoot of meristematic tissue, primarily, often covered and protected by scales (modified leaves).

Buffer system: A partnership between a weak acid and base that forms when it dissolves in water. The two work as a pair to counter slight shifts in pH.

C

C4 pathway: A pathway photosynthesis in which carbon dioxide is fixed twice, in two different cell types. Carbon dioxide accumulates in the leaf and helps counter photorespiration. The first compound formed is the 4-carbon oxaloacetate.

CAM Plant: A plant that conserves water by opening stomata only at night, when it fixes carbon dioxide by way of a C4 pathway.

Cambium: One of two types of meristems responisible for secondary growth (increases in stem and root diameter). Vasscular cambium gives rise to secondary xylem and secondary phloem; cork cambium gives rise to periderm.

Cancer: A malignant tumor; weakend capacity for adhesion within the parent tissue (leading to metastasis)cancer is lethal.

Carbohydrate: A molecule that consists of carbon, hydrogen, and oxygen in a 1:2:1 ratio. All cells use carbohydrates as structural material, energy reservoirs, and transportable forms of energy.

Carcinogen: A substance or agent, such as ultraviolet radiation; that can trigger cancer.

Cardiac cycle: The sequence of muscle contraction and relaxation for one heartbeat.

Cardiac pacemaker: Sinoatrial (SA) node; the basis of normal rate of heartbeat. The self-excitatory cardiac muscle cells that spontaneously generate rhythmic waves of excitation over heart chambers.

Cardiovascular system: System of blood, one or more hearts, and blood vessels that functions in rapid transport of substances to and from cells.

Carnivore: An animal that eats other animals; a type of heterotroph.

Carotenoid: A light sensitive, accessory pigment that transfers absorbed energy to chlorophylls. Different types absorb violet and blue wavelengths and transmit red, orange and yellow.

Carpal: The female reproductive part of a flower; sometimes called a pistil.

Cartilage: A type of connective tissue with solid yet pliable intracellular material that resists compression.

Casparian strip: A waxy band that is an impermeable barrier between the walls of abutting cells making up the endodermis inside roots.

cDNA: Any DNA molecule copied from a mature mRNA transcript by way of reverse transcription.

Cell: The smallest living unit; an organized unit that can survive and reproduce on its own.

Cell differentiation: Developmental process in which different cell populations activate and suppress a fraction of their genes in different ways and so become specialized in composition, structure, and function.

Cell plate: A disc like structure that forms from remnants of a microtubular spindle when a plant cell divides; it develops into a cross wall that partitions the cytoplasm.

Cell theory: A theory in biology stating.

1. All organisms are composed of one or more cells,
2. The cell is the smallest unit that retains a capacity for independent life, and
3. All cells arise from preexisting cells.

Cell wall: A semi rigid, permeable structure that helps a cell hold its shape and resist rupturing if internal fluid pressure rises.

Central vacuole: A fluid-filled organelle in mature, living plant cells that stores amino acids, sugars, ions and toxic wastes. As it enlarges, it forces increases in cell surface area that improve nutrient uptake.

Centriole: A cylinder of triplet microtubules that gives rise to microtubules of cilia and flagella.

Chemical bond: A union between the electron structures of two or more atoms or ions.

Chlorophyll: A light-sensitive pigment that absorbs violet-to-blue and red wavelengths but that transmits green.

Chloroplast: An organelle that specializes in photosynthesis in plants and photosynthetic protists.

Chordata: An animal having a notochord, a dorsal hollow nerve cord, a pharynx, and gill slits in the pharynx wall for at least part of the life cycle. Mostly tail as fourth character.

Chromosome: Of eukaryotes, a DNA molecule with many associated proteins. Of prokaryotes, a DNA molecule without a comparable profusion of proteins.

Cloaca: Of some vertebrates, the last of a gut that receives feces, urine, and sperm or eggs; of some invertebrates, an excretory, respiratory, or reproductive duct.

Coelom: A cavity, lined with peritoneum, between the gut and body wall of most animals.

Cohesion: Capacity to resist rupturing when placed under tension (stretched).

Collenchyma: A simple plant tissue that offers flexible support for primary growth, as in lengthening stems.

Commensalism: A ecological interaction between species that directly benefits one but does not affect other much, if at all.

Community: All populations living in the same habitat. Also, a group of organisms with similar life-styles in a habitat, such as a community of birds.

Companion cell: A specialized parenchyma cell that helps load organic compounds into conducting cells of phloem.

Complement system: A set of about twenty proteins circulating in inactive form within vertebrate blood; different kinds induce lysis of pathogens, promote inflammation, and stimulate phagocytes to act during both nonspecific defenses and immune responses.

Compound: A substance consisting of two or more elements in unvarying proportions.

Condensation reaction: Through covalent bonding, two molecules combine to form a larger molecule, often with the formation of water as a by-product.

Conifer: A pollen and seed-bearing plant of dominant group of gymnosperms; mostly evergreen, woody trees and shrubs with needle like or scale-like leaves.

Cotyledon: A seed leaf, which develops as part of the embryo of monocots and dicots; cotyledons provide nourishment for the seeding at the time of germination and initial growth.

Covalent bond: A sharing of one or more electrons between atoms or group of atoms.

Cuticle: A body covering. Of land plants, a transparent cover of waxes and lipid-rich cutin deposited on the outer surface of epidermal cell walls.

Cycle AMP: A nucleotide; its functions in intercellular communications, as when it is a second messenger.

Cytochrome: Iron-containing protein molecule; a component of the electron transport systems used in photosynthesis and aerobic respiration.

Cytoplasm: All cellular parts, particles, and semi-fluid substances enclosed within the plasma membrane except for the nucleus (or nucleoids, in bacterial cells).

D

Denaturation: Of any molecule, the loss of three-dimensional shape following disruption of hydrogen bonds and other weak bonds.

Dermis: The layer of skin underlying epidermis; consists of primarily of dense connective tissue.

Diaphragm: Muscular partition between the thoracic and abdominal cavities.

Diffusion: Net movement of like molecules (or ions) down their concentration gradient.

DNA replications: Of cells, the process by which hereditary material is duplicated for distribution to daughter nuclei. Occurs prior to mitosis and meiosis in eukaryotic cells and during prokaryotic fusion in bacterial cells.

Double fertilization : Of flowering plants only, the fusion of one sperm nucleus with the egg nucleus (to produce a zygote), and the fusion of a second sperm nucleus with nuclei of the endosperm mother cell, which gives rise to a nutritive tissue (endosperm).

E

Emulsification: Of the chyme in the small intestine, a suspension of droplets of fat coated with bile salts.

Endocrine gland: A ductless gland that secretes hormones, which usually enter interstitial fluid and then the bloodstream.

Endocytosis: Movement of a substance into a cell by a vesicle.

Endosperm: Nutritive tissue that surrounds a flowering plant embryo and becomes food for the young seedling.

Endospore: A resting structure that forms around a copy of the chromosome and part of the cytoplasm of certain bacteria.

Epiglottis: A flap like structure at the start of the larynx, the position of which directs the movement of air into the trachea or of food into the esophagus.

Epithelium: An animal tissue of one or more layers of adhering cells that covers the body's external surfaces and lines its internal cavities and tubes.

Essential amino acid: An amino acid that an organism cannot synthesize for itself and must obtain from food source.

Enthylene: plant hormone that stimulate fruit ripening and abscission.

Exocrine gland: Secretes product, usually thought ducts or tubes, to a free epithelial surface.

Exocytosis : Transport of a substance out of a cell by mean of a vesicle.

F

FAD : Flavin adenine dinucleotide, one of the nucleotide coenzymes that transfers electrons and unbound protons (H+) from one reaction site to another. At such times it is abbreviated FADH2.

Fin: Of fish generally, an appendage that help propel, stabilize, and guide the body through water.

Fossil: Recognizable, physical evidence.

Fossil fuel: Coal, petroleum and natural gas.

G

Gametes: Sex cells, sperms and eggs.

Ganglion: Group of neuron outside CNS.

Gene: unit of information about a heritable trait that pass from parent cell to daughter cell.

Genome: All the DNA or genes in a single or haploid set of chromosomes of a given species.

Germ cells: Of animals, give rise to eggs and sperms.

Gland: A secretory cell or structure.

Gonads: Sex organs, that is testes or ovaries.

H

Habitat: The type of place where an organism normally lives.

Hermaphrodite: An individual with both male and female gonads.

Hormones: Signaling molecule that stimulates or stop or modified cells having receptors for them.

I

Infection: Invasion and multiplication of a pathogen in host cells or tissue.

Integument: Of animals, a protective body cover such as skin. Of seed-bearing plants, one or more layers around an ovule that form a seed coat.

Invertebrate: An animal without backbone.

K

Keratin: A tough, water- insoluble protein made by most epidermal cell which becomes deposit in outer body coverings (skin).

L

Larva: An immature developmental stage between the embryo and adult.

Ligament: A band of connective tissue that bridge a joint.

Lymph: Tissue fluid that has drained into the vessels of the lymph system.

M

Mutagen: Any environmental agent that can alter the molecular structure of DNA.

Mutation: a heritable change in the molecular structure of DNA.

N

Necrosis: Of multicelled organisms, the passive death of many cells that results from severe tissue damage.

Nerve cord: Of many animals, a cord like communication line of axons of neurons.

Neuron: A nerve cell; the basic unit nervous systems.

Node: A site where one or more leaves are attached to a plant stem.

Nucleoid: The region in bacterial cell where chromosome is located (but not bounded by membrane)

Nutrition: All of those processes by which food is selectively taken in, digested, absorbed, and later converted to the body's own organic compounds.

O

Obesity: An excess of fat in the body.

Ovum: The mature female egg (ovum)

P

Parasitism: A two species interaction in which one species lives in or on a host species and uses its tissue for nutrients. The parasite benefits; the host damage.

Passive transport: The movement of substances from higher to lower concentration without energy.

Pathogen: A disease causing organism.

Perennial: a flowering plant that lives for more than two growing season.

Phloem: Of vascular plants, a tissue with living cell that inter connect and form the tubes through which sugars and other dissolved organic compounds are conducted.

Phycobilin: One of the light sensitive, accessory pigments that transfer energy they absorb to chlorophylls, abundant in red algae and cyanobacteria.

Phytoplankton: A community of floating or weekly swimming phytoautotroph in salt and fresh water habitat.

Pigment: A light absorbing molecule.

Plankton: Any community of floating or weekly swimming organisms, mostly microscopic.

Plasmolysis: an osmotically induced shrinkage of a cell's cytoplasm.

Pollen tube: A tube formed after a pollen grain germinates; grows through carpel tissues, and carries sperm to the ovule.

Pollination: The arrival of pollen grain on the stigma of carpel (in seeded plants)

Predators: An organism that feeds on another organism.

R

Rhizoid: A root like absorptive structure of some fungi and in nonvascular plants.

S

Salts: A compound that releases ions other than H+ and OH+ in solution.

Saprobs: A heterotroph that obtains energy and carbon from non living organic matter so cause it's decay. E.g., fungi and bacteria.

Secretion: A product release across the plasma membrane of a cell that may act singly or as a part of glandular tissue.

Semen: sperms bearing fluid expelled from a penis during male orgasm.

Solute: Any substance dissolved in solution (in water)

Solvent: A fluid, such as water, in which one or more substances is dissolved.

Somatic cell: A body cell that is not a germ cell (which give rise to egg and sperm).

Sperm: A type of mature male gametes.

Spleen: It is lymphoid organ; also filtering station for blood, a reservoir of red blood cells and macrophages.

Stamen: A male reproductive structure in a flower.

Stem cell: A type of cell perpetuating cell that remains unspecialized.

T

Tendon: A strap of dense connective tissue that attaches muscle to bones.
Tracheid: One of two types of cells in xylem that conduct water and dissolved minerals.
Transcription: The first stage of protein synthesis; when a RNA strand is assembled from one two strand of DNA.
Transpiration: In the presence of sun light, evaporation of water from above ground plant parts, leaves especially.

V

Vascular plants: A plant with a transport system i.e., xylem and phloem,
Vascular tissue: Xylem and phloem.
Vertebrates: Animal with a backbone.
Vesicle: In cytoplasm of cells, one of variety of small membrane bound sac that function in the storage, transport and digestion of substances or in some other activity.
Vitamin: Any of more than ten substances that animals require in small amount for metabolism.

W

Water Potential: The tendency of water molecules to move from one region to another. The greater the difference in water potentials between two regions, the greater and faster the net movement of water molecules from a region of higher water potential to a region of lower water potential.
White blood cell: One type of blood cell. It is colorless and has a nucleus. It helps to keep the body healthy by fighting germs.
Wilting: A process by which the leaves lose water (as water vapour) faster than the roots absorb water and mineral salts from the roots to the root hair cells lose water to the very dry soil.

X

Xylem: A tissue that transport water and solutes through the vascular plants.

Y

Yeast: A tiny, oval, unicellular organism which does not contain chlorophyll. It reproduces by budding and can respire under anaerobic conditions.

Z

Zooplankton: A freshwater or marine community of floating or weakly swimming heterotroph (animal).
Zygote: The first cell of new individual, formed by the fusion of nuclei of gametes at fertilization.