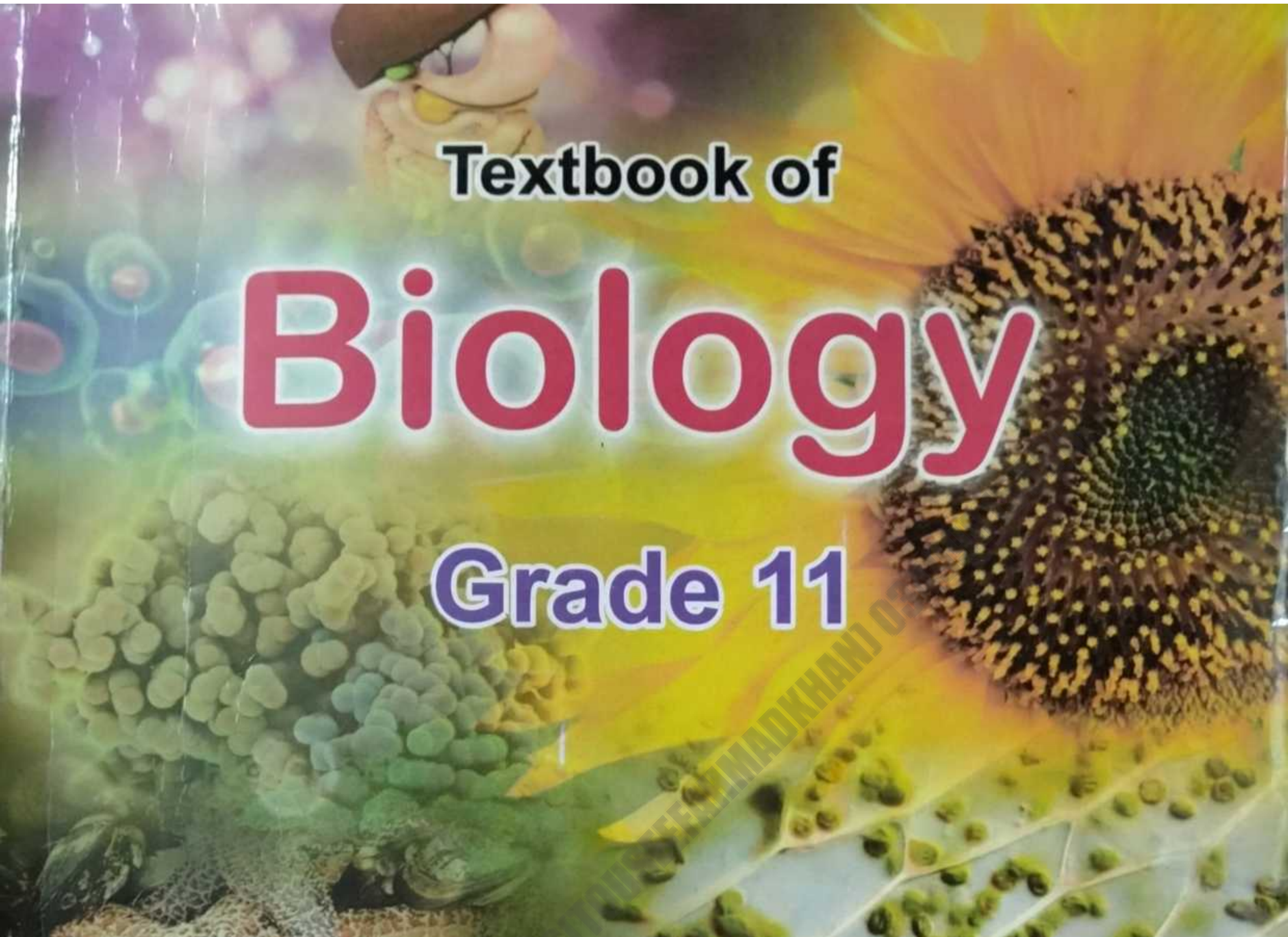
Textbook of

Biology

Grade 11



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Prof. Jawaid Mohsin Malick was born on 8th February 1945 in the province of Bihar. Malick is the title given to his ancestor Syed Ibrahim by the King Muhammad Tughlaq. Syed Ibrahim was a saint, the commander in chief of the army and conqueror of Bihar. Syed Ibrahim is the descendent of Hazrat Ghos-e-Azam, Syed Abdul Qadir Jilani (رحمة للهعليه) at the seventh generation. The ancestors of Syed Ibrahim migrated from Iraq to Afghanistan and settled in the village 'But Nagar' near Ghazni. Prof. Jawaid served as lecturer in Quaid-i-Azam College and Notre Dame College Dhaka. He is a former head of the department of Zoology, F.G. Postgraduate College, H-8, Islamabad where he served for more than twenty five years. He is also a former Principal, Federal Government College, H-9, F-10/4 Islamabad, and Director Colleges and Director Administration, Federal Directorate of Education, Islamabad. He did his post-graduation in Zoology with specialization in Entomology from Dhaka University, East Pakistan (former). He taught various classes for more than forty five years in various capacities. He has also worked as Education Officer, in Nigeria for four years. He has successfully completed the 61st advance course in administration and development held in 1996 at National Institute of Public Administration (NIPA), Karachi. In 1995, he was awarded a shield by the honourable Mr. Rafiq Tarrar, the then President of Pakistan, for his services to humanity.

He published four research papers in Science Journals of Pakistan on Butterflies of Pakistan. He has contributed articles on science and sports in Urdu and English dailies of Islamabad. He is co-author and managing author of more than forty five textbooks on General Science and Biology as well as Biology Practical Notebooks. He has travelled to Singapore, Thailand, Indonesia, India, Bangladesh, UAE, Saudi Arabia, Egypt, Italy, Holland, UK, Qatar, USA and Nigeria. He has also served as a National Consultant, Science Education, JICA sponsored project for the promotion of Student Centred and Inquiry Based (SCIB) learning, National Institute of Science and Technical Education, Ministry of Education, Islamabad.

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OUR MOTTO

• Standards • Outcomes • Access • Style

Note

The material given in the box (Science titbits, Did you know, Critical thinking, STSC, Activity, Teacher's Point) and parenthesis, are not part of the textor SLO's.

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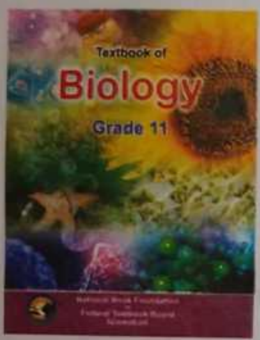

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Preface

Biology Grade - 11 is developed according to the National Curriculum 2006. It is being published since 2013 and now it is presented under the supervision of textbook development, principles and guidelines with new design and layout.

The standard includes higher thinking, deep knowledge, problem solving substantive conversation and connections to the world beyond the class room and achieve the target set by the curriculum. The special features of the textbook are:

- Each chapter begins with a brief recalling statement i.e., introduction to the chapter. The textbook has coloured illustrations to capture the students' attention. Where necessary, concept mapping has also been incorporated.
- Necessary 'Titbits' and 'Critical Thinking' have been added in each chapter for motivating the students to apply their intelligence and acquire more knowledge.
- The exercises include multiple choice questions, short answer questions and extensive questions. These are given for reinforcement. The teachers should develop assessments questions as per Bloom's Taxonomy.
- At the end of the book a glossary has been annexed.

In each chapter Science, Technology and Society connections are explained in accordance with the curriculum. These interventions will serve as a guide for evaluating the students' skills development through the chapter knowledge and their abilities to apply knowledge to the scientific and social problems. The duration or the number of periods is also allocated to complete each chapter, so that the teachers can develop their teaching strategy and plans in an effective manner accordingly.

Quality of Standards and Actualization of Style is our motto. With these elaborations, this series of new development is presented for use. However there is always room for improvement and suggestions from the teachers and the community will be highly appreciated to make the book more valuable and to make the textbook more interesting, informative and useful for the student. After educational feedback, research report and reviewed by NCC through review committees, **now this is the revised addition of the book biology for Grade- I for the year 2020.**

May Allah Guides and helps us. (Ameen).

National Book Foundation

Contents

بِسْمِ اللّٰهِ الرَّحْمٰنِ الرَّحِيْمِ ○

In the Name of Allah, the Most Gracious, the Most Merciful

CONTENTS

SECTION 1
Cell Biology

Electron microscope

1

CELL STRUCTURE AND FUNCTIONS

After completing this lesson, you will be able to

- List the principles and identify the apparatus used in the techniques of fractionation, differential staining, centrifugation, micro-dissection, tissue culture, chromatography, electrophoresis and spectrophotometry.
- Describe the terms of resolution and magnification with reference to microscopy.
- Explain the use of graticule and micrometer.
- 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 chromosome.
- 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.

You are quite familiar with the word "cell" i.e., a basic unit of life. By the middle of the nineteenth century, biologists had formulated **cell theory** which is a fundamental concept in biology. The generally accepted portions of the modern cell theory are as follows:

(1) The cell is the fundamental unit of structure and function in living things.

(2) All organisms are made up of one or more cells.

(3) Cells arise from other cells through cellular division.

This chapter will help you to become familiar with the structure of cells and how they work, and also the basic techniques essential for cell study.

1.1 TECHNIQUES USED IN CELL BIOLOGY

To know the structure and functions of cells etc., and cell organelles some of the techniques will be discussed here in brief.

1.1.1 Cell Fractionation

Cell fractionation is the combination of various methods used to separate a cell organelle and components based upon size and density. It is very useful for electron microscopy of cell components. The principle of cell fractionation consists of two steps i.e., homogenization and centrifugation.

Homogenization

It is the formation of a homogenous mass of cells. It involves the grinding of cells in a suitable medium with correct pH, ionic composition and temperature. In plants enzyme pectinase is added to digest middle lamella. This can be done in a blender. This procedure gives rise to a uniform mixture of cells which is then centrifuged.

Centrifugation

Centrifugation is the process to separate substances on the basis of their size and densities under the influence of centrifugal force. It is done by the machine called **centrifuge**. This machine can spin the tubes at very high speed. Spinning the tubes exerts a centrifugal force on the contents. There are two major ways of centrifugation i.e., density gradient centrifugation and differential centrifugation. In **density gradient centrifugation** the cell components of different sizes and densities are separated in different layers. The upper layers are less dense than lower layers.

In **differential centrifugation** the size and shape of particles determines how fast it settles. A series of increasing speeds can be used. At each step, the content which settles in the bottom of the tube are called **pellet** and those that remain suspended above in the form of liquid are called **supernatant**. After each speed, the supernatant can be drawn off and centrifuge again. A series of pellets containing cell organelles of smaller and smaller size can therefore be obtained.

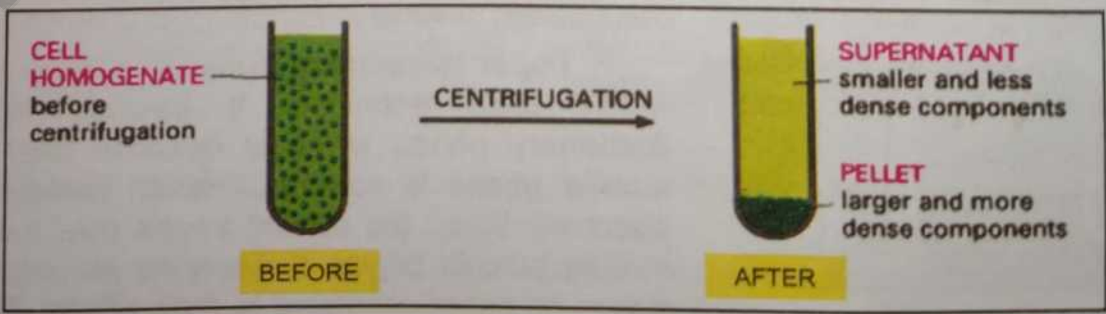


Fig 1.1: Centrifugation of cells

Science Titbits

During centrifugation the bigger particles sediment faster and have higher sedimentation coefficients (Svedberg, or S values). Sedimentation coefficients are, however, not additive. Sedimentation rate does not depend only on the mass or volume of a particle, and when two particles bind together there is inevitably a loss of surface area. Thus when measured separately they will have Svedberg values that may not add up to that of the bound particle. This is notably the case with the ribosome. Ribosomes are most often identified by their sedimentation coefficient. For instance, the 70 S ribosome that comes from bacteria has actually a sedimentation coefficient of 70 Svedberg, although it is composed of a 50 S subunit and a 30 S subunit.

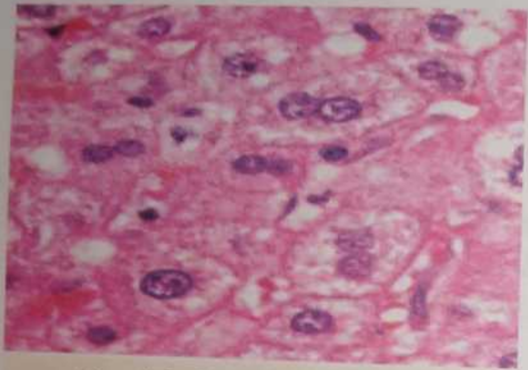


Fig. 1.2: Differential staining

1.1.2 Differential Staining

Most biological structures are transparent. In order to differentiate between these structures various colour dyes are applied. Such techniques are called **staining techniques**. When only one stain, such as borax carmine (that stains nucleus) is used it is called **single staining**. When two stains, one that will stain nucleus e.g., haematoxylin and other that will stain cytoplasm e.g., eosin are used, the process is called **double staining** or **differential staining**.

1.1.3 Microdissections

Microdissection refers to the variety of techniques where a microscope is used to assist in dissection. It is done to remove tumour or granules from delicate tissue or cells like, brain, heart and nerve cells. In this technique, the image is seen on large TV screen or monitor while dissecting

1.1.4 Tissue Culture

Growth of a cell or a tissue on chemically defined nutrient medium under sterile conditions is called **tissue culture**. This technique can be employed for both plants and animals.

Plant tissue culturing is mainly used for plant cloning i.e., production of genetically identical plants (clones). Animal tissue culture is usually set up by growing individual cells to form a single layer of cells over the surface of a glass container. Animal tissue cultures are used to see any abnormality in the cell, e.g., cancer, chromosomal disorder etc.

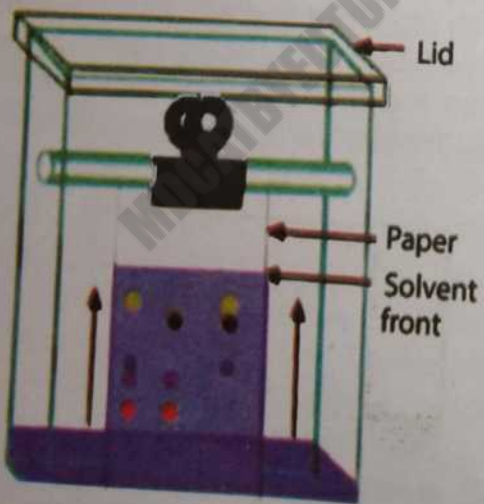


Fig. 1.3: Chromatography chamber

1.1.5 Chromatography

Chromatography is a technique which is used to separate different chemical compounds from a mixtures. It is generally used for the separation of mixtures of proteins, amino acids or photosynthetic pigments. There are different types of chromatographic techniques.

Paper chromatography is a simple and most widely used technique. It involves two phases. **Stationary phase** which is cellulose filter paper and **mobile phase** is solvent in which sample mixture is dissolved. When the solvent travels over the paper, the mixture sample begins to separate as dots at different places on paper according to their affinity. This paper is then called **chromatogram**.

1.1.6 Electrophoresis

It is a technique which is used to separate fragments of a charge bearing polymer molecule according to their size, shape, molecular weight and surface charge whether (+) or (–). Such charge bearing polymer molecules are DNA, RNA, protein etc.

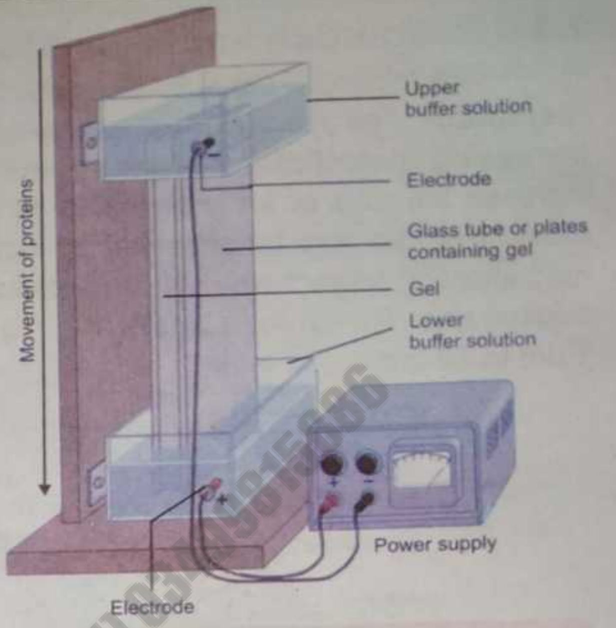


Fig. 1.4: Gel electrophoresis

This technique utilizes a gel medium for separation of fragments which is done under the influence of an electric field. Often the gel is sandwiched between glass or plastic plates to form a viscous slab. The two ends of the slabs are suspended in two salt solutions that are connected by electrodes to a power source. At one end of the slab the samples are loaded. When voltage is applied to the apparatus, the molecules present in the gel migrate through the electric field.

The negative charged molecule will move towards the positive pole and the molecule having positive charge will move towards the negative pole. The velocity of movement of fragments is inversely proportional to the size. Therefore smaller fragments move faster than larger. In this way all the fragments are separated in the gel after some time. Later on the molecules can be pin pointed by staining the gel.

1.1.7 Spectrophotometry

Spectrophotometry is a technique which is used to determine the absorption of different wavelength of light by a particular chemical compound or a photosynthetic pigment. For this purpose the instrument used is **spectrophotometer.** The amount of light absorbed at each wavelength is plotted in a graph called the **absorption spectrum**.

Fig. 1.5: Spectrophotometer

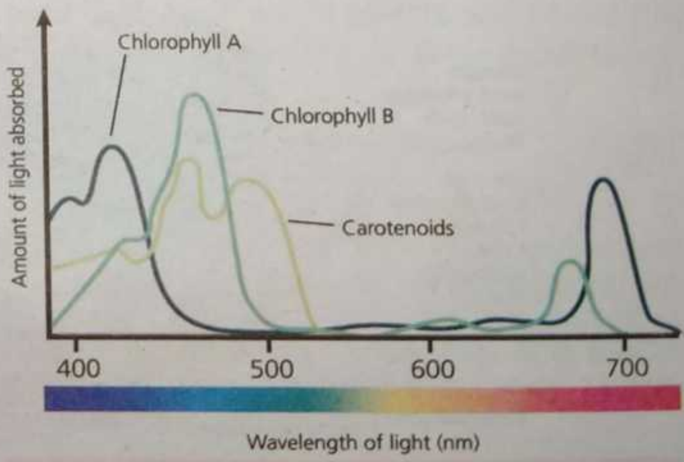


Fig. 1.6: Absorption spectrum

Spectrophotometry can be used to determine the wavelengths of light that take part in photosynthesis. It can also be used to determine the very minute quantity of a substance (such as DNA) in a sample.

1.1.8 Resolution and Magnification in Microscopy

The minimum capacity of a lens to differentiate between two adjacent points is called **resolution**. The resolution of naked eye is 0.1 mm. This resolution can be increased by increasing magnification. The **magnification** is the capacity of an optical instrument to increase the size of an object than its original size. The objects which cannot be seen by naked eye can also be observed by increasing magnification. Different lenses have different magnification powers which are represented by letter "X" that means the number of times than original size. Therefore, a lens of 10X magnification power can increase the size of an object of 1 μm to 10 μm.

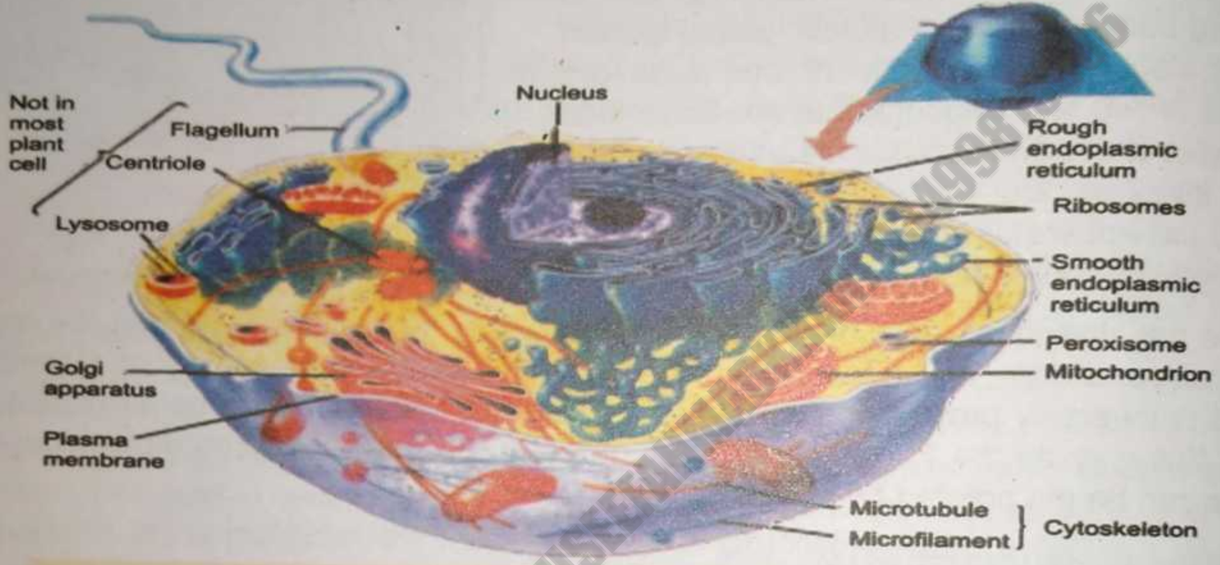


Fig. 1.7: Electron microscopic structure of an animal cell

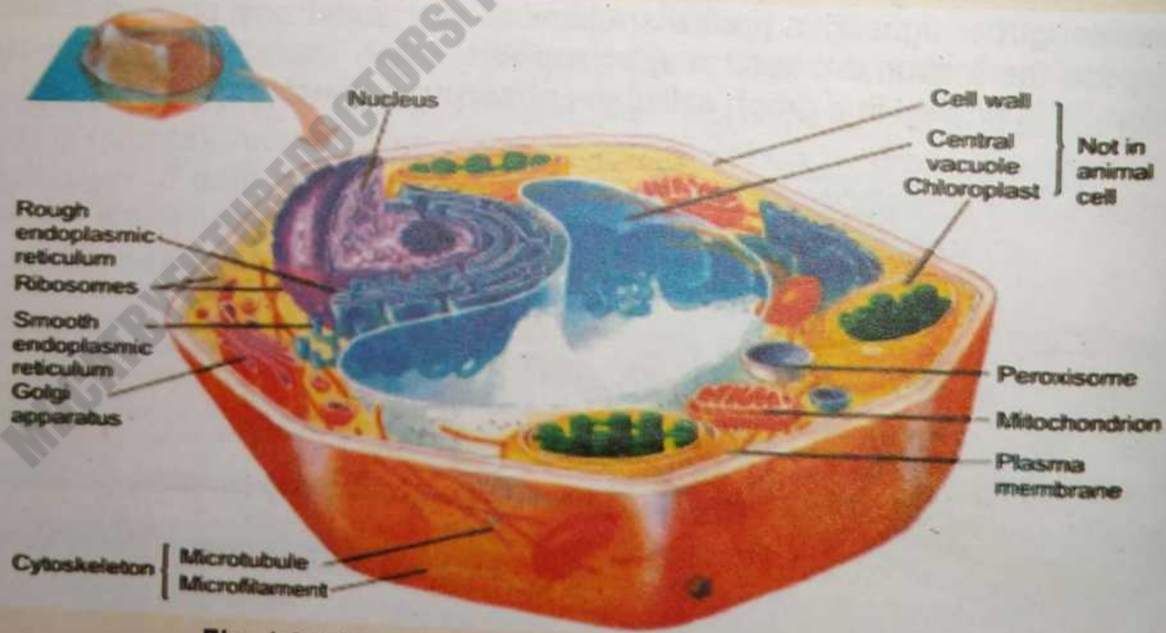


Fig. 1.8: Electron microscopic structure of a plant cell

Microscopy is the technique used to view objects that cannot be seen by the naked eye. The range can be anything between mm and nm. Most animal cells and plant cells are between 10 μm and 30 μm. A common compound microscope consists of ocular lens and objective lens. The overall magnification power of such a microscope is equal to the product of magnification powers of both lenses. The resolving power of light microscope is 250 nm and its magnification is up to 4000X. The resolving power of electron microscope is 0.2 nm and its magnification is up to 2,000,000X.

1.1.9 Micrometry

Micrometry is the measurement of the size of objects under microscope. It involves two micrometres. The ocular micrometre is a glass disc with 100 equal divisions with no absolute value. It is placed in the eye piece of the microscope. Then it is calibrated by using a **stage micrometre**. This is a glass slide with an exact scale like a miniature transparent ruler. By superimposing the images of the ocular micrometre and stage micrometre scales, it is calibrated so the size of any given object viewed under the microscope can be estimated.

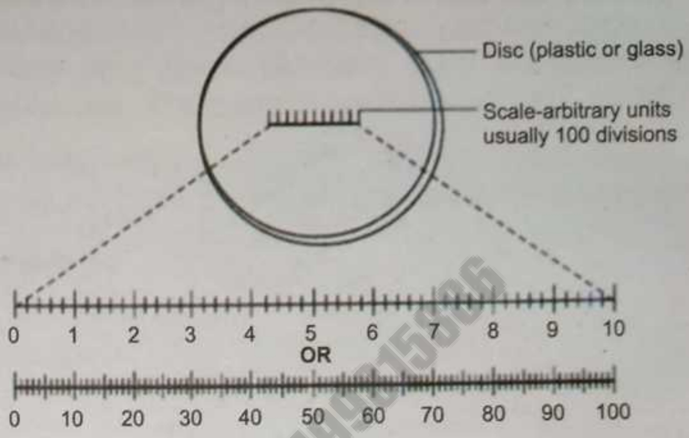


Fig. 1.9: Ocular micrometre

1.2 CELL WALL AND PLASMA MEMBRANE

The plasma membrane is the outer living boundary of the cell. Many cells have an extracellular component that is formed exterior to the membrane, which is called cell wall.

1.2.1 Cell Wall

> **Critical Thinking**
>
> Is plant cell wall permeable, semipermeable or impermeable boundary?

The cell wall is present in plant cells, prokaryotes and fungi but animal cells do not have cell wall. This is probably due to their locomotor mode of life. Plant cell walls (made up of cellulose) differ in chemical composition from those of the prokaryotes (made up of peptidoglycan) and fungi (made up of chitin). We will discuss here only plant cell wall. The cell wall is secreted by the cell. The cell wall is porous and allows free passage of water and dissolved material. The plant cell wall consists of three main layers, primary cell wall, middle lamella and secondary cell wall.

Fig. 1.10 : Crisscross arrangement of cellulose

> **Science Tidbits**
>
> Pectin is a polymer of around 200 galacturonic acid molecules. Majority of its carboxyl groups are methylated ($COOCH_3$). It is less hydrophilic then pectic acid but soluble in hot water. It is another major component of middle lamella but also found in primary walls.

Primary cell wall

Primary cell wall is a true wall and develops in newly growing cell i.e., during cell division. Each cell produces a primary cell wall. The primary cell wall is present inner to the middle lamella. The primary cell wall is thin and slightly flexible. The primary cell wall is composed of cellulose microfibrils (bundles of cellulose chains), running through the matrix of other polysaccharides like hemicelluloses and pectin. The microfibrils show a crisscross arrangement in layers one above the others. This feature gives the cell great strength. The primary cell wall is adapted to growth. The wall stretches plastically i.e., irreversibly.

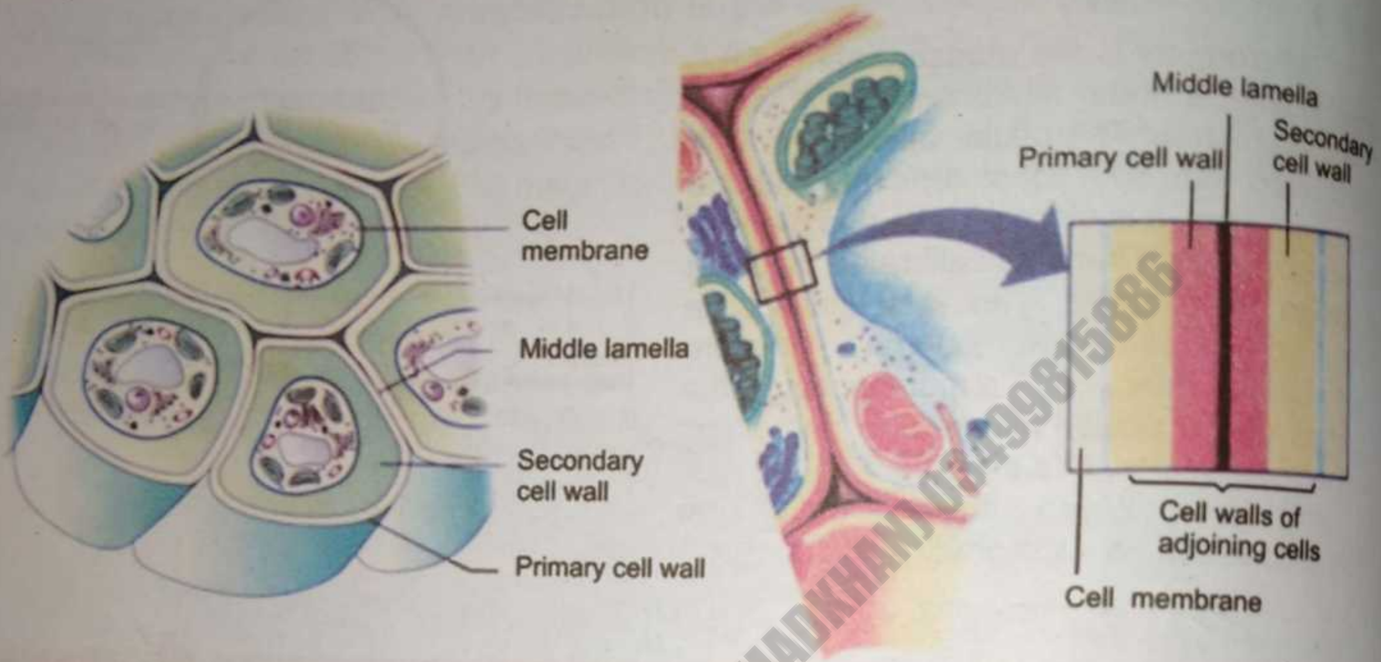


Fig. 1.11: Plant cell wall

Secondary cell wall

Secondary cell wall is formed between the primary cell wall and plasma membrane only in sclerenchyma cells. The plant cells possessing secondary cell wall are generally dead and provide support for the plant. The secondary cell wall develops only when the cell has reached maximum size i.e., completes its growth because it is very much thick and rigid therefore it does not allow further growth. The secondary cell wall consists of cellulose, hemicelluloses, lignin, inorganic salts and waxes. Its cellulose microfibrils also show crisscross arrangement. Lignin cements and anchors cellulose microfibrils together and it is mainly responsible for rigidness. The secondary cell wall provides definite shape and mechanical support to the cell.

> **Science Titbits**
> Pectic acids are polymer of around 100 galacturonic acid molecules. These are very hydrophilic and form salts with Ca^{++} and Mg^{++} that are insoluble gels. These are major components of middle lamella but also found in primary cell walls

Middle lamella

Middle lamella is present between primary cell walls of adjacent cells which holds the cells together. It is composed of sticky, gel-like magnesium and calcium salts and pectin.

1.2.2 Plasma Membrane

Plasma membrane is the boundary of protoplasm. It is found in all living prokaryotic and eukaryotic cells. Plasma membrane is also called cell membrane or plasmalemma or cell surface membrane. It controls the passage of materials into and out of the cell.

Composition of plasma membrane

Chemically cell membrane consists of proteins 60-80%, lipids 20-40% and small quantity of carbohydrates.

> **Critical Thinking**
> Why the cell surface membrane is described as fluid mosaic?

Structure of plasma membrane

Fluid mosaic model of plasma membrane: The model proposes that the membrane is a phospholipids bilayer in which protein molecules are either partially or wholly embedded. The proteins are scattered throughout the membrane in an irregular pattern just like large ice bergs float in the sea. The pattern of distribution of proteins can vary from membrane to membrane and also vary on both surfaces of membrane. The membrane is about 7 nm thick.

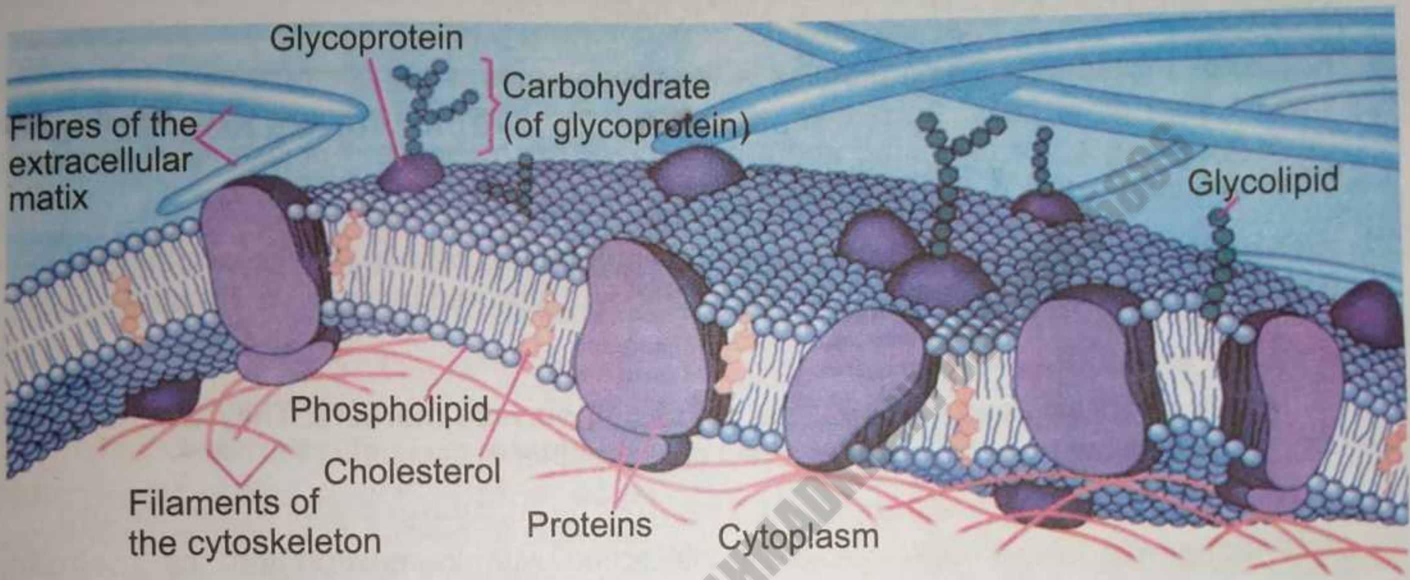


Fig. 1.12: Fluid mosaic model of plasma membrane

The lipid part of plasma membrane consists of two layers (bilayer) of phospholipids which are arranged in such a way that their hydrophobic ends face each other while hydrophilic ends are appeared on the surface. The steroids, cholesterols are wedged into the phospholipid bilayer at some intervals. The plasma membrane is asymmetrical i.e., their two surface and halves are not identical.

> **Science Titbits**
> The fluidity of membrane is dependent on its lipid components, including phospholipids, glycolipids and cholesterol.

In general most membrane proteins drift sideways in the fluid bilayer. The proteins within a membrane determine most of the functions. Carbohydrates are either attached to proteins (glycoproteins) or lipids (glycolipids) generally on the outer side of membrane. Filaments of the cytoskeleton are also present on the inner surface of the membrane. These support the plasma membrane.

Functions of plasma membrane lipids

The lipid part of plasma membrane controls the fluidity of the membrane. When the concentration of unsaturated fatty acid in phospholipids becomes greater, the bilayer becomes more fluid that makes cell membrane more flexible. The cholesterol helps to stabilize the lipid bilayer. It also restricts entry and exit of polar molecules and ions.

Functions of plasma membrane proteins

A great variety of proteins are found in plasma membrane which may act as transport channel or carrier, enzyme, receptors or as antigens.

1. **Channel proteins and Carrier proteins:** Certain plasma membrane proteins are involved in the passage of molecules through the membrane. Some of those have a channel through which a substance simply can move across the membrane, other are carriers that combine with a substance and help it to move across the membrane.

2. **Enzymes:** Some plasma membrane proteins have enzymatic functions e.g adenylate cyclase which converts ATP to cyclic AMP (cAMP).

3. **Receptor molecules:** Some proteins in the plasma membrane are receptors that receive signals from other cells. Each type of receptor has a specific shape. The binding of a molecule on receptor can bring about an intracellular response. For example, hormones circulate in the blood, but bind to specific target cells, with specific receptors.

4. **Antigens:** Some proteins are antigens which enable the cells to recognize other cells for example the foreign antigens can be recognized and attacked by immune system.

Roles of glycolipids and glycoproteins as cell surface markers

Mostly glycolipids and glycoproteins act as **cell surface markers.** They are involved in cell to cell recognition and sticking the correct cells together in tissues.

Regulation of cell's interaction with its environment by the plasma membrane

Plasma membrane regulates cell's interaction with its environment by controlling transport of material across the cell. Transport across plasma membrane occurs to: (1) obtain nutrient (2) excrete waste substances (3) secrete useful substances (4) generate ionic gradients essential for nervous and muscular activity (5) maintain a suitable pH and ionic concentration within the cell for enzyme activity.

1.3 CYTOPLASM AND ORGANELLES

The living matter of a cell is called protoplasm. In eukaryotic cells it can be divided into two parts i.e., cytoplasm and nucleus.

1.3.1 Cytoplasm

Cytoplasm is the region between nuclear membrane and plasma membrane. This is also a common component of both prokaryotic and eukaryotic cells. The major difference between the cytoplasm of these two kinds of cells is the presence or absence of cytoskeleton and membrane bounded organelles. These structures are absent in prokaryotic cells.

Physico-chemical nature of cytoplasm

It is about 90% water and forms a solution that contains all the fundamental biochemicals of life. Some of these are ions and small molecules in true solution, such as salts, sugars, amino acids, fatty acids, nucleotides, vitamins and dissolved gases. Others are large molecules, such as proteins, which form the colloidal solutions. The inner portion of cytoplasm i.e., towards the nucleus is less viscous and is called **cytosol** while the peripheral part of cytoplasm i.e., towards the plasma membrane is more viscous and is called **cytogel**. A circular streaming movement can also be observed in cytoplasm due to the contractile activity of microfilaments. This movement is called **cyclosis** which is responsible for distribution of cell contents in cytoplasm.

Metabolic and storage role of cytoplasm

The cytoplasm acts as a site of metabolism and storehouse of a cell. The metabolic pathways generally occur in the cytosol which includes **protein synthesis**, **glycolysis** etc. The cytogel is usually concerned with storage of useful compounds which are subsequently used in various cellular activities and waste compounds which are eliminated from the cell time to time.

1.3.2 Cell Organelles

In a eukaryotic cell, the cytoplasm contains highly organized discrete structures which are specific for various cellular functions are called **cell organelles**. The cell organelles are generally enclosed by the membrane except few such as ribosome.

The organelles in the cytoplasmic matrix of a cell are: endoplasmic reticulum, ribosomes, Golgi complex, lysosomes, peroxysomes, glyoxysomes, vacuoles, mitochondria, and chloroplasts etc.

Endoplasmic reticulum

An interconnecting network of cisternae (elongated closed sacs) which is generally extended from nuclear membrane to the plasma membrane throughout the cytoplasm of all eukaryotic cells is called **endoplasmic reticulum** (ER). There are two types of ER, rough ER and smooth ER. Most cells contain both types of ER. However, some cells (skeletal muscle cells) have smooth ER more, where these are called **sarcoplasmic reticulum**.

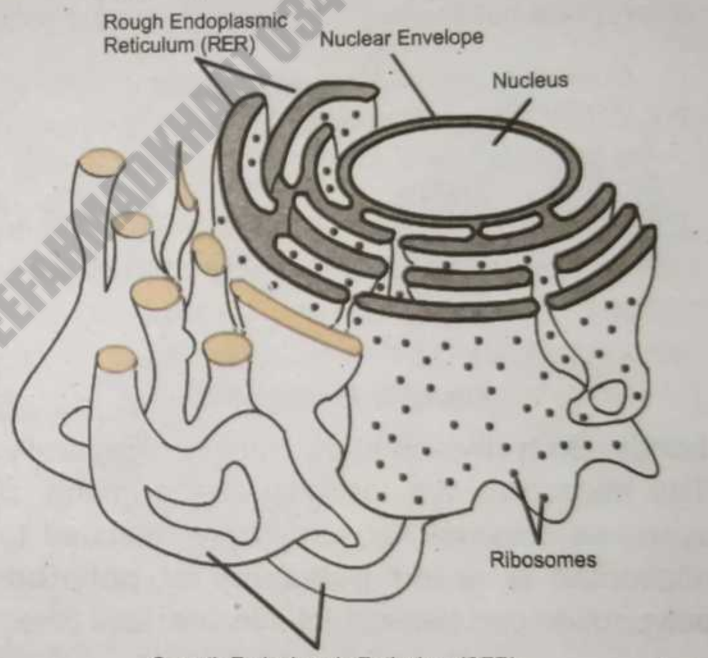


Fig.1.13: Endoplasmic reticulum

Rough ER has ribosomes attached to the sides facing the cytoplasm and has rough appearance under electron microscope. Rough ER is mainly concerned with the events of protein synthesis (translation) due to the association of ribosomes; however, their presence in the cell also provides a mechanical support to the cell.

Smooth ER is continuous with the RER. Since, ribosomes are not attached to it, therefore, it has smooth appearance under electron microscope. The smooth ER functions in various metabolic processes, e.g., metabolism of carbohydrates. The detoxification of drugs and poison especially in the liver cells and synthesis of lipids including oils, phospholipids and steroid take place in smooth ER. It also stores calcium ions, when released calcium ions trigger contraction of the muscle. Smooth ER also transports various cellular products within the cell or out of the cell e.g., proteins from rough ER are also transported to the Golgi complex through smooth ER. Like rough ER, the presence smooth ER in the cell also provides a mechanical support to the cell.

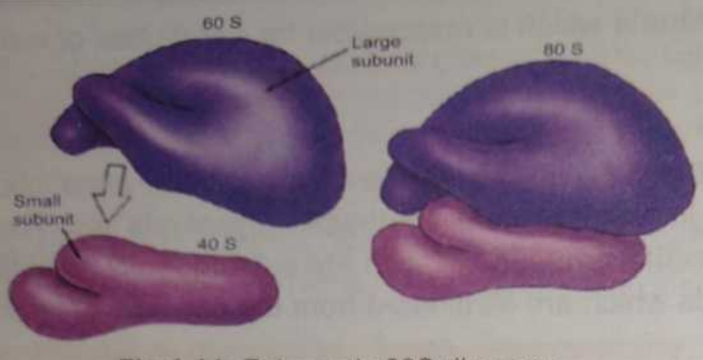


Fig.1.14: Eukaryotic 80S ribosome

Ribosomes

Ribosomes were first observed using electron microscope as dense granules. Ribosomes are roughly spherical, granular, non membranous bodies found in both eukaryotic as well as prokaryotic cells. However, eukaryotic ribosomes are lager and characterized as 80S ribosomes while the prokaryotic ribosomes are slightly smaller and are characterized as 70S ribosomes. They can be seen only under the electron microscope. They are made of almost an equal amount of RNA and protein so they are **ribonucleoprotein**. Ribosomes are formed in the nucleolus. Then these are transported to the cytoplasm through the nuclear pore.

In a eukaryotic cell, the ribosomes may be found as attached with RER or freely dispersed in the cytoplasm. Ribosomes are also found in matrix of mitochondria and stroma of chloroplast but these ribosomes are prokaryotic (70S) in nature.

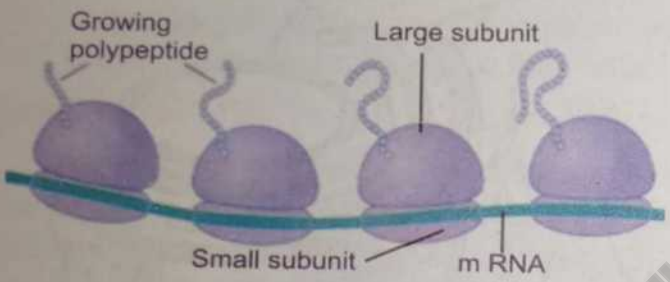


Fig.1.15: Polysome

The eukaryotic ribosomes are composed of two subunits (particles) of different sizes. The larger one is 60S particles and the smaller one is 40S particles. The two subunits on attachment form 80S particles. The attachment is controlled by presence of magnesium ions concentration or forming salt bonds between phosphate group of RNA and amino group of amino acid or both by magnesium ions and salt bonds. Both ribosomal subunits are generally attached together at the time of their function. The ribosomes are involved in the events of protein synthesis. Sometimes, during protein synthesis, several ribosomes are attached to one mRNA molecule. Such a chain of many ribosomes is called **polysome** or **polyribosomes**. In this way several copies of same polypeptide can be produced in very less time.

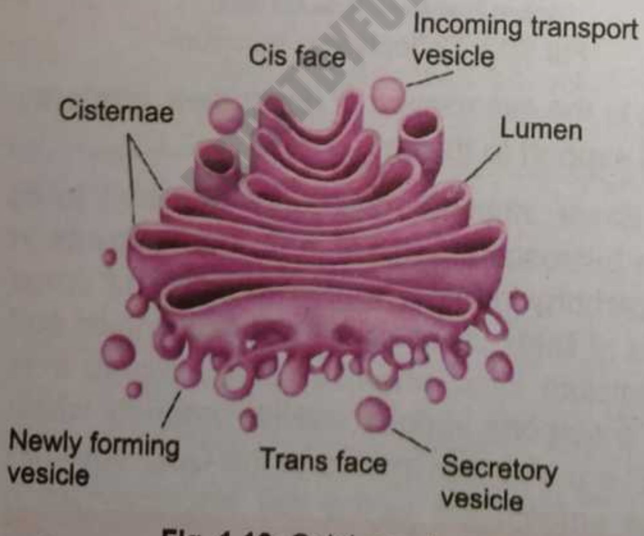


Fig. 1.16: Golgi complex

Golgi complex

It is found in all eukaryotic cells. It was discovered by Italian biologist **Camillo Golgi** in 1898.

Golgi complex consists of a stack of flattened, membrane bound sacs called **cisternae**, together with system of associated vesicles called **Golgi vesicles**. It is a complex system of interconnected tubules formed around the central stack. At one end of the stack a new cisternae are constantly being formed by the fusion of vesicles from the smooth ER. This outer or **forming face** (cis face) is convex, while the inner end is concave and is called **maturing face** (trans face) where the cisternae breakup into vesicles again.

The most important function of Golgi complex is the processing of cell secretions. Therefore these organelles are abundant in secretory cells. The cell secretions mainly consist of proteins. Golgi complex collects these proteins from RER through SER, modifies them to perform specific function and then exports these modified products in the form of vesicle. Certain organelles, such as lysosomes, peroxisomes and glyoxysomes also originate from Golgi complex. Golgi complex is also involved in the formation of conjugated molecules like glycoprotein, lipoprotein etc. In plant cell during cell division, Golgi complex also gives rise vesicles which contain cell wall synthesizing materials. At cytokinesis, these Golgi vesicles are arranged on the cell equator, fuse together and form a structure, called **phragmoplast**. Later on new cell wall is derived from this structure.

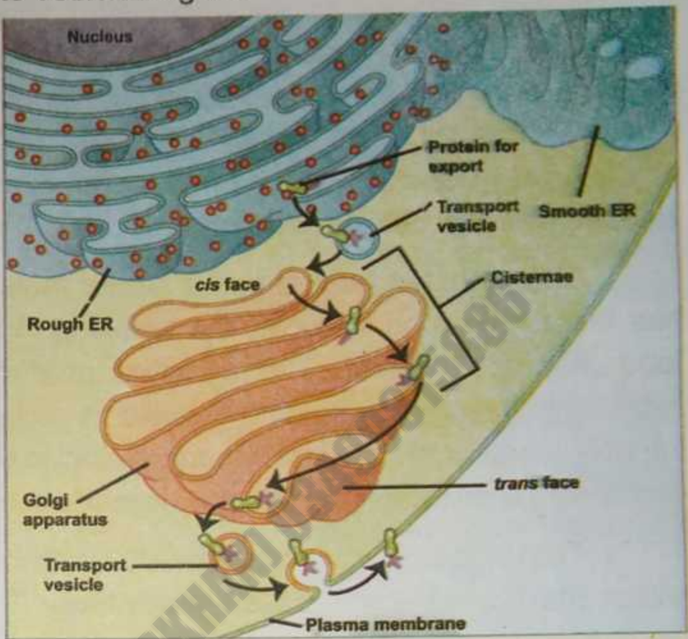


Fig. 1.17: Role of Golgi complex in a glandular cell

Lysosomes

Lyso means splitting and *soma* means body. These are single membranous, spherical vesicles. They contain digestive or hydrolytic enzymes. The lysosomal enzymes are made by the RER and then are transported to Golgi complex through SER. After modification, these enzymes are released from the *trans* face Golgi complex in the form of vesicles. Such vesicles are called lysosomes. The newly formed lysosomes before the start of their functions are usually called **primary lysosomes**. In plants and fungi, certain vacuoles carryout enzymatic hydrolysis, a function shared by lysosomes in animal cells.

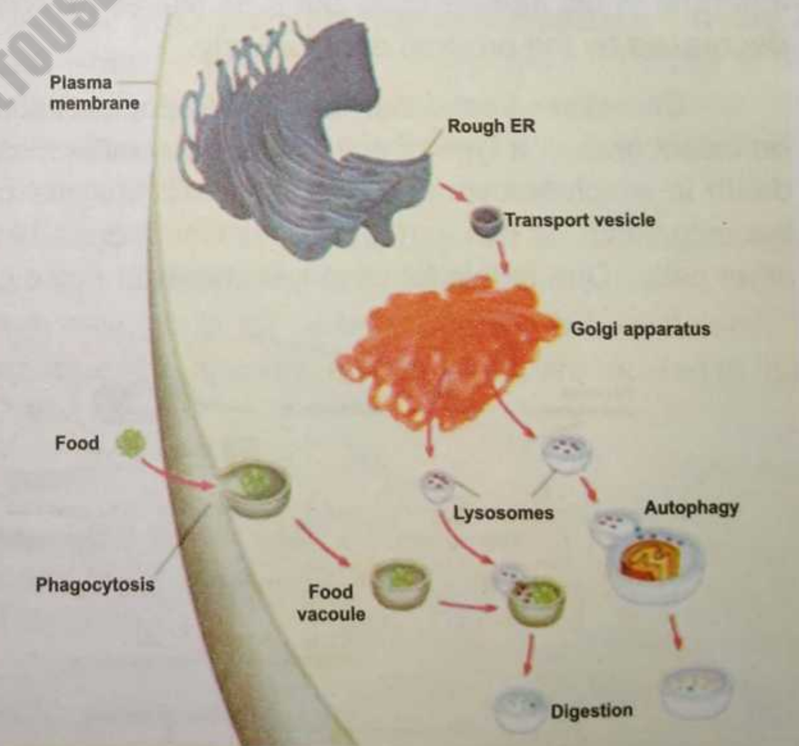


Fig. 1.18: Formation and functions of Lysosomes

Lysosomes contain about 40 different digestive enzymes. These enzymes can breakdown every major macromolecule of the cell. The contents of the **lysosome** are acidic. In order to perform its function the lysosomes fuses with membrane bound vesicle that arises from any of these pathways **endocytosis**, **phagocytosis** or **autophagocytosis.** These vesicles are referred to as endosomes, phagosomes and autophagosomes respectively. These endosomes fuses with lysosomes (primary lysosomes) and forms **secondary lysosomes**. The bio-molecules are further broken down into smaller forms like amino acids, monosaccharides, nucleotides and fatty acids which are then recycled in the cell. Major functions of lysosomes include **intracellular digestion**, **autophagy**, **autolysis** and sometimes **release of extra cellular enzymes**.

The ingested food of cell is stored in vesicles, called **food vacuoles**. Once a lysosome has fused with food vacuole, the resulting structure is called **secondary lysosome** in which food begins to digest. The digested products are absorbed by the cytoplasm while the remaining wastes containing vesicle is now called **contractile vacuole**. Later on these vacuoles fuse with cell membrane (exocytosis) to eliminate undigested wastes. This whole process is known as **intracellular digestion**.

The process by which unwanted structures within the cell are engulfed and digested within the lysosomes is called **autophagy**. This is self-eating process of a cell in which a lysosome begins to digest cell's own organelles. Such lysosomes are also called **autophagosomes**. This process either takes place in starvation period in order to obtain energy or it occurs in routine in order to control number of specific organelle. For example: If someone starts to perform heavy muscular exercise, the number of mitochondria begins to increase in his muscle cells, but if he leaves exercise, the number of mitochondria are again decreased by the process of autophagy.

Sometimes, especially during developmental phase, when a particular cell is required to be disintegrated, a type of cell death is committed, called **autolysis.** This is a programmed cell death in which lysosomes burst and their enzyme contents are quickly dispersed throughout the cytoplasm. In this way the cell is disintegrated into fragments which are phagocytosed by other cells. Due to this function lysosomes are also called **suicidal bags**.

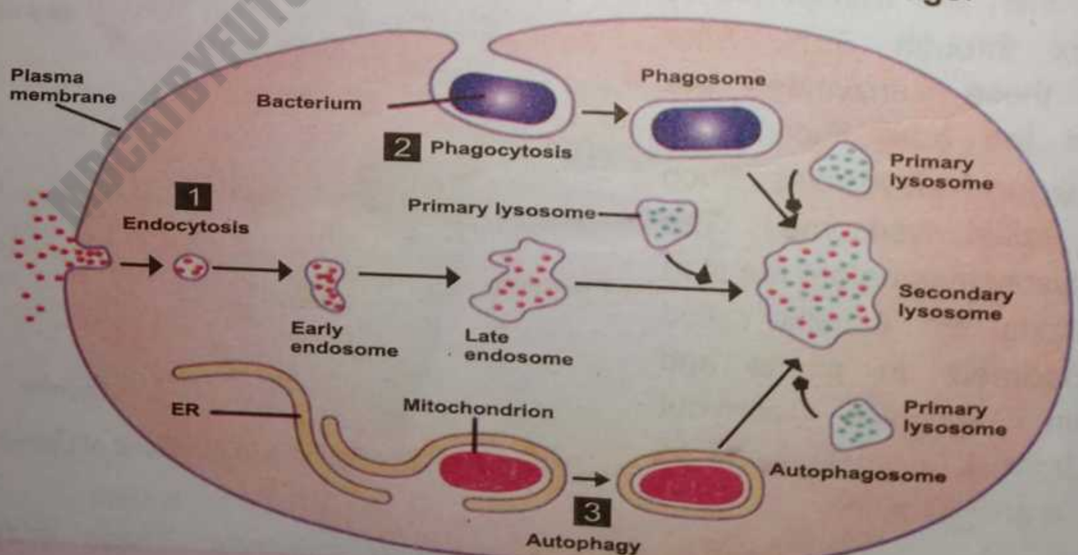


Fig. 1.19: Functions of Lysosomes

Since, lysosomes contain various digestive enzymes, if a particular lysosomal enzyme is missing in an individual, the digestion of that particular substance (for which enzyme was specific) will be affected. As a result, the substance begins to accumulate in the cell and cause different problems. Such complications which are caused by the accumulation of various substances in the cell due to lack of certain lysosomal enzymes are called **lysosomal storage diseases**. These diseases are hereditary and congenital therefore run in particular families and exist by birth in an individual. Most of these diseases are fatal in early childhood. About more than 20 such diseases have been discovered so far. One of the common examples is **Tay-Sachs disease** in which a lipid digesting enzyme is missing or inactive and the brain becomes impaired by an accumulation of lipids in the cell.

Peroxisomes and Glyoxysomes

Peroxisomes and glyoxysomes are collectively called **microbodies.** These are similar to lysosomes in the sense that they are single membranous, vesicular structures. They contain enzymes (although different than lysosome) and originate from Golgi complex but they are smaller than lysosome.

Fig. 1.20: Peroxisomes

Peroxisomes contain some oxidative enzymes like peroxidases, catalases and glycolic acid oxidases. They are abundant in liver cells where they are specifically involved in the formation and decomposition of hydrogen peroxide so they are named **peroxisomes**. They are mainly concerned with the detoxification of alcohol. In this activity alcohol is oxidized into hydrogen peroxide (H_2O_2) with the help of **peroxidase** enzyme. Hydrogen peroxide is itself a toxic molecule, which is immediately broken down to water and oxygen by another enzyme called **catalase**. In plant cell, peroxisomes are involved in **photorespiration**. A step of photorespiration takes place in peroxisomes in which **glycolate** is converted into **glycine** with the help of an enzyme called **glycolic acid oxidase**.

Glyoxysomes are found only at seedling stage in oil seed plants. These organelles have a number of enzymes specific for plant lipid metabolism that are not found in animal cells. The germinating seedlings convert stored fatty acids to carbohydrates. This is achieved through a metabolic pathway called **glyoxylate cycle**, the enzymes of which are located in the glyoxysomes.

Vacuoles

Vacuoles are large vesicles originate from the endoplasmic reticulum and Golgi complex and plasma membrane. Vacuoles perform a variety of functions in different kinds of cells. In animal cells **food vacuoles** are formed by phagocytosis. Many freshwater protists have **contractile vacuoles** that pump excess water out of the cell, thereby maintaining a suitable concentration of ions and molecules inside the cell.

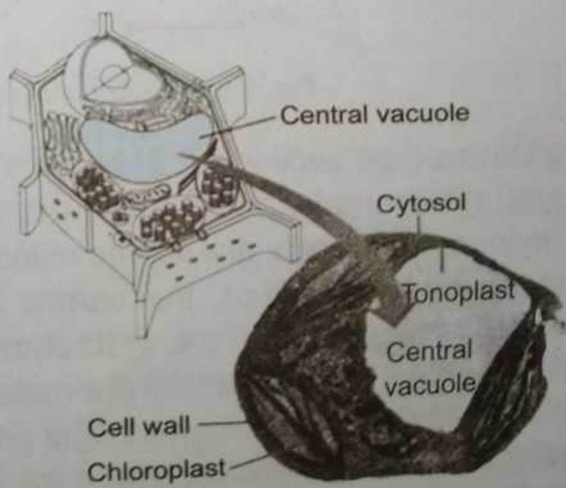


Fig. 1.21: Vacuole of a mature plant cell

In young plant cells, many small vacuoles are present which can hold reserves of important organic compounds. These vacuoles may also help in protection of plant against herbivores by storing compounds that are poisonous or unpleasant to animals. Mature plant cells generally contain a large **central vacuole** develops by the joining of smaller vacuole. The solution inside the central vacuole, called **cell sap**, is plant cell's main reservoir of inorganic ions, including potassium and chloride. The central vacuole plays a major role in mechanical support by maintaining turgor and also acts a storehouse of the cell. The membrane separating the vacuole from cytoplasm is called **tonoplast**.

Mitochondria

Mitochondria (singular: *mitochondrion*) are present in all eukaryotic cells. Some cells have a single large mitochondrion, but more often a cell has hundreds or even thousands of mitochondria; the number correlates with the cell's level of metabolic activity. For example, cells that move or contract have proportionally more mitochondria per volume than less active cells. Mitochondria are capable to divide themselves (self-replicating) in order to increase their number. They divide by fission.

Mitochondria are cylindrical or rod shaped structures. They are enclosed by double membrane, the outer **membrane** and the **inner membrane**. The outer membrane is smooth and somewhat like a sieve due to presence of **porins**. These are special proteins responsible for the transport of molecules across the membrane. Porins allow free passage of various molecules into the inter-membrane space. The inner membrane is selectively permeable and folded inwards. The folds are called **cristae** which serve to increase the surface area. The inner surface of cristae has granular structures called **F0-F1 particles**. These particles are actually **ATP synthase** (see section 4.2.7) enzymes. In addition, several other complexes are also found in inner mitochondrial membrane, which serve as electron carriers in electron transport chain. The inner membrane divides the mitochondrion into two internal compartments. The first is the **intermembrane space**, the narrow region between the inner and outer membranes. The second compartment, the **mitochondrial matrix**, is enclosed by the inner membrane. Mitochondrial matrix is a jelly like material that contains a small circular DNA, all kinds of RNA, ribosomes (70S) and enzymes. The presence of these components indicates that mitochondria have their own genetic system. It means, the protein, which are required by mitochondria are synthesized by their own metabolic machinery.

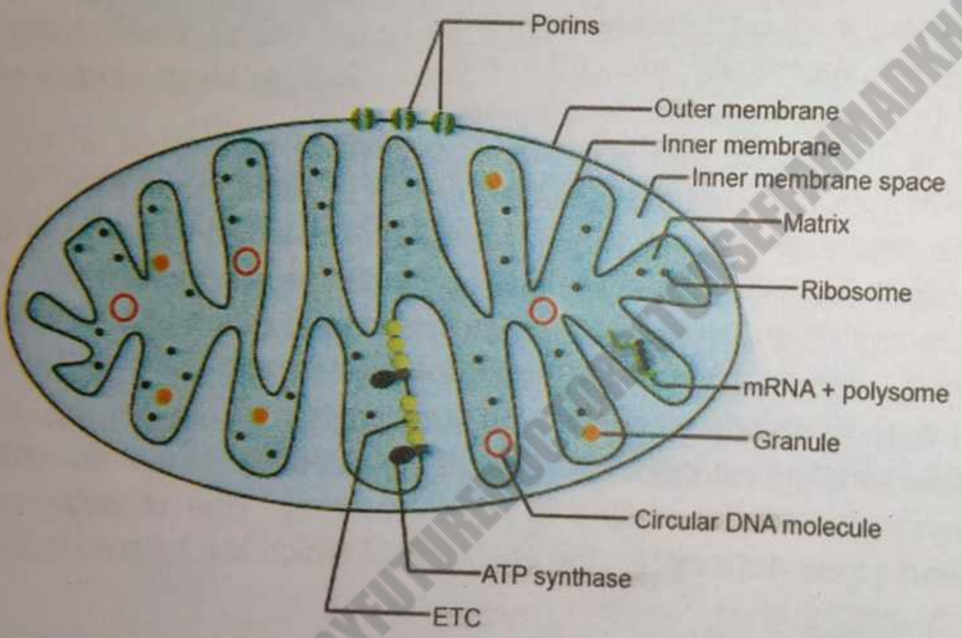


Fig. 1.22: Mitochondrion structure

Mitochondria are the sites of **cellular respiration**, the metabolic process that uses oxygen to generate ATP by extracting energy from sugars, fats, and other organic compounds. Enzymes in the matrix catalyze some of the steps of cellular respiration like Krebs cycle. Other proteins that function in ATP generation through electron transport chain are found into the inner membrane.

Mitochondria (extra reading material)

Mitochondria and chloroplasts display similarities with bacteria like both are self-replicating organelles, both have their own genetic system and metabolic machinery i.e., both has small circular DNA, all kinds of RNA and ribosomes (70S). An interesting fact about them is that they are capable to survive outside the cell in artificial medium if carefully fractionated. Based upon these observations evolutionists believe that they were independent organism and the early ancestor of eukaryotic cells engulfed them. Eventually, the engulfed cells formed a relationship with the host cell in which they were enclosed, becoming an *endosymbiont* (a cell living within another cell). Therefore, they are supposed as organisms within organism.Mitochondria divide and in this way their number doubles before cell division. Lysosomes regulate the number of mitochondria. Excess of mitochondria are digested by Lysosomes. Because mitochondria are contained within ova (egg cells) but not within the heads of the sperm cells, all the mitochondria in a fertilized egg are derived from mother.

Plastids

Plastids are found in plant and algal cells, and they are necessary for essential life processes, like photosynthesis and food storage. On the basis of presence or absence and type of pigments, and the stage of development, plastids have been classified into proplastids, leucoplasts, chromoplasts and chloroplasts.

Proplastids are young, immature and developing plastids. They are self-replicating organelles. They divide and re-divide in meristematic cells and are distributed to different cell types. Depending upon the structures in which they found, the intracellular factors and on exposure to light, they may develop into leucoplast (colourless plastids) or chloroplast (green plastids).

Leucoplasts are found in parenchyma cells of root, stem and seeds. They act as storage organelles. Based on the kind of substance they store they are further classified into **amyloplasts** (store starch), **elaioplast** (store lipids) and **proteinoplast** (store protein). **Chromoplasts** synthesize different coloured pigments other than green. Therefore, they are found in coloured parts of plant such as flower petals and fruit wall where they attract insects and thus help in pollination. **Chloroplasts** are found in green parts of the plants and act as site of photosynthesis.

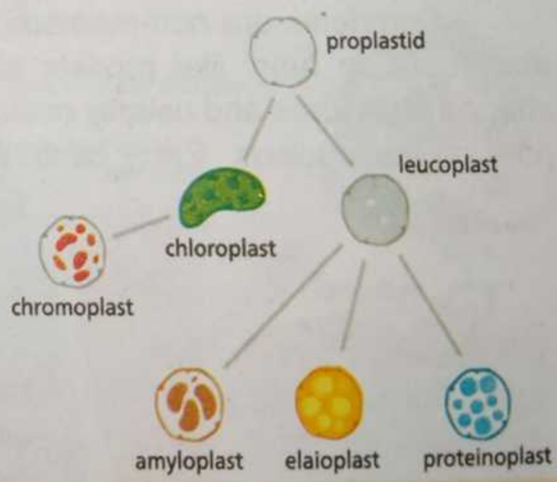


Fig. 1.23: Types of plastids

Structure and functions of chloroplast

Chloroplast is a discoid structure which consists of three parts i.e., envelope, stroma and thylakoids. Each chloroplast is bounded by a smooth double membrane (envelope). The outer membrane like mitochondria contains porins and therefore freely permeable to small molecules. The inner membrane is semipermeable and rich in protein. Between the outer and inner membrane there is intermembrane space.

The ground mass of chloroplast is called **stroma**. It is the colourless proteinaceous substance which like mitochondrial matrix also contains a small circular DNA, all kinds of RNA, ribosomes (70S) and various enzymes. The stroma contains a system of chlorophyll bearing double membrane, flattened sac-like structures called **thylakoids**. There are two types of thylakoids: smaller thylakoids and the larger thylakoids. **Smaller thylakoids** are disc like sacs which are piled over one another like stack of coins. Each stack of smaller thylakoids is called **granum** (plural: *grana*). Each granum consists of 25-50 thylakoids and there are about 40 - 60 grana found in each chloroplast. Photosynthetic pigments are also found in the membranes of smaller thylakoids. **Larger thylakoids** connect the grana with each other and are also called **intergrana**. These membranes are colourless as they do not have pigments.

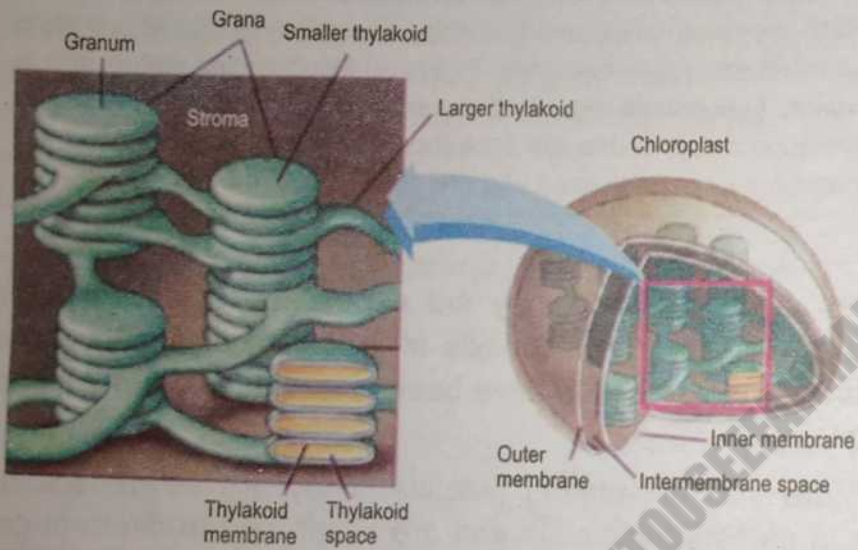


Fig. 1.24: Chloroplast

Chloroplast is the site of photosynthesis in a plant cell. The first phase of photosynthesis is light dependent reaction in which sunlight is captured and transformed into ATP. This phase takes place in grana region of chloroplast. The second phase of photosynthesis is light independent reaction (dark reaction) in which CO_2 is reduced to make carbohydrates. The enzymes for this activity are found in stroma region of chloroplast.

Centrioles

Centrioles are non-membranous cell organelles found mainly in animal cells. They are also found in fungi like protists such as slime molds and water molds. Centrioles are rod shaped structures and usually occur in pairs. These occur at right angle to each other near one pole of the nucleus. Each centriole is composed of nine triplets of microtubule which are circularly arranged around a central axis.

Fig. 1.25: Centrioles

Just before the cell division, the pair of centrioles duplicates and becomes two pairs which later on migrate to the opposite sides of the nucleus. Both centriole pairs give rise microtubules (spindle fibres) during cell division. The whole structure of spindle fibres is known as **mitotic apparatus** which helps in the distribution of chromosomes between the daughter cells during cell division. In addition, centrioles also give rise to **basal bodies** of cilia and flagella.

Cytoskeleton

The term cytoskeleton is generally applied to three different kinds of fibrous structures which are distributed from nucleus to the plasma membrane throughout the cytoplasm of a eukaryotic cell. These fibres include: microfilaments, microtubules, and intermediate filaments.

Microfilaments are also known as **actin filaments**. These are extremely thin contractile fibres about 7 nm in diameter. It consists of four twisted chains. Two chains of **F-actin** and two chains of **tropomyosin** with triplet **troponin** at intervals. They form myofibrils in muscles, involved in muscle contraction and relaxation. They perform **cyclosis** as well.

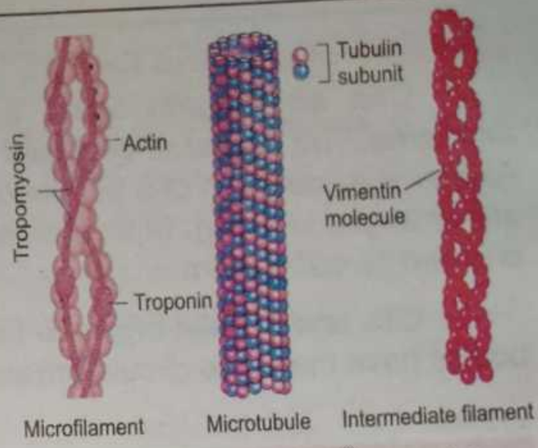


Fig. 1.26: Three types of cytoskeleton

Microtubules are small hollow cylinders about 25nm in diameter and 0.2-25μm in length. They are composed of a protein, the **tubulin**. Each tubulin is a dimer. In plant cells at the time of cell division freely dispersed microtubules organize themselves to form spindle fibres. In animal cells, the microtubules are involved in the formation of centrioles, cilia, flagella and basal body.

Science Titbits

In muscle cells the microfilaments are called myofilaments which are of two different types i.e., thin and thick myofilaments. The thin filaments are actin filaments while the thick filaments (16μm thick) are composed of another protein, the myosin; therefore, they are also called myosin filaments.

Intermediate filaments are 8 to 10 nm in diameter i.e., intermediate in size between actin filaments and microtubules, this is why they are called intermediate filaments. The basic protein subunit of the filament is **vimentin**. The vimentin subunits also form chains by linear arrangement. Each intermediate filament is composed of three chains of vimentin which are twisted about each other in such a way that no hollow space is left between them. They usually form a network in the cytoplasm which provide a mechanical support to nuclear envelope and plasma membrane.

Cilia and Flagella

Cilia and flagella are hair like projection on the surface of the cells. The internal structure of both cilia and flagella is same but they may differ in size, number and pattern of movement. The flagella are longer, few in number, exhibit undulating motion and beat independently. Whereas, cilia are numerous and relatively short and beat perpendicularly in metachronous (cilia of a row beating one after the other) or in synchronous rhythm (all cilia of a row beating simultaneously).

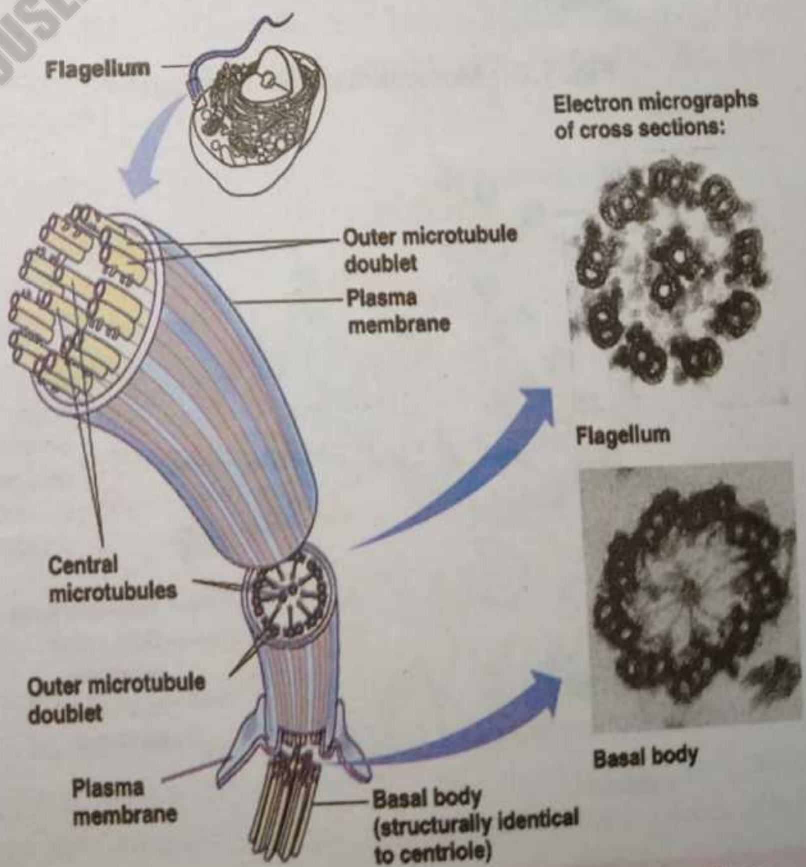


Fig. 1.27: Structure of a eukaryotic flagellum or cilium

Structure of cilia and flagella

Cilia and flagella share a common ultrastructure. Each consists of a longitudinal **axoneme.** The axoneme enclosed is in a spiral sheath of cytoplasm and a plasma membrane. Axoneme is made up of a bundle of eleven longitudinal microtubules. Nine peripheral doublets are arranged in a ring. In the centre of the ring are two single microtubules. This arrangement is called "9 + 2" pattern.

Cilia and flagella originate from their **basal bodies** embedded in the cytoplasm. Basal bodies have the same circular arrangement of microtubule triplets as centrioles.

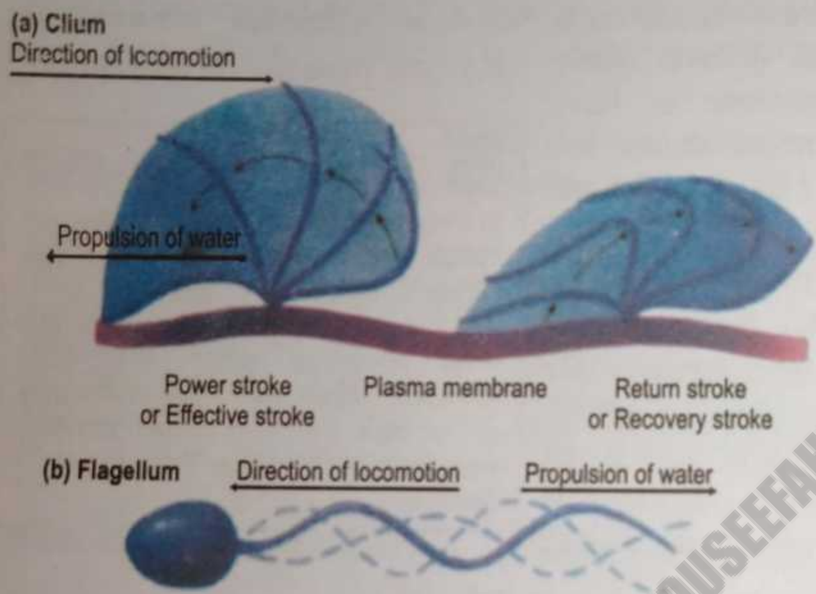


Fig. 1.28: Movement of cilia and flagella

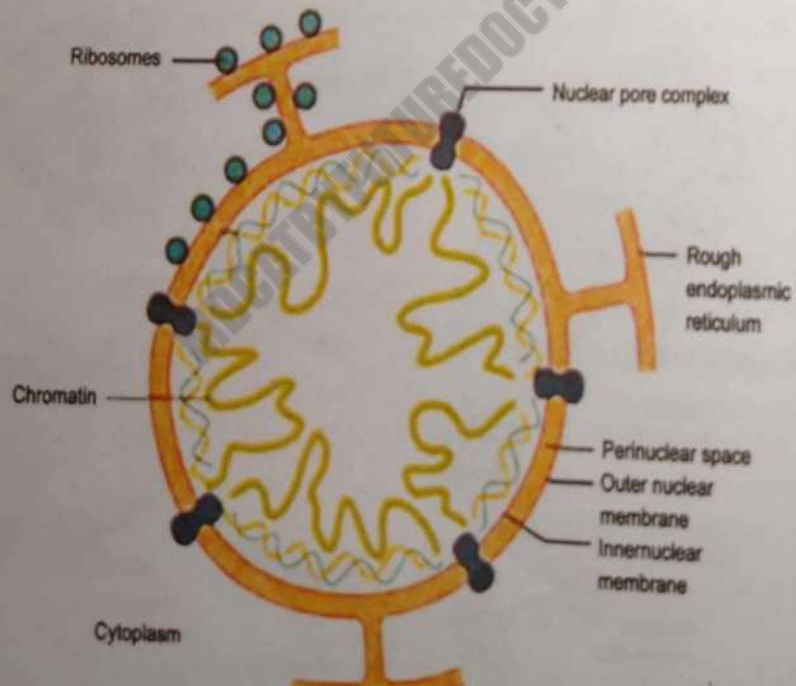


Fig. 1.29: Nucleus

Mechanism of movement of cilia and flagella

Movement of cilia: The movement of cilia is due to sliding of double fibrils in two groups one after the other. Five out of nine double fibrils contract simultaneously. As a result cilium bends or shortens. It is called **effective stroke**. Four out of nine double fibrils contract and cilium becomes straight. It is called **recovery stroke**.

Movement of flagella: A flagellum causes movement by the passage of rapid successive waves of bending from the attached to the free end, as it can be seen in flagellar movement of human sperms, which propel them forward within the fluid medium of the female reproductive tract.

1.3.3 Nucleus

Nucleus is the most prominent and the most important part of a cell. In animal cells it is found in the centre (with exception of muscle fibre cells) but in adult plant cell it is slightly away from the centre due to the presence of a large central vacuole. A typical eukaryotic nucleus consists of nuclear envelope, nucleoplasm, nucleoli and chromatin.

Nuclear envelope

Nuclear envelope (also called nuclear membrane) is a double membrane covering which makes the boundary of nucleus. Both membranes of nuclear envelope are separated by a fluid-filled **perinuclear space**. The membranes are composed of lipid bilayer and proteins. The outer membrane of nuclear envelope is covered with ribosomes and is connected with the membranes of ER. There are numerous pores in nuclear envelope called **nuclear pores** which are composed of a specialized transport protein called **nucleoporin**.

At the point of nuclear pore both the membranes are interconnected. These pores regulate the nucleo-cytoplasmic exchange of materials. This exchange includes RNA and ribosomal proteins moving from nucleus to the cytoplasm and proteins (such as DNA polymerase), carbohydrates, signalling and lipids moving into the nucleus. Although smaller molecules simply diffuse through the pores, larger molecules may be recognized by specific signal sequences and then be diffused with the help of nucleoporin into or out of the nucleus.

> **Science Titbits**
> Sieve tube cells in plants and red blood cells in human are exceptional living cells that do not possess nucleus. On the other hand some cells have more than one nuclei i.e., binucleate or dikaryotic cells (cells having two nuclei) and multinucleate or coenocytic cells (cells having many nuclei).

Nucleoplasm

Nucleoplasm is the transparent semifluid ground substance formed of a mixture of proteins, enzymes (DNA and RNA polymerase), free nucleotide and some metal ions (Mg) for the synthesis of DNA and RNAs. It also contains histone and non-histone protein. So the nucleoplasm is slightly different from cytoplasm.

Nucleolus

Nucleolus is a non-membrane bound structure in the nucleoplasm. A cell may have one or more **nucleoli**. Nucleolus appears during interphase and disappears during cell division. A nucleolus consists of a peripheral granular area (contains ribosomal subunits) and a central fibriler area (contains rRNA and rDNA). Therefore, nucleolus is involved in the construction of ribosomes.

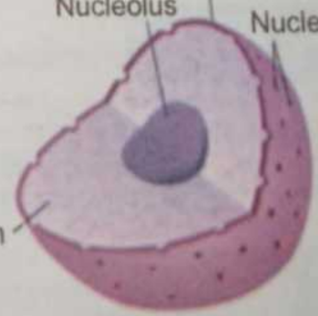


Fig. 1.30: Nucleolus

Chromatin and Chromosomes

Chromatin is a network of thin thread like structures made up of DNA and proteins. During cell division chromatin fibres begin to condense and coil up into separate structures called **chromosomes**, which are thick enough to be seen with a light microscope. A typical chromosome consists of two strands called **chromatids** which are attached with each other at a point known as **centromere**. The centromere lies within a thinner segment of the chromosome called **primary constriction**.

The **centromere** is a constriction functionally related to the movement of chromosomes during cell division. Each centromere has a complex of **kinetochores** protein present on the opposite sides of the constriction. Each kinetochore forms the site of attachment for a single microtubule during cell division. Some chromosomes may have another point of union along the length of chromatids, called **secondary constriction** or **nucleolar organizer**. It gives rise to nucleoli during interphase.

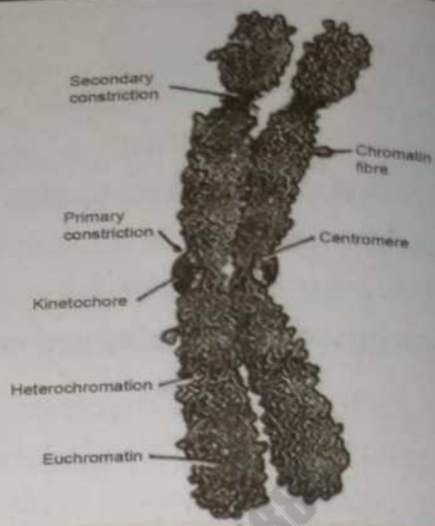


Fig. 1.31: A pair of chromosome

1.4 PROKARYOTIC AND EUKARYOTIC CELLS

Two kinds of structurally different cells have been evolved overtime. Prokaryotic cells include archaea, bacteria and cyanobacteria whereas all other forms of life are composed of eukaryotic cells. A prokaryotic cell lacks definite membrane bounded nucleus and other organelles. Its DNA is dispersed in cytoplasm. On the other hand, a eukaryotic cell contains a nucleus, endoplasmic reticulum, Golgi complex, mitochondrion, lysosomes, nucleolus, chloroplast, cytoskeleton, 80S ribosomes (larger), and flagella or cilia which are made up of microtubules. All these structures are missing in prokaryotic cells. Furthermore, the prokaryotic and eukaryotic flagella have different structure and composition. The prokaryotic cells do not divide by typical mitosis or meiosis like eukaryotic cells, instead their cell division is very simple and is called binary fission. A detailed account on prokaryotic cells is given in chapter 6 of this book.

Skills: Analyzing, Interpreting and Communication

1. Compare and contrast the structure and function of mitochondria with those of chloroplasts.
2. Compare in tabular form, the functions of organelles with the processes occurring in animals and plants.
3. List the structure and molecules. which can cross the nuclear envelope.

Activity

1. Measure the size of *Paramecium*, pollen grains, hair etc., by micrometry.
2. Prepare and examine the slides of animal and plant cells using differential staining.

Exercise

MCQs

1. Select the correct answer

(i) Which of the following is the major advantage of using a light microscope instead of an electron microscope?

(A) superior resolving power
(B) constant depth of focus
(C) observation of living matter
(D) use of very thin sections

(ii) Some cellular organelles are bound by a single membrane, while other organelles have two membranes (envelopes) around them. Which one of the following is correct?

	Single membrane	Double membranes
(A)	peroxysomes, lysosome	nucleus, chloroplast
(B)	chloroplast, lysosome	nucleus, peroxysomes
(C)	nucleus, chloroplast	lysosome, peroxysomes
(D)	nucleus, lysosome	chloroplast, peroxysomes

(iii) Which of the following cell structures contains the highest concentration of RNA?
(A) centriole (B) lysosome (C) chromosome (D) nucleolus

(iv) A tadpole's tail is gradually broken down during metamorphosis into an adult frog. Which organelle increases in number in the cells of the tail at this time?
(A) centriole (B) endoplasmic reticulum
(C) Golgi complex (D) lysosomes

(v) Which of the following organelles always contains DNA?
(A) centriole (B) Golgi complex (C) lysosome (D) mitochondria

(vi) Which distinguishes a prokaryotic cell from a eukaryotic cell?
(A) prokaryotic cell have a cell wall and a nucleus
(B) prokaryotic cells have no membrane bound organelles
(C) prokaryotic cells have a centriole
(D) prokaryotic cells have no ribosomes

(vii) The elasticity of the plasma membrane demonstrates that it is made up in part of
(A) lipids (B) nucleic acids (C) carbohydrates (D) proteins

(viii) Filaments present in flagella and cilia are
(A) microfibrils (B) microtubules (C) microfilaments (D) microvilli

(ix) Which of the following structure is found in all living organisms:
(A) cell membrane (B) nucleus (C) lysosome (D) vacuole

(x) The cell wall of plant cell is different from that of prokaryotes in:
(A) both structure and chemical composition (B) structure only
(C) chemical composition only (D) number of layers only

(xi) Which of the following are present in prokaryotic cells:
(A) chloroplast, DNA, nuclear envelope
(B) chromosomes, mitochondria, nuclear envelope
(C) cytoplasm, DNA, mitochondria
(D) cytoplasm, DNA, ribosome

(xii) Which of the following is present in all eukaryotic cells:
(A) cell wall (B) diploid nucleus
(C) flagellum (D) membrane bounded organelles

(xiii) Which of the following would be more prominent in a secretory cell than non-secretory cell:

(A) lysosome (B) Golgi complex (C) mitochondrion (D) ribosome

(xiv) When a glycoprotein is being synthesized for secretion from a cell, which route is it most likely to take?

(A) Golgi complex → RER→ SER (B) RER→ Golgi complex → SER

(C) RER→ SER→ Golgi complex (D) SER→ Golgi complex → RER

(xv) Which one of the following is responsible for cyclosis?

(A) microtubule (B) microfilament

(C) intermediate filament (D) none of them

Short Questions

2. Name three organelles revealed by an electron microscope.
3. Why cell wall is not present in animal cells? due to their locomotor mode of life
4. What holds the ribosomes together in a polysome?
5. What would happen if there are no lysosomes in human cells?
6. Why lysosomes are called suicidal bags?
7. Name the structures and organelles which are common in plant cell, animal cell and a prokarytic cell.
8. How is a chloroplast similar to a bacterium?
9. Name the organelles of eukaryotic cell and write their specific functions.
10. What are prokaryotic cells? List the structures missing in prokaryotic cells.
11. Compare microfilaments and microtubules.
12. Which organelles are single membrane bound, double membrane bound and lacking any membrane?
13. How cytoskeletons are important to eukaryotic cells?
14. Compare the chemical composition of nucleoplasm with that of cytoplasm.
15. Explain that nucleoli are the areas where ribosomes are assembled.
16. Draw a labelled diagram of a section through:
    (a) mitochondrion (b) chloroplast
17. Write the difference between:
    (a) resolution and magnification
    (b) cytoplasm of eukaryotic and prokaryotic cell
    (c) rough ER and smooth ER
    (d) chromatin and chromosome

Extensive Questions

18. Describe the principles and uses/applications of the apparatus used in the techniques of:
    (a) Fractionation (b) Microdissection (c) Tissue culture
    (d) Differential staining (e) Centrifugation (f) Chromatography
    (g) Electrophoresis (h) Spectrophotometry
19. What are the locations, chemical compositions and significance of the following in a plant cell wall? (a) Primary cell wall (b) Secondary cell wall (c) Middle lamella.
20. Explain the (a) Chemical composition of plasma membrane (b) Role of plasma membrane in regulating cell's interactions with environment.
21. Describe the lipid composition and variety of proteins of the plasma membrane.
22. What are the functions of the plasma membrane proteins?
23. What is the role of glycolipids and glycoproteins as the cell surface markers?
24. What is the chemical nature of cytoplasm? Explain the metabolic roles of cytoplasm.
25. Describe the structures and functions of smooth and rough endoplasmic reticulum
26. Explain the structure, chemical composition and function of ribosomes.
27. Explain the structure, and functions of Golgi complex.
28. Explain the structure, and functions of the peroxysomes and glyoxisomes in animal and plant cells.
29. Explain the formation, structure and functions of the lysosomes.
30. What are the storage diseases? Explain with reference to the malfunctioning of lysosomes.
31. Describe the external and internal structure of mitochondrion? What are the functions of these structures present in mitochondria?
32. Describe the external and internal structure of chloroplast? What are the functions of these structures present in chloroplast?
33. Compare and contrast the structure and functions of mitochondria and chloroplasts.
34. What are centrioles? Describe the structure, composition and functions of centriole.
35. What are cytoskeletons? Describe the types, structure, composition and functions of cytoskeleton.
36. Describe the structure of cilia and flagella. Explain the mechanism of movement of cilia and flagella.
37. What is nuclear envelope? Describe the chemical composition and structure of nuclear envelope.
38. What are chromosomes? Describe the structure, chemical composition and function of chromosome.
39. What is the relationship of endoplasmic reticulum with Golgi complex, lysosome and plasma membrane?

2

BIOLOGICAL MOLECULES

After completing this lesson, you 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 the following properties of water that make it the cradle of life.
  high polarity,
  hydrogen bonding,
  high specific heat
  high heat of vaporization
  cohesion,
  hydrophobic exclusion
  ionization
  lower density of ice
- 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 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 cannot be metabolized by the "right-handed" enzymes.
- Define proteins and amino acids and draw the structural formula of amino acid.
- Outline the synthesis and breakage of peptide linkages.
- Justify the significance of the sequence of amino acids through the example of sickle cell hemoglobin.
- Classify proteins as globular and fibrous proteins.
- List examples and the 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 nucleotide.
- Distinguish among the nitrogenous bases found in the nucleotides of nucleic acids.
- Outline the examples of a mononucleotide (ATP) and a dinucleotide (NAD).
- 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 formation of a polypeptide.
- Explain the general structure of RNA.
- Distinguish in term 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.

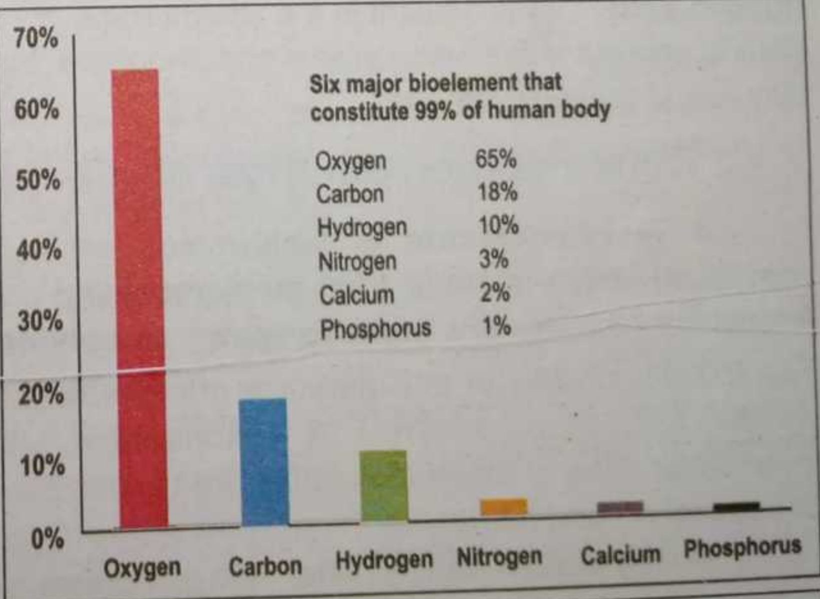
You have got a very brief introduction about biological molecules in IX-X biology course. This chapter caters the detailed study of carbohydrates, proteins, lipids and nucleic acid as well as the importance of water and the role of conjugated molecules.

2.1 BIOLOGICAL MOLECULES IN PROTOPLASM

Biological molecules are different chemical compounds of living beings. **Biochemistry** is the branch of biology that deals with such molecules. It also deals with various chemical reactions (metabolism) of living beings.

2.1.1 Chemical Composition of Protoplasm

Approximately 25 elements out of 92 naturally occurring elements of earth are found in living beings. These are called **bioelements**. However, human body is composed of only 16 of these bioelements. These elements can be classified on the basis of their proportions in organisms. The six commonest bioelements that constitute 99% of protoplasm are called **major** bioelements. **Minor** bioelements are those that are found as less than 1% whereas those that are found as less than 0.01% of the protoplasm are called **trace elements**. The proportions of these



Minor elements include: potassium (0.35%), sulphur (0.25%), chlorine (0.15%), sodium (0.15%) and magnesium (0.05%).
Trace elements include iron, copper, manganese, zinc

Fig. 2.1: Proportions of various bioelements in human body

elements are given in the fig: 2.1. Some trace elements such as iron are needed by all forms of life. Others are required only by certain species.

The bioelements are combined with each other and can form thousands of different biomolecules which may be **inorganic** (water and minerals) and **organic** (carbohydrates, lipids, proteins and nucleic acids). The proportions of these biomolecules are given in the table.

Table 2.1: Proportions of various biomolecules in bacterial and mammalian cells

Biomolecules	Bacterial cell	Mammalian cell
Water	70%	70%
Protein	15%	18%
Carbohydrates	3%	4%
Lipids	2%	3%
DNA	1%	0.25%
RNA	6%	1.1%
Other organic molecules (enzymes, hormones, metabilites)	2%	2%
Inorganic ions (Na^+, K^+, Ca^{++}, Mg++, Cl^-, SO4⁻⁻)	1%	1%

The four fundamental kinds of biological molecules are carbohydrates, proteins, lipids and nucleic acids. **Carbohydrates** are present in the cytoplasm of the cells and provide fuel for the metabolic activities of the cell. **Proteins** are present in the membranes, ribosomes, cytoskeleton and enzymes of the cell. **Lipids** are present in the membranes and cytoplasm of the cell. Lipids provide a reserved energy source, shape, protect and insulate the cells. The **nucleic acid** DNA is present in the chromosome. It controls the cell activity. The nucleic acid RNA is present in the nucleoplasm and cytoplasm. It takes genetic information from DNA and play role in protein synthesis.

2.1.2 Condensation and Hydrolysis

A **macromolecule** is high molecular weight compound which is made from many repeating units. Molecules built like this are also known as **polymers**. The individual units of polymers are **micromolecules** which are also known as **monomers**. The interconversions of these molecules are carried out by condensation and hydrolysis.

During **condensation**, when two monomers join, a hydroxyl (–OH) group is removed from one monomer and a hydrogen (–H) is removed from the other to make water and as a result a bond is synthesized between the monomers. The product of such reaction is called a

Fig: 2.2: Monomer and polymer

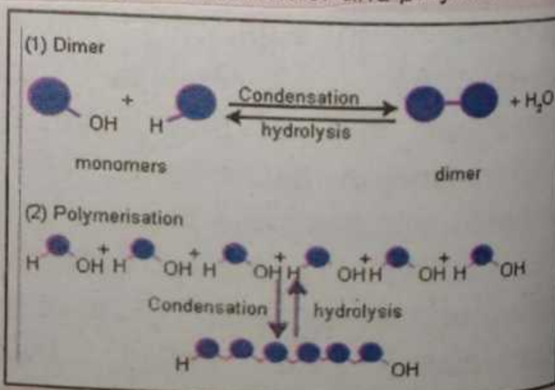


Fig. 2.3: Condensation and Hydrolysis

dimer. If the same reaction is repeated several times the resulting molecule will be a **polymer**. Condensation is also called **dehydration synthesis** because water is removed (dehydration) and bond is made (synthesis). Condensation does not take place unless the proper enzyme is present and the monomers are in an activated energy- rich form.

Science Titbits

Do not confuse involvement of water in hydrolysis with making a solution, in which the role of water is to act as a solvent, rather than taking part in a chemical reaction. Also do not assume that this breakdown releases energy, which is usually produced when the simpler substances are oxidized in respiration. Hydration is yet another completely different process, involving the addition of water, but not breaking of bonds.

The **hydrolysis** is essentially the reverse of condensation i.e., the breakdown of a polymer into its monomers by the addition of water. During hydrolysis, an (–OH) group from water is attached to one monomer and (–H) is attached to the other monomer. Actually all digestion reactions are examples of hydrolysis, which are controlled by enzymes such as carbohydrases, proteases, lipases, nucleases.

2.2 IMPORTANCE OF WATER

Water is one of the main constituents on earth. More than two thirds of the earth is covered by water. Approximately 70 percent of the any organism is formed of water. Water is the most abundant component in any organism, the lowest is 20% in seeds and bones and highest is 85-90% in brain cells. Jellyfish has exceptionally large amount of water i.e., 99% (hence the body shows transparency).

Critical Thinking

When hydrogen gas combines with oxygen gas to form water, is the hydrogen reduced or oxidized?

2.2.1. Properties of water

The properties of water that make it the cradle of life are:

1. High polarity

The bonds which are formed by the mutual sharing of electrons between two atoms are called **covalent bonds**. Normally the sharing of electrons between two atoms is fairly equal and the covalent bond is **nonpolar**. In the case of water, however the sharing of electrons between oxygen and hydrogen is not completely equal so the covalent bond is **polar**. A polar covalent bond is a chemical bond in which shared electrons are pulled closer to the more electronegative atom, making it partially negative and the other atom partially positive. Thus, in H_2O, the O atom actually has a slight negative charge and each H atom has a slight positive charge, even though H_2O as a whole is neutral. Because of its polar covalent bonds, water is a polar molecule i.e., it has a slightly negative pole and two slightly positive ones.

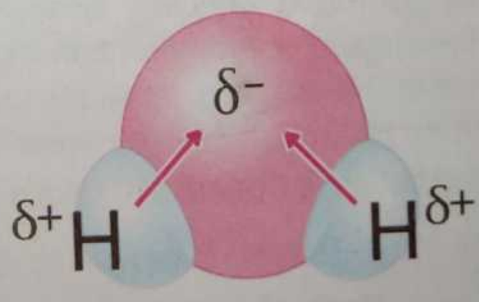


Fig: 2.4: Polarity of water molecule

This is polarity of water molecules that makes it an excellent or **universal solvent** for polar substances. Ionic compound or electrolytes can be easily dissolved in water, non-polar substances having charged groups in their molecules can also be dissolved in water. Such compounds when dissolved in water, disassociates into positive and negative ions and are in more favourable state to react with other molecules and ions. This is the reason why all chemical reactions in living beings occur in aqueous medium.

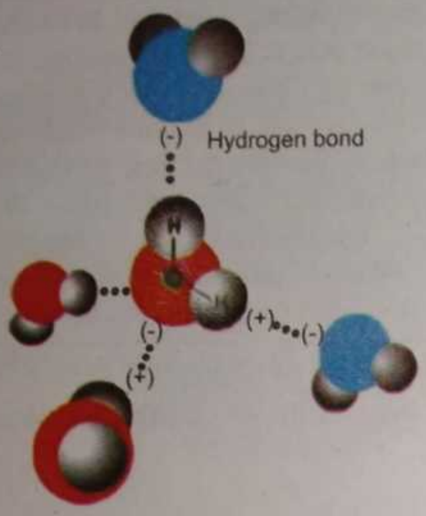


Fig: 2.5 Hydrogen bonds between water molecules

2. Hydrogen bonding

The polarity of water molecules makes them interact with each other. The charged regions on each molecule are attracted to oppositely charged regions on neighbouring molecules, forming weak bonds. Since the positively charged region in this special type of bond is always an H atom, the bond is called a **hydrogen bond**. This bond is often represented by a dotted line because a hydrogen bond is easily broken.

Because of hydrogen bonding, water is a liquid at temperatures suitable for life. The high cohesion and adhesion force of water is due to the presence of hydrogen bonds in water, which in turns makes water as transport medium.

3. Cohesion and adhesion

Cohesion is the attraction among the water molecules which enables the water molecules to stick together. Water flows freely due to cohesion. Water molecules also have attraction to polar surfaces. This attraction is called **adhesion**. Both cohesion and adhesion are due to hydrogen bonds among water molecules. These properties of water enable it to circulate in living bodies and to act as transport medium.

4. High specific heat capacity

Heat capacity can be defined as the amount of heat required for minimum increase in temperature of a substance. The specific heat capacity of water can be represented as number of calories required to raise the temperature of 1g of water up to 1°C i.e., **1 Calorie (4.18 Joules)**. Water has relatively a very high heat capacity than any other substance due to its hydrogen bonding, because much of the heat absorbed by water is utilized in the breakdown of hydrogen bonding therefore it does not manifest itself to raise the temperature of water. Hence, very large amount of heat can increase very little in temperature in water. Due to its high heat capacity water works as **temperature stabilizer** or regulator for organisms in the hot environment and hence protects the living material against sudden thermal changes.

5. High heat of vapourization

Heat of vapourization is the amount of heat required to convert a unit mass of a liquid into gaseous form. Heat of vapourization of water is represented as number of calories absorbed per gram vapourized. Water has high heat of vapourization i.e., **574 calories per gram**. The high heat of vapourization means that a large amount of heat can be lost with minimal loss of water from the body. This is high heat of vapourization of water that gives animals an efficient way to release excess body heat in a hot environment. When an animal sweats, body heat is used to vapourize the sweat thus cooling the animal. Due to this property of water, evaporation of only 2 ml out of one litter of water lowers the temperature of the remaining 998 ml water by 1°C.

6. Hydrophobic exclusion

Hydrophobic exclusion can be defined as reduction of the contact area between water and hydrophobic substances which are placed in water. For example, if you place few drops of oil on the surface of a water solution, the oil drops will tend to join into a single drop. Biologically, hydrophobic exclusion plays key roles in maintaining the integrity of lipid bilayer membranes.

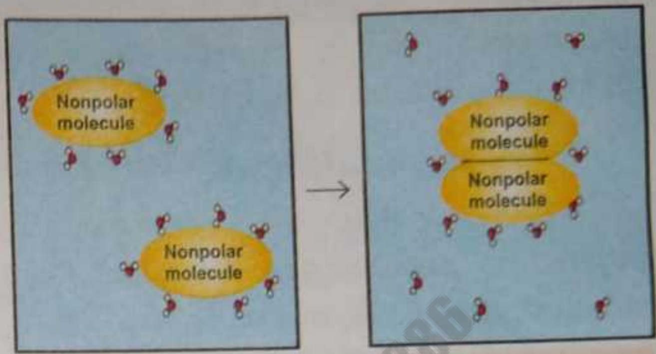


Fig: 2.6: Hydrophobic exclusion

7. Ionization

The dissociation of a molecule into ions is called **ionization**. When water molecule ionizes, it releases an equal number of positive hydrogen and negative hydroxyl ions.

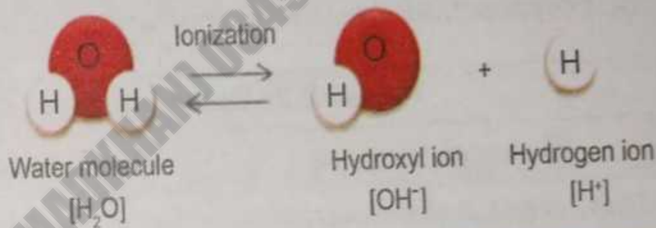


Fig: 2.7: Ionization of water

This reaction is reversible but equilibrium is maintained at 25°C. The H^+ and OH^- ions affect and take part in many of the reactions that occur in cells, e.g., it helps to maintain or change the pH of the medium.

8. Lower density of ice

Ice floats on water. This is because ice is less dense than water. The reason is that ice has a giant structure and show maximum number of hydrogen bonding among water molecules; hence, they are arranged like a lattice. In freezing weather, ice forms on the surface of ponds and lakes forming an insulating layer above the water below. This provides a living environment for some organisms until the ice melts. Organisms can also live under the ice.

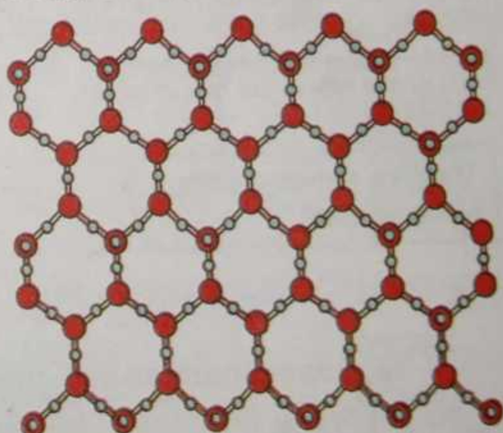


Fig: 2.8: Lattice likes arrangement of water molecules in ice

Skills: Analyzing, Interpreting and Communication
- Draw model diagrams to describe the hydrogen bonding.

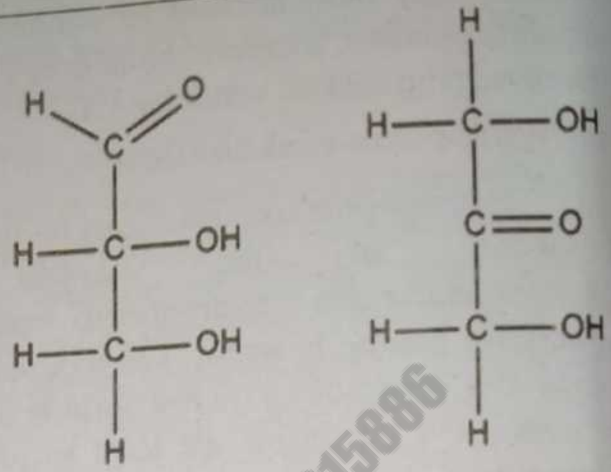
2.3 CARBOHYDRATES

Carbohydrates are the compounds of carbon, hydrogen and oxygen. Literally word carbohydrate means "hydrates of carbon" i.e., a carbon associated with water. Chemically carbohydrates are:

"Organic compounds that are polyhydroxy aldehydes or polyhydroxy ketones, or change to such substances on simple chemical transformations, as hydrolysis, oxidation, or reduction."

2.3.1 Classification of Carbohydrates

Carbohydrates are commonly known as **sugars** or **saccharides** because more familiar carbohydrates have sweet taste. Classification of carbohydrates is based upon number of saccharide units. Carbohydrates are generally classified into three group i.e., monosaccharides, oligosaccharides and polysaccharides.



Polyhydroxy aldehyde   Polyhydroxy ketone

Fig: 2.9: Chemical nature of carbohydrates

Table: 2.2: Comparison of characteristics of carbohydrates

Monosaccharides	Oligosaccharides	Polysaccharides
They consist of single saccharide unit.	They are composed of 2 to 10 saccharide units.	They are composed of more than 10 saccharide units.
They are simplest carbohydrates; therefore, they cannot be further hydrolyzed.	They have less complex structure, so upon hydrolysis they yield at least 2 and maximum 10 monosaccharides.	They have highly complex structure, so upon hydrolysis they yield at least 11 monosaccharides.
They are highly soluble in water.	They are less soluble in water.	They are generally insoluble in water.
They are sweetest among all carbohydrates.	They are less sweet in taste.	They are tasteless.

2.3.2 Monosaccharides

Monosaccharides are true carbohydrates which are either polyhydroxy aldehydes or polyhydroxy ketones. The range of number of carbons in monosaccharides is 3 to 7. All the carbon atoms in a monosaccharide except one, have a hydroxyl group (-OH) while the remaining carbon atom is either the part of aldehyde or ketone. The general formula for the representation of monosaccharides is $C_nH_{2n}O_n$, where, n is the number of carbon atoms in monosaccharides.

Classification of monosaccharides

Classification of monosaccharides is based upon functional group and number of carbon atoms. On the basis of functional group, the monosaccharides containing aldehyde are called **aldoses** while those containing ketone are called **ketoses**. On the other hand monosaccharides are classified into five groups based upon number of carbon atoms i.e., **trioses** (3C), **tetroses** (4C), **pentoses** (5C), **hexoses** (6C) and **heptoses** (7C).

Table: 2.3: Examples and functions of monosaccharides

Class	Formula	Aldoses	Ketoses	Function
Trioses (3C)	$C_3H_6O_3$	Glyceraldehyde	Dihydroxy acetone	Intermediates in photosynthesis and cellular respiration.
Tetroses (4C)	$C_4H_8O_4$	Erythrose	Erythrulose	Intermediates in bacterial photosynthesis.
Pentoses (5C)	$C_5H_{10}O_5$	Ribose, Deoxyribose ($C_5H_{10}O_4$)	Ribulose	Ribose and deoxyribose are components of RNA and DNA respectively. Ribulose is an intermediates in photosynthesis.
Hexoses (6C)	$C_6H_{12}O_6$	Glucose, Galactose	Fructose	Glucose is respiratory fuel (initial substrate) Fructose is an intermediate in respiration. Galactose is the component of milk sugar.
Heptoses (7C)	$C_7H_{14}O_7$	Glucoheptose	Sedoheptulose	Intermediates in photosynthesis.

Chemical structures of monosaccharides

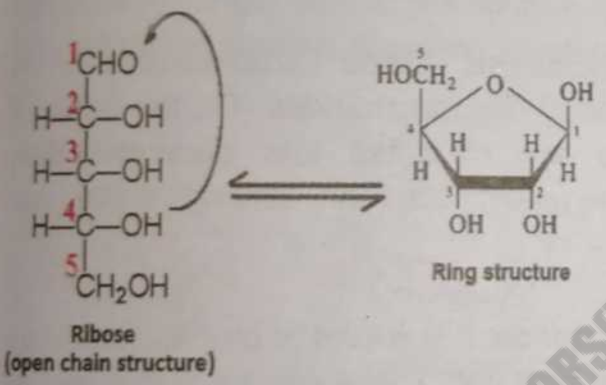


Fig: 2.10: Conversion of open chain into ring chain

Monosaccharides are usually found in open chain structure in crystalline form but when they are dissolved in water most of them (pentoses and hexoses) are converted into ring chain structure.

Let us understand it by taking ribose ($C_5H_{10}O_5$) as an example. It can exist in open chain structure in dried form but it exists in ring structure in aqueous medium. When it is dissolved in water, the oxygen atom from aldehyde group reacts with second last carbon i.e., C4 in case of ribose. In this way oxygen atom forms a link between C1 and C4 while the OH group of C4 is shifted to C1. After this modification ring structure of ribose is formed.

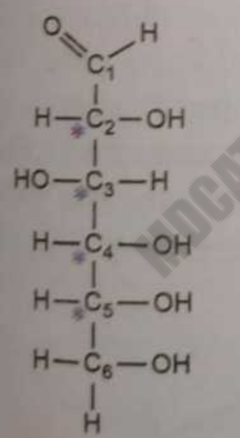


Fig: 2.11: Glucose open chain structure

Each pentose or hexose molecule in ring structure exists in either α or β form depending upon the position of –H and –OH group on C-1. If –OH group is found downward on C-1 then it is called **α sugar** and if –OH is present upward on C-1 then it is known as **β sugar** as shown in the fig: 2.12.

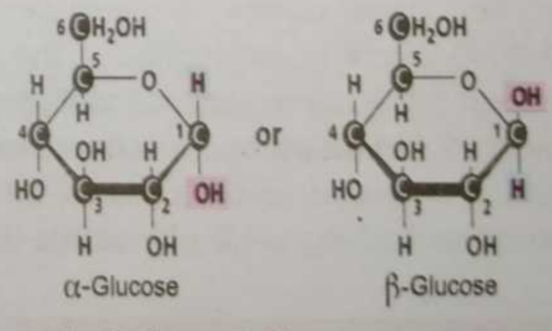


Fig: 2.12: α and β isomers of glucose

Stereoisomerism in Glucose

Stereoisomers are molecules that have the same molecular formula and differ only in how atoms are arranged in 3D space. Enantiomers is a type of stereoisomers in which molecules are nonsuperimposable mirror-images. This means that the molecules are mirror image but they cannot be placed on top of one another to give the same molecule. An example of enantiomer is D and L glucose. D sugars are right handed and L sugars are left handed molecules.

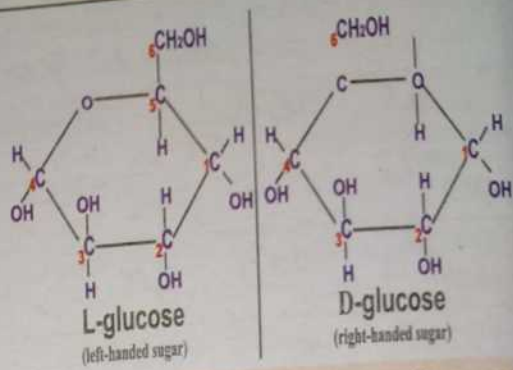


Fig: 2.13: An example of enantiomers

Laboratory Manufactured (Artificial) Sweeteners

Laboratory manufactured sugars are L sugars. On the other hand the naturally occurring sugars in bodies are D sugars. Proteins and cell receptors are designed to react only with D sugars. For example the enzymes in your stomach can digest only right-handed sugars. Likewise left-handed sugars cannot be metabolized by right-handed enzymes. Just as the glove fits only on the proper hand, a right-handed enzyme cannot fit on or react with a left-handed substrate. The substrate must fit on the proper active site of the enzyme. So for the left handed substrate (artificial sweetener) the enzyme must be left-handed.

2.3.3 Oligosaccharides

This group consists of derivatives of monosaccharides. Those carbohydrates which upon hydrolysis yield 2 to 10 saccharide units are called oligosaccharides. On the basis of number of saccharide units, the oligosaccharides are classified into **disaccharides**, **trisaccharides**, **tetrasaccharides** and so on. The most common among these are disaccharides.

Disaccharides

Two monosaccharides combine to form a disaccharide. It is a kind of oligosaccharides. Disaccharides are less sweet in taste and less soluble in water. These can be hydrolyzed to give monosaccharides. Examples are: maltose, lactose, sucrose. The general formula of disaccharide is: $C_{12}H_{22}O_{11}$. Some common disaccharides are as follows:

Sucrose: It is commonly known as cane sugar. It is widely used as sweetener at homes for making sweet dishes. In plants sucrose is also called **transport disaccharide** as prepared food in plants is transported in the form of sucrose. It is very soluble and can therefore be moved efficiently in high concentration in plants. It is also relatively unreactive chemically. The sucrose is formed by the condensation of glucose and fructose. In this reaction, the –OH group at C-1 of glucose reacts with the –OH group at C-2 of fructose, liberating a water molecule forming **α-1,2-glycosidic linkage**.

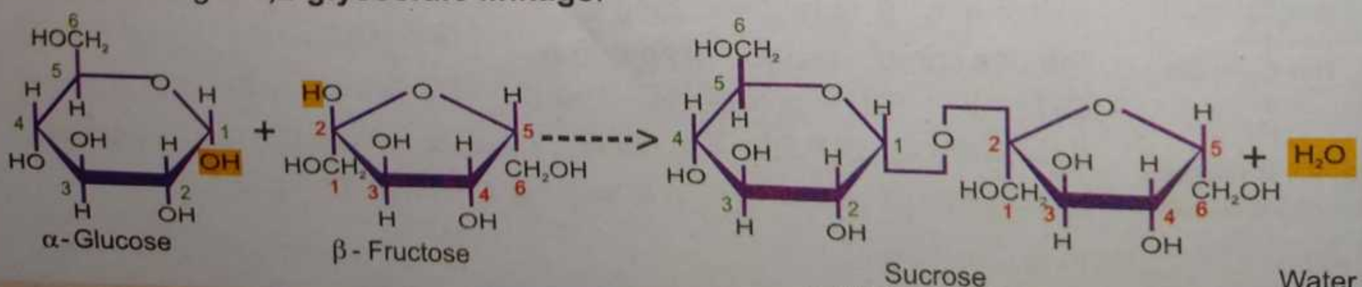


Fig: 2.14: Formation of sucrose

Maltose: It is commonly known as malt sugar. It is an intermediate disaccharide produced during the breakdown of starch and glycogen. Maltose is generally found in germinating seeds. The maltose is formed by the condensation of two α-glucoses. In this reaction, the –OH group at C-1 of one glucose reacts with the –OH group at C-4 of other glucose, liberating a water molecule forming **α-1, 4-glycosidic linkage**.

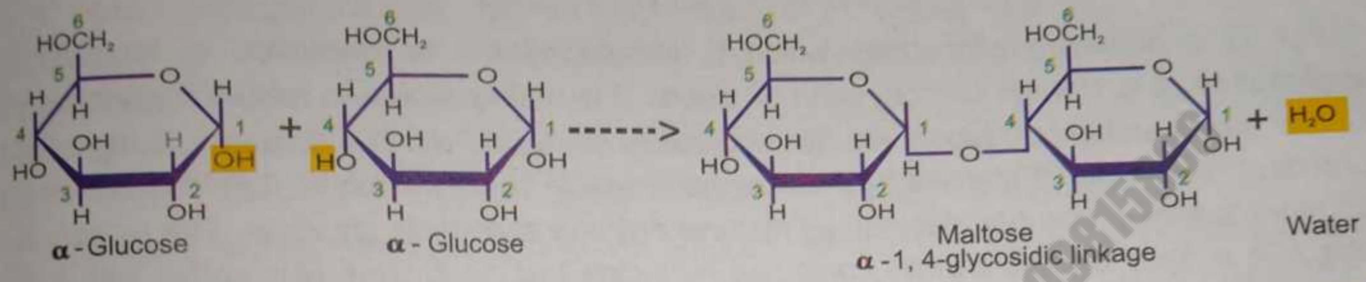


Fig: 2.15: Formation of maltose

Lactose: It is commonly known as milk sugar. The lactose is formed by the condensation of β-galactose and β-glucose. In this reaction, the –OH group at C-1 of galactose reacts with the –OH group at C-4 of glucose, liberating a water molecule forming **β-1, 4-glycosidic linkage**.

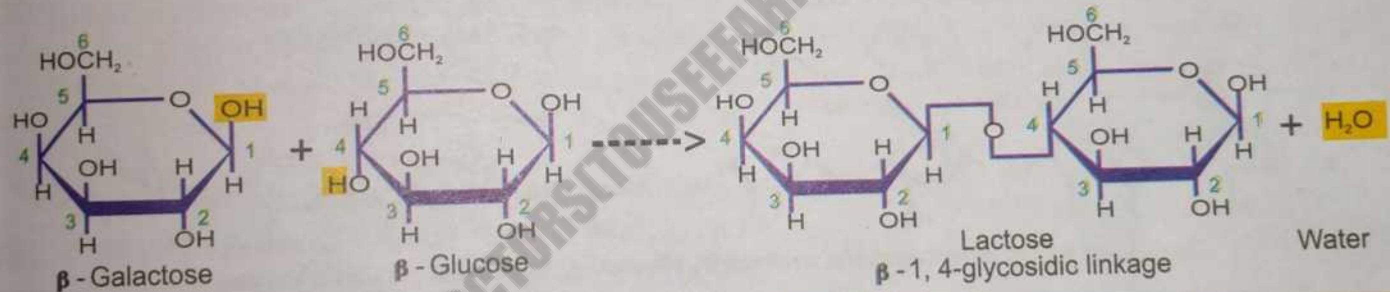


Fig: 2.16: Formation of lactose

Science Titbits

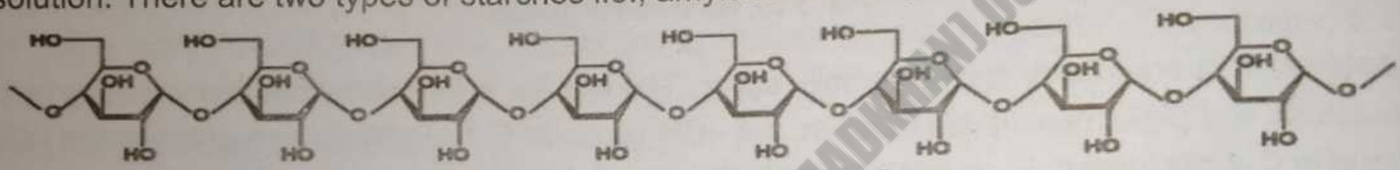
Any carbohydrate which is capable of being oxidized and causes the reduction of other substances without having to be hydrolyzed first is known as **reducing sugar**, but those which are unable to be oxidized and do not reduce the other substances are known as **non-reducing sugars.** All monosaccharides and two of three types of disaccharides (maltose and lactose) have the open chemical structure needed to act as reducing agents. The third type of disaccharides, sucrose, and polysaccharides are non-reducing sugars.

2.3.4 Polysaccharides

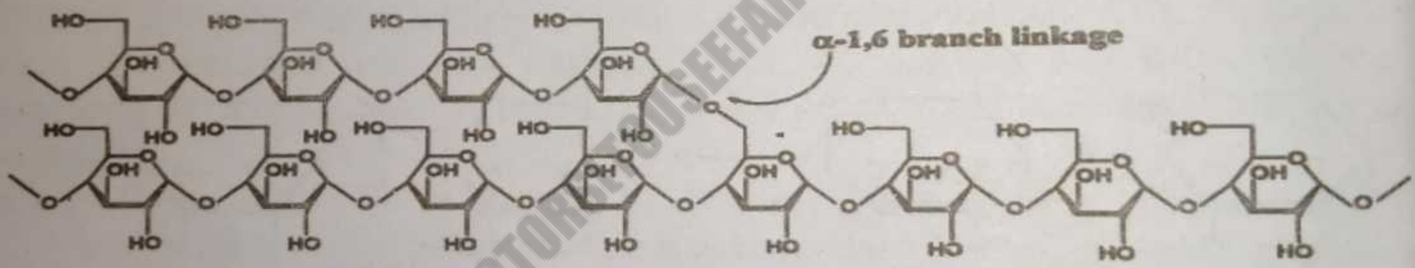
Those carbohydrates which upon hydrolysis yield more than ten monosaccharide units are called polysaccharides. This is largest group of carbohydrates. The polysaccharides which are composed by the condensation of only one kind of monosaccharides are called **homopolysaccharides** e.g., starch, glycogen, cellulose, chitin; whereas the polysaccharide which are composed by the condensation of different kind of monosaccharides are called **heteropolysaccharides** e.g., agar, pectin, peptidoglycan. Polysaccharides function chiefly as food and energy stores, e.g., starch, glycogen, and structural material, e.g., cellulose and chitin. They are convenient storage molecule for several reasons. Their large size makes them more or less insoluble in water, so they exert no osmotic or chemical influence in the cell; they fold into compact shapes and they are easily converted to sugars by hydrolysis when required. Some common polysaccharides e.g., starch, cellulose, and chitin are being discussed here.

Starch

Starch is a homopolysaccharides which is formed by the condensation of hundreds of **α-glucoses**. It is storage carbohydrate of plants. It is mainly stored in root, stem and seeds. Cereal grains and potato tubers are rich sources of starch in human diet. Starch is digested in oral cavity and in small intestine by the enzyme amylase. Upon hydrolysis it yields maltose first and then maltose is further digested by maltase enzyme and yields glucoses. The presence of starch in a given sample can be confirmed by iodine test as it gives blue colour with iodine solution. There are two types of starches i.e., amylose and amylopectin.



Segment of an amylose molecule



Segment of an amylopectin molecule, showing one α-1,6 branch linkage

Fig: 2.17: Structure of starches

Amylose is un-branched i.e., a linear chain of glucoses in which glucoses are attached together by **α-1, 4-glycosidic linkages**. It is soluble in hot water only. On the other hand, **amylopectin** has branched structure i.e., a linear chain of glucoses but more chains of glucoses in the form of branches are also attached by **α-1, 6-glycosidic linkages**. It is completely insoluble in water.

Glycogen

Like starch, glycogen is also a homopolysaccharides composed of **α-glucoses**. It is storage carbohydrate of animals. It is mainly stored in liver and muscles. Therefore it is also known as **animal's starch**. The digestion of glycogen is also quite similar to that of starch. The presence of glycogen in a given sample can

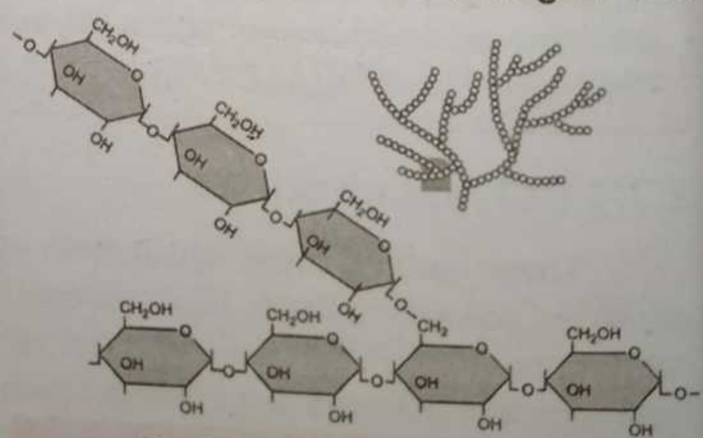


Fig: 2.18: Structure of glycogen

also be confirmed by iodine test as it gives red colour with iodine solution. Structure of glycogen resembles with amylopectin starch but glycogen has much more branching than amylopectin.

Cellulose

Cellulose is most abundant carbohydrate on earth. It is also a homopolysaccharides but unlike starch and glycogen it is formed by the condensation of hundreds of **β-glucoses**. It is structural carbohydrate of plants as it is major constituent of plant cell wall. Cotton and paper are the pure forms of cellulose.

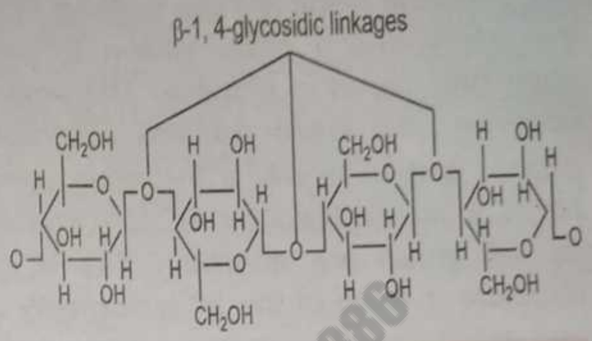


Fig: 2.19: Structure of cellulose

Cellulose shows no colour with iodine solution. Structure of cellulose resembles with amylose starch in such a way that it has un-branched structure but it has **β-1, 4-glycosidic linkages** between glucose residues.

Science Titbits

Cellulose cannot be digested by human body but it has to be taken into diet because it works as roughage or fibre so it prevents abnormal absorption of food in intestine. However, herbivore animals have some symbiotic bacteria that secrete **cellulase** enzyme for its digestion. Upon hydrolysis it first yields a disaccharide, the **cellubiose** and then cellubiose is further digested into glucoses.

Chitin

Chitin is the second most abundant organic molecule on earth. It is also a homopolysaccharides. It is a structural carbohydrate found in the cell walls of fungi and in the exoskeleton of arthropods. Due to the occurrence of chitin in fungal cell wall, it is also known as **fungal cellulose**. Chitin is the derivative of **N-acetyl glucosamine** monomers which is a modified form of glucose. It has an un-branched structure and its monomers are linked together by **β-1, 4-glycosidic linkages**.

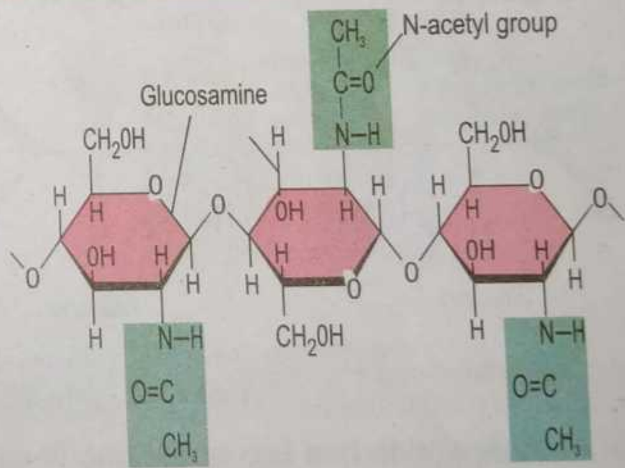


Fig: 2.20: Structure of chitin

2.4. PROTEINS

Proteins are the main structural components of the cell. All proteins contain C, H, O and N, while some contains P, S. Few proteins have Fe, I and Mg incorporated into the molecule.

2.4.1 Structure of Proteins

Chemically proteins can be defined as **polymers of amino acids** or **polypeptide chains**. A protein may consist of a single polypeptide or more than one polypeptide.

Amino acids

Fig: 2.21 General structure of an amino acid

Amino acids are the building blocks of proteins. There are many amino acids known to occur, but only 20 are commonly found in proteins. The amino acids are built on a common plan. Each contains a carbon atom. It is called α (alpha) carbon to this a hydrogen atom, an amino group (–NH2), a carboxyl group (–COOH) and a variable group known as –R group are attached. The R group has a different structure in each of the 20 biologically important amino acids and determines their individual chemical properties. Two simplest amino acids i.e., glycine and alanine are shown in figure 2.21.

Dipeptides and Polypeptides

Dipeptides and polypeptides are formed by the condensation of amino acids on the ribosome under the instructions of mRNA which takes these instructions from DNA. This process is known as **translation**. During this process, when an amino acid reacts with another amino acid, the –OH from carboxylic acid group of one amino acid and –H from amino group of other amino acid are liberated and form a water molecule, as a result a bond is established between C of carboxylic acid group and N of amino group of two amino acids called **peptide bond**. Hence, a product of two amino acids is formed which is known as **dipeptide**.

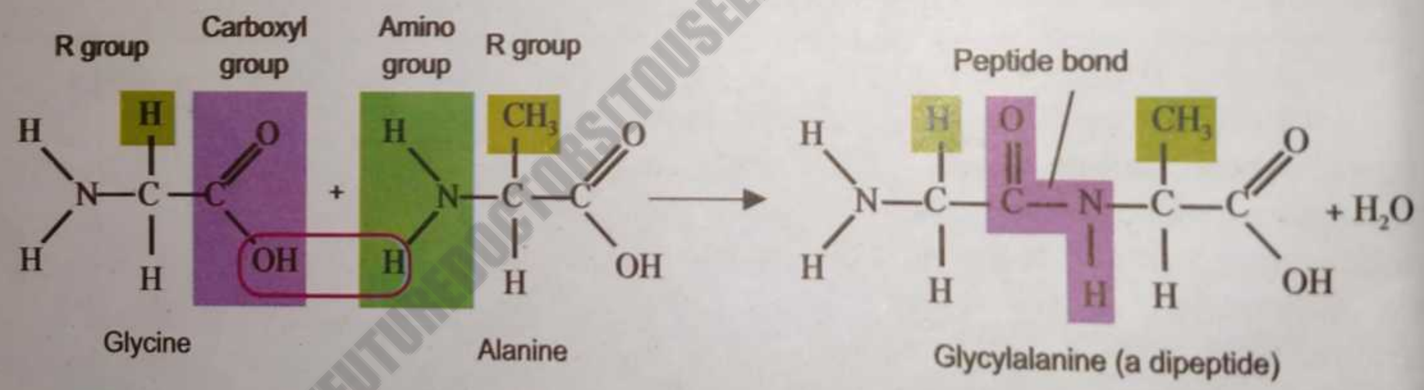


Fig: 2.22: Formation of a dipeptide and peptide bond

A dipeptide has two ends; one is called amino or **–N terminal** end while other is called carboxylic acid or **–C terminal** end. A new amino acid can be added in this chain from its carboxylic acid or –C terminal end in the same way. Thus, a **tripeptide** (a product of three amino acids) is formed and another water molecule is also released. Similarly, when several amino acids are linked together by many peptide bonds, the **polypeptide** chain is formed.

Structural conformations in proteins

A linear polypeptide with a specific sequence and number of amino acids is called **primary structure**. It is shown by all proteins at the time of their synthesis on ribosomal surface. After synthesis a protein does not remain in its primary structure but can be changed into some other structural conformations (particular form, shape or structure).

A helical **(α-helix)** or flattened sheets **(β-pleated sheet)** like structures which are established by **H-bonding** between opposite charge bearing groups of different amino acids are called **secondary structures**. In some proteins the linear polypeptide is changed into α-helix, then α-helix fold again and again by **ionic bonds** and **disulfide bridges** to form a globular shaped structure, the **tertiary structure**. Some proteins exist in very complex structure in which more than one globule is attached together by **hydrophobic interaction**. Such structures are called **quaternary structures**.

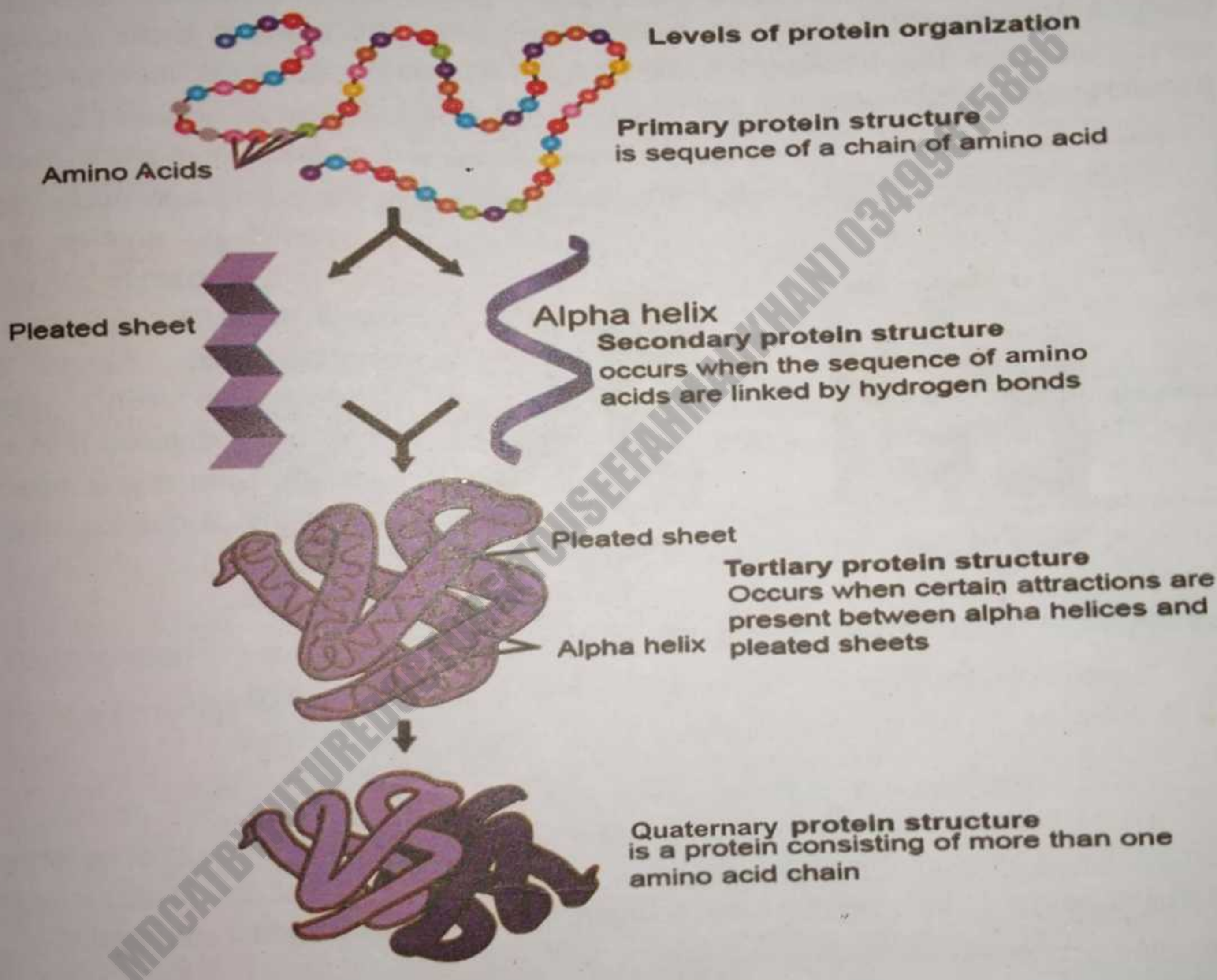


Fig: 2.23: Structural conformations in proteins

2.4.2 Significance of Amino Acid Sequence

Sequence of amino acid in a polypeptide is a characteristic feature of primary structure of protein which is responsible for proper functioning of protein. It is determined by the sequence of nucleotide in DNA. Even due to **point mutation** (change of single or few nucleotides in DNA) the sequence of amino acid in a particular protein (polypeptide) may be disturbed which causes severe defects in the body as it happens in sickle cell anemia, a hereditary disease.

Normal red blood cells are disc-shaped and look like doughnuts without holes in the centre. They move easily through your blood vessels. Red blood cells contain an iron-rich protein called haemoglobin. This protein carries oxygen from the lungs to the rest of the body. **Normal haemoglobin (Hb^A)** contains four polypeptides i.e. two α-chains which consist of 141 amino acids each and two β-chains which consist of 146 amino acids each.

Sickle cell anemia is a serious disorder in which the body makes sickle or crescent shaped red blood cells. Sickle cells contain abnormal hemoglobin called **sickle haemoglobin (Hb^S)**. Sickle haemoglobin causes the cells to develop a sickle, or crescent, shape. Sickle cells are stiff and sticky. They tend to block blood flow in the blood vessels of the limbs and organs. Blocked blood flow can cause pain and organ damage. Sickle cell anemia is caused by a point mutation in β-globin gene in which only one nucleotide is replaced by another which causes a change in amino acid sequence of β-chain of haemoglobin. Sickle cell haemoglobin (Hb^S) shows only one difference from Hb^A i.e., **glutamic acid** is replaced by **valine** at position number six in β-chain.

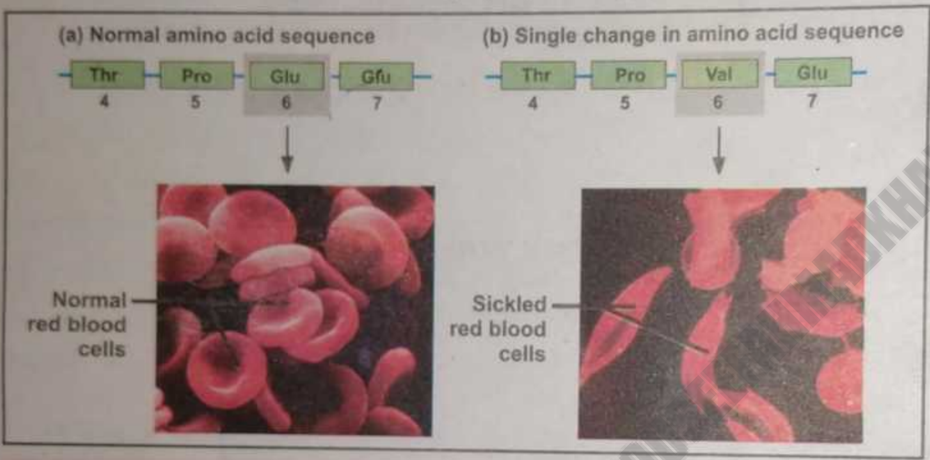


Fig: 2.24: Difference in β-chain of Hb^A and Hb^S

2.4.3 Classification of Proteins

Based upon structure and shape proteins can be classified into two groups i.e., fibrous and globular.

Fibrous proteins

These proteins have fibre or filament like shape. Therefore, they exist in secondary structure during function. These proteins are insoluble in aqueous medium, elastic in nature and cannot be crystalized. Examples are: collagen, fibrinogen, actin, myosin and keratin.

Globular proteins

These proteins have spherical or globules like shape. Therefore, they exist in tertiary or quaternary structure during function. These proteins are soluble in aqueous medium, inelastic in nature and can be crystalized. Examples are: enzymes, hormones, antibodies, channel proteins.

2.4.4 Role of Proteins

Proteins are very important molecules in our cells. They are involved in virtually all cell functions. Each protein within the body has a specific function. Some proteins are involved in support or composition of body parts i.e., structural roles, while others are involved in various physiological activities like bodily movement or in defence against germs i.e., functional roles. A list of several types of proteins and their functions is given in table 2.4 and 2.5.

Table: 2.4: List of structural proteins	
Types	**Roles of proteins**
Collagen	It establishes the matrix of bone and cartilages.
Elastin	Elastin provides support for connective tissues such as tendons and ligaments.
Keratin	It strengthens protective coverings such as hair, nails, quills, feathers, horns, and beaks.
Histone	It arranges the DNA into the chromosome.

Table: 2.5 List of functional proteins	
Types	**Roles of proteins**
Enzymes	The most of enzymes are protein which control metabolism i.e., they speed up the biochemical reactions.
Hormones	Some hormones are protein in nature which are involved in the regulation of physiological activities such as regulation of glucose level, calcium level, digestion, blood pressure etc.
Antibodies	These proteins are produced by WBCs in response to antigen (a foreign particle) and provide immunity.
Haemoglobin	It is found in RBCs and is involved in the transport of oxygen mainly and carbon dioxide to some extent.
Fibrinogen	It is found in blood plasma and is involved in blood clotting process.
Ovalbumin and Casein	Ovalbumin is found in egg whites and casein is a milk-based protein. Both of them are involved in the storage of amino acids.

Skills: Analyzing, Interpreting and Communication

- Draw table to illustrate different structural and functional proteins with roles of each.

2.5 LIPIDS

Lipid is the collective name for variety of organic compounds such as fats, oils, waxes and fat-like molecules (steroids) found in the body. Therefore, it is defined as a heterogeneous group of organic compounds which are insoluble in water (hydrophobic) but soluble in organic solvent such as acetone, alcohol, and ether etc. Lipids are composed of carbon, hydrogen and oxygen as carbohydrates. However, they have relatively less oxygen in proportion to carbon and hydrogen than do carbohydrates. For instance, **tristearin** is a simple lipid which shows molecular formula as $C_{57}H_{110}O_6$. Due to high contents of carbon and hydrogen, they contain double amount of energy than carbohydrates.

In general lipids are components of cell membranes (phospholipids and cholesterol), act as energy stores (triglycerides), steroid hormones and are also involved in protection, waterproofing, insulation and buoyancy.

Some common lipids are acylglycerol, waxes, phospholipids, terpenes, prostaglandin and steroids.

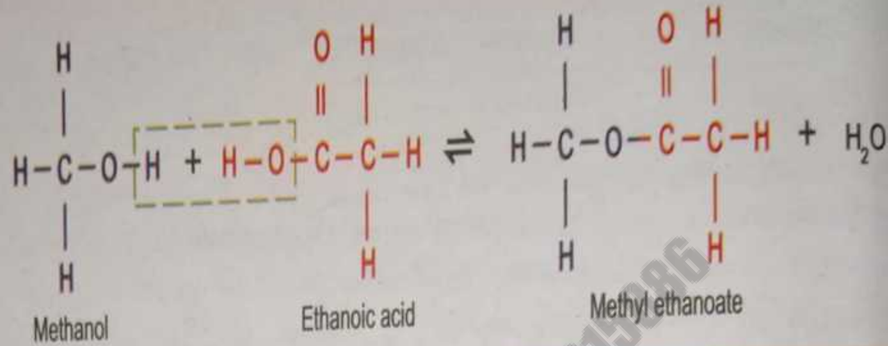


Fig: 2.25: Esterification

Acylglycerol

The most abundant lipids in living things are acylglycerol. Chemically, acylglycerols can be defined as esters of glycerol and fatty acids. An **ester** is the compound produced as the result of a chemical reaction of an alcohol with acid and a water molecule is released such a reaction is called **esterification**.

Glycerol is a trihydroxy alcohol which contains three carbons, each bears an OH group. A **fatty acid** is a type of organic acid containing one carboxylic acid group attached to a hydrocarbon. Fatty acids contain even number of carbons from 2 to 30. Each fatty acid is represented as R-COOH, where R is a hydrocarbon tail. When a glycerol molecule combines chemically with one fatty acid, a **monoacylglycerol** (monoglyceride) is formed. When two fatty acids combine with a glycerol a **diacylglycerol** (diglyceride) is formed and when three fatty acids combine with one glycerol molecule a **triacylglycerol** (triglyceride) is formed. Triacylglycerols are also called **neutral lipid** as all three OH groups of glycerol are occupied by fatty acids and no charge bearing OH group is left.

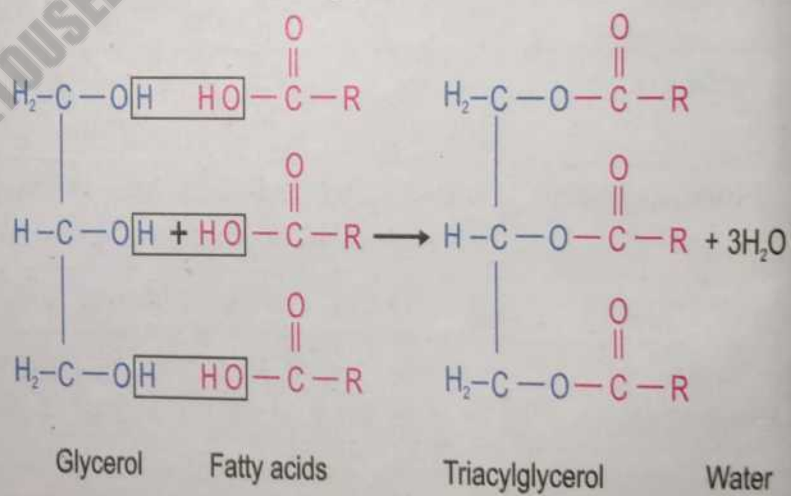


Fig: 2.26: Formation of a triacylglycerol (neutral lipid)

Properties and types of fatty acids

About 30 different fatty acids are found. Fatty acids vary in length. Acetic acid (2C) and butyric acid (4C) are simplest fatty acid, whereas palmitic acid (16C) and stearic acid (18C) are most common fatty acids. Some properties of fatty acid are increased with an increase in number of carbon atoms, such as melting point, solubility in organic solvent and hydrophobic nature. Some common fatty acids are given in the table 2.6. Fatty acids are either saturated or unsaturated. Fatty acids in which all of the internal carbon atoms possess hydrogen side groups are said to be **saturated fatty acids** because they contain the maximum number of hydrogen atoms that are possible, e.g., palmitic acid. Saturated fatty acids tend to be solid at room temperature (higher melting point) and are more common in animal lipids (fats).

Unsaturated fatty acids have one or more pairs of carbon atoms joined by a double bond. They therefore are not fully saturated with hydrogen, e.g., oleic acid. Unsaturated fatty acids are liquid at room temperature (lower melting point) and are more common in plant lipids (oils). Triglycerides containing hydrocarbon chains melt at a low temperature. This is useful for living things.

Table: 2.6: Common types of fatty acids

Name	Typical source	No. of Carbon	Condensed Formula	Melting point (°C)
Saturated				
1.Palmitic	Most fats and oils	16	$CH_3-(CH_2)_{14}-COOH$	63
2.Stearic	Most fats and oils	18	$CH_3\ (CH_2)_{16}\ COOH$	70
Unsaturated				
3.Oleic	Olive oil	18	$CH_3-(CH_2)_7-CH=CH-(CH_2)_7-COOH$	4
4.Linoleic	Vegetable oils	18	$CH_3-(CH_2)_4CH=CHCH_2CH=CH-(CH_2)_7-COOH$	-5

Waxes

Waxes are highly hydrophobic compounds. There are two types of waxes. **Natural waxes** are simple lipids. They are typically esters of long chain fatty acids and long chain alcohols, such as bee's wax (found in honeycomb) and cutin (on leaf surfaces of plants). These are chemically inert and resistant to atmospheric oxidation. Waxes have protective functions in plants and animals.

Synthetic waxes are generally derived from petroleum or polyethylene e.g. paraffin wax which is used to make candles.

Phospholipids

Phospholipids are derived from **phosphatidic acid**. A phospholipid is formed when phosphatidic acid combines with one of the four organic compounds such as **choline** (a nitrogenous base), **ethanolamine** (an amino alcohol), **inositol** (an amino alcohol) and **serine** (an amino acid). A phosphatidic acid molecule is most similar to diglyceride that it contains a glycerol, two fatty acids esterified with first and second OH groups of glycerol and a phosphate group esterified with third OH group of glycerol. Most common type of phospholipid is **phosphatidylcholine** also called **lecithin** in which choline is attached to phosphate group of phosphatidic acid. One end of the phospholipid molecule, containing the phosphate group and additional compound is hydrophilic i.e., polar and readily soluble in water. The other end, containing the fatty acid side

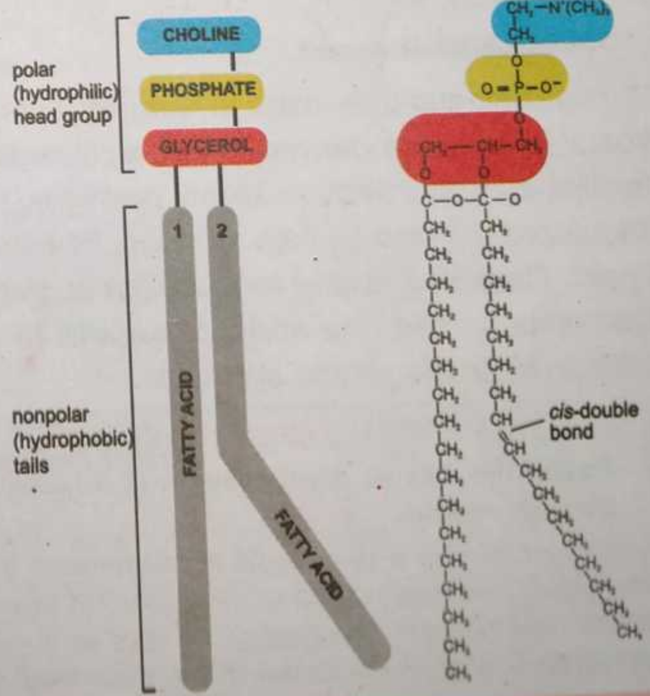


Fig. 2.27: Phosphatidylcholine (Lecithin)

chains, is hydrophobic i.e., non-polar and insoluble in water. These phospholipids are major constituents of lipid bilayer of cell membrane.

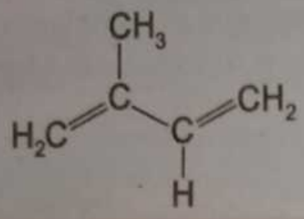


Fig. 2.28 Isoprene unit

Terpenes

All the terpenes are synthesized from a five-carbon building block known as **isoprene unit**. This unit condenses in different ways to form many compounds. Two isoprene units form a **monoterpene** e.g., menthol, four form a **diterpene** e.g., vitamin A, phytol (chlorophyll tail) and six form a **triterpene** e.g., ambrein. Natural rubber is a **polyterpene**.

Steroids

Steroids are lipids of high molecular weight which can be crystalline. A steroid nucleus consists of 17 carbon atoms arranged in four attached rings, three of the rings contain six carbon atoms, and the fourth contains five. The length and structure of the side chains that extend from these rings distinguish one steroid from other steroids. These structures are synthesized from isoprene units.

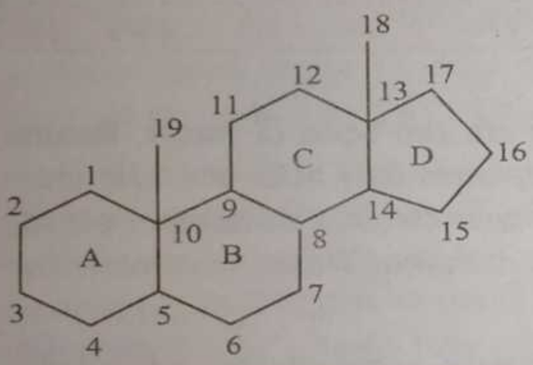


Fig. 2.29 Steroid nucleus

Cholesterol is a structural component of cell membrane. Cholesterol is the precursor of a large number of equally important steroids which include the bile acids, male sex hormone testosterone, female sex hormone progesterone and estrogen etc. Bile salts which emulsify fats and Vitamin D, which helps to regulate calcium metabolism are also steroid.

Prostaglandins

Prostaglandins exist in virtually every mammalian tissue, acting as local hormones. Prostaglandins are derived from **arachidonic acid**. Their functions vary widely depending on the tissue. Some reduce blood pressure, whereas others raise it. In the immune system, various prostaglandins help to induce fever and inflammation and also intensify the sensation of pain. They also help to regulate the aggregation of platelets an early step in the formation of blood clots. In fact, the ability of **aspirin** to reduce fever and decrease pain depends on the inhibition of prostaglandin synthesis.

Science, Technology and Society Connections

- **Relate the role of prostaglandin in inflammation with the inhibition of prostaglandin synthesis through aspirin.**

Prostaglandins play a pivotal role in inflammation a process characterized by redness (*rubor*), heat (*calor*), pain (*dolor*), and swelling (*tumor*). The changes associated with inflammation are due to dilation of local blood vessels that permits increased blood flow to the affected area. The blood vessels also become more permeable, leading to the escape of white blood cells (leukocytes) from the blood into the inflamed tissues.

Aspirin is anti-inflammatory, analgesic, and antipyretic. Aspirin inhibits prostaglandin synthetase salicylate. This drug affects the metabolism of arachidonate via the lipoxygenase pathway by inhibiting the conversion of 12-hydroperoxy- to 12-hydroxy-5, 8, 10, 14-eicosatetraenoic acid.

2.6 NUCLEIC ACID

Nucleic acids were first reported (in 1869) by a Swiss physician when he isolated a new compound from the nuclei of pus cells (white blood cells). This compound was neither a protein nor lipid nor a carbohydrate; therefore, it was a novel type of biological molecule. He named this molecule as **nuclein**, because it was located in the nucleus. The basic structure and chemical nature of nuclein was determined (in 1920) and was renamed as **nucleic acid** because of its acidic nature.

2.6.1 Chemical Structure of Nucleic Acids

Now it has been cleared that nucleic acids are of two types i.e., **deoxyribo nucleic acid (DNA)** and **ribo nucleic acid (RNA)**. Both nucleic acids are linear un-branched polymers. The monomers of the nucleic acid are called **nucleotides**.

Composition of a nucleotide

Nucleotides of DNA are called **deoxyribonucleotides** and of RNA are known as **ribonucleotides**. Each nucleotide consists of pentose sugar, a phosphate and a nitrogen containing ring structure called base. The **pentose sugar** in deoxyribonucleotides is

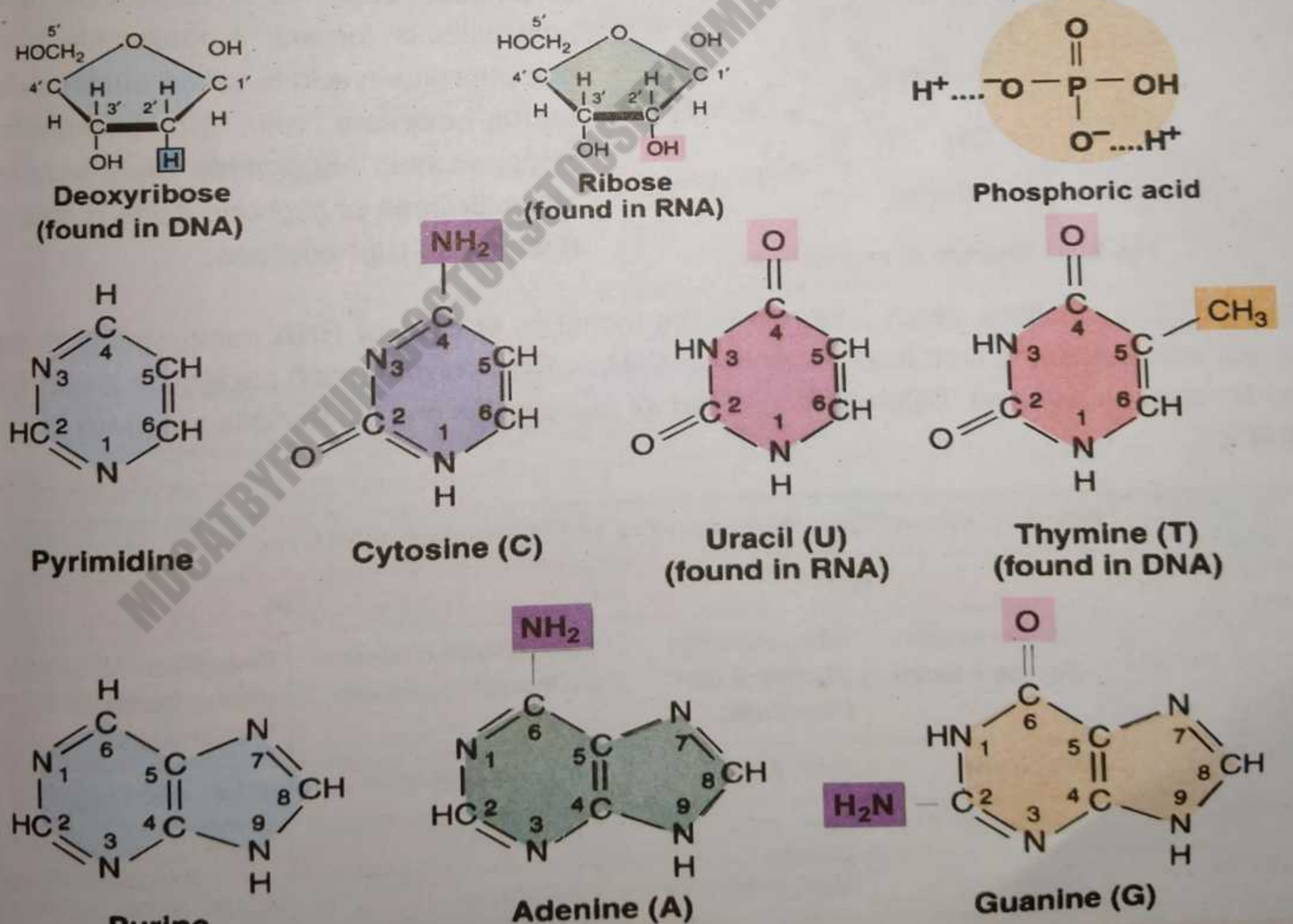


Fig. 2.30: Components of nucleotides

deoxyribose and in ribonucleotides is ribose. **Phosphoric acid** is a common component of both nucleotides which provides acidic properties to DNA and RNA. The nitrogen containing ring structures are called **bases** because of unshared pair of electron on nitrogen atoms, which can thus acquire a proton.

There are two major classes of nitrogenous bases i.e., single ring **pyrimidine** and double ring **purines**. Pyrimidine bases are of three types i.e., cytosine (C), thymine (T) and uracil (U). Thymine is only found in DNA while the uracil is only found in RNA. On the other hand, the purine bases are also of two types i.e., adenine (A) and guanine (G).

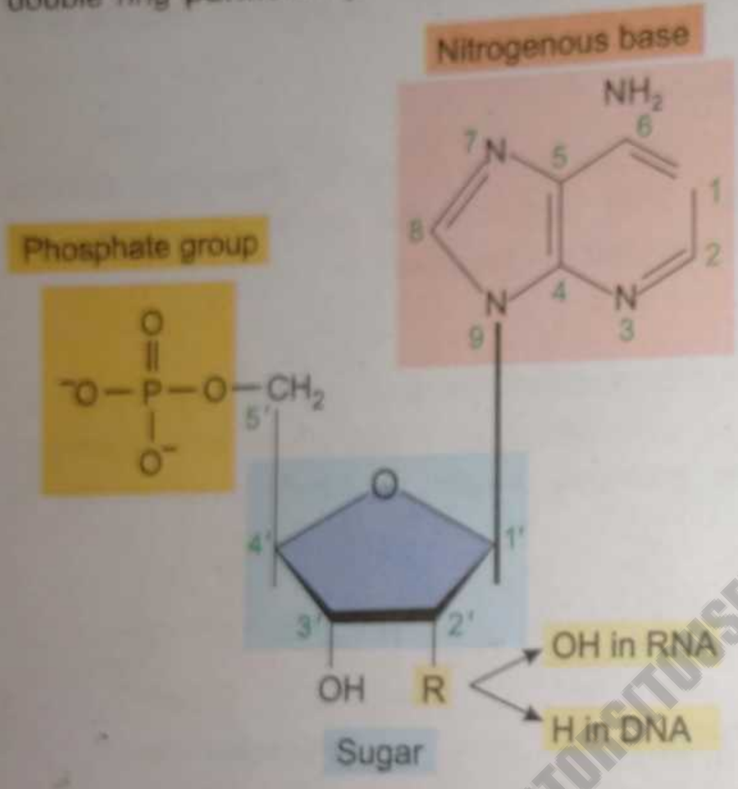


Fig. 2.31: Structure of a nucleotide

During the formation of a nucleotide, first nitrogenous base is linked with 1′ carbon of pentose sugar. Such combination is called **nucleoside**. When a phosphoric acid is linked with 5′ carbon of pentose sugar of a nucleoside, the nucleotide is formed. A nucleotide with one phosphoric acid is called **nucleoside monophosphate** with two phosphoric acids is called **nucleoside diphosphate** and with three phosphoric acids is called **nucleoside triphosphate.**

The nucleotides which take part in the formation of DNA or RNA must contain three phosphates but during their incorporation into DNA or RNA polymer each nucleotide losses its two terminal phosphates. Different terms used for nucleosides and nucleotides are given in the table 2.7.

Table: 2.7: Different types of nucleosides and nucleotides of RNA and DNA

Nitrogenous base	RNA		DNA	
	Ribonucleosides (Ribose + Base)	Ribonucleotides (Ribose+Base+ Phosphate)	Deoxyribonucleosides (Deoxyribose + Base)	Deoxyribonucleotides (Deoxyribose+Base+ Phosphate)
Adenine	Adenosine	AMP, ADP, ATP	d-Adenosine	dAMP, dADP, dATP
Guanine	Guanosine	GMP, GDP, GTP	d-Guanosine	dGMP, dGDP, dGTP
Cytosine	Cytidine	CMP, CDP, CTP	d-Cytidine	dCMP, dCDP, dCTP
Uracil/ Thymine	Uredine	UMP, UDP, UTP	d-Thymidine	dTMP, dTDP, dTTP

Polymerization of nucleotides (Formation of polynucleotide)

Nucleotides are also joined together by a condensation reaction like other biomolecules. Unlike proteins, carbohydrates, and lipids, however, the molecule that is released is not water but pyrophosphate (two phosphate groups bound together). When pyrophosphate is cleaved by the addition of water, a great deal of free energy is released which derives the process. In this way nucleotides begin to link by phosphodiester bonds and a polymer of nucleotides (polynucleotide) is formed. Polynucleotides have a free 5' phosphate group at one end and a free 3' hydroxyl group at the other end. By convention, these sequences are named from 5' to 3'.

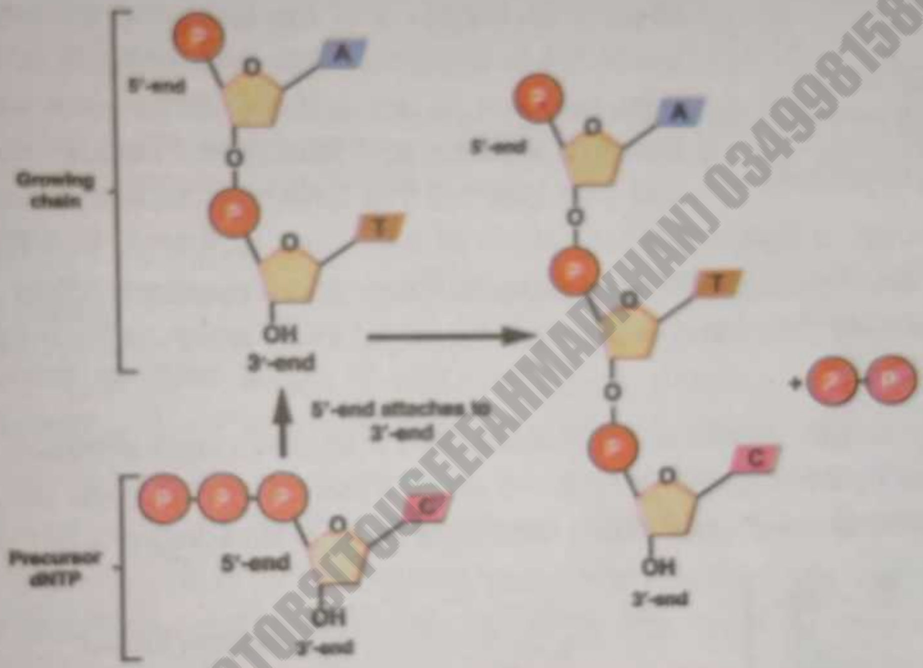


Fig. 2.32 Polymerization of nucleotides

2.6.2 Chemical Nature and Role of ATP and NAD

Adenosine triphosphate (ATP) is a mononucleotide. As shown in fig. 2.32 ATP has three parts, connected by covalent bonds: (a) adenine, a nitrogen base, (b) ribose, a five carbon sugar, (c) three phosphates. The two covalent bonds linking the three phosphates together are called **high-energy bonds**. ATP can be converted to ADP and inorganic phosphate (iP) by hydrolysis. ATP is known as the energy currency of cells.

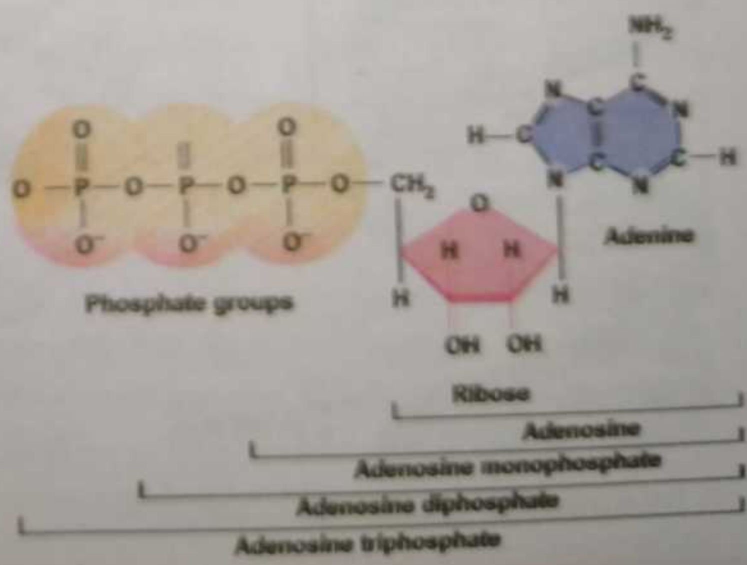


Fig. 2.33 Structure of ATP

Nicotinamide adenine dinucleotide (NAD) consists of two nucleotides. One

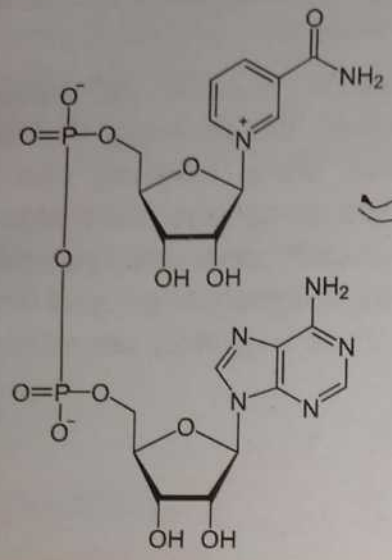


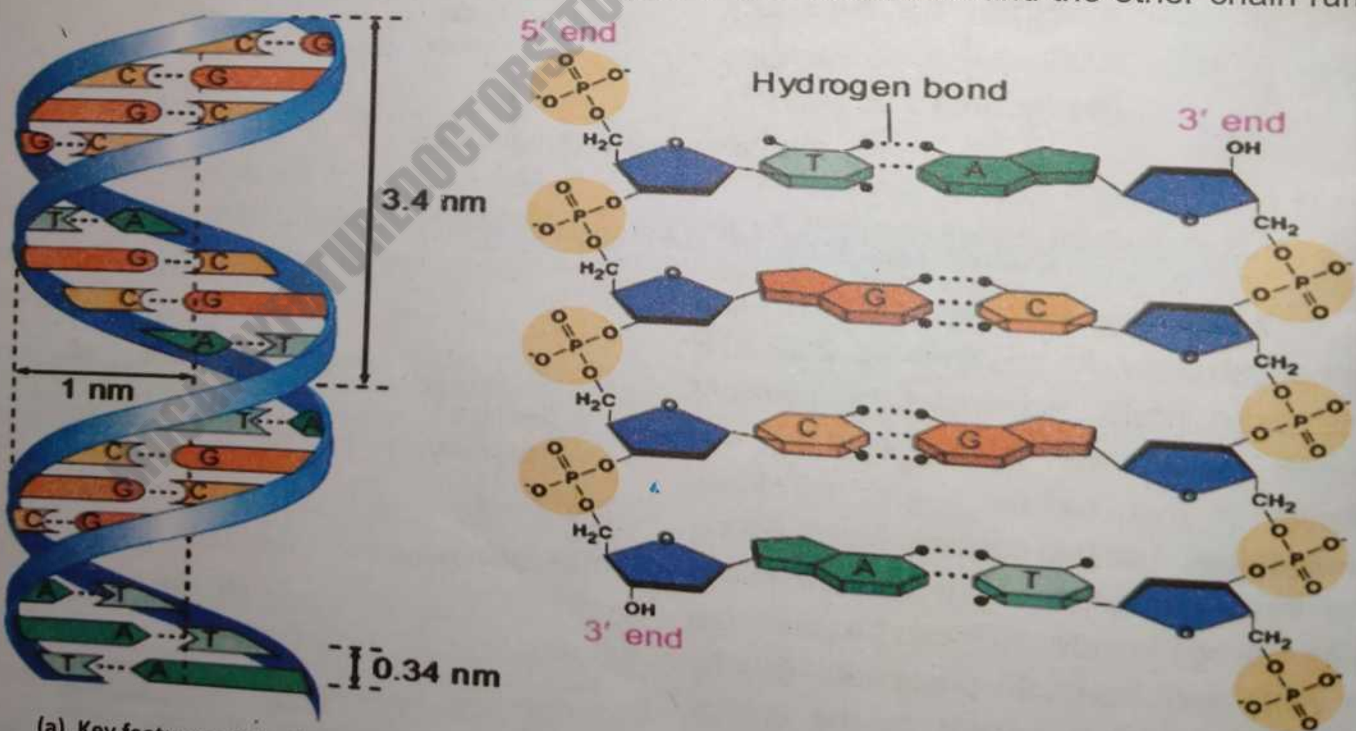
Fig. 2.34 Structure of NAD

nucleotide consists of nicotinamide, sugar and phosphate. Other nucleotide consists of adenine-sugar and phosphate. The two nucleotides are joined by their phosphate group forming a dinucleotide. NAD is a coenzyme.

2.6.3 Watson and Crick Model of DNA

In 1951, **Erwin Chargaff** found that the nitrogenous bases in a DNA show specific ratios. He observed that amount of adenine is always equal to the amount of thymine and amount of guanine is always equal to the amount of cytosine in DNA. This implies that the total purines and total pyrimidines are in 1:1 in any DNA. This conclusion is known as **Chargaff's rule**. In those days the **X-ray diffraction analysis** of DNA by **Maurice Wilkins** and **Rosalind Franklin** was published. They first time claimed that DNA is a duplex (double helix) molecule. The width of duplex is 2ηm while the length of each turn is 3.4ηm. In 1953, on the basis of these observations a graduate student **Francis Crick** and a research fellow **James Watson** of Cambridge University proposed a physical model of DNA which is now called **Watson and Crick Model of DNA**.

According to this model a DNA is made up of two polynucleotide chains which are attached together by base pairs. In order to make base pairing the two polynucleotide chains are opposite in direction i.e., one chain runs from 5′ to 3′ downward and the other chain runs



(a) Key features of double helix model

(b) Partial chemical structure

Fig. 2.35 Watson and Crick model of DNA

from 5′ to 3′ upward. Both chains show a constant width of 2 ηm. Therefore, both chains are supposed be antiparallel to each other. The base pairing is very specific i.e., Adenine makes the pair with Thymine and Guanine with Cytosine. The base pairs are held together by the hydrogen bond. There are three hydrogen bonds between Guanine and Cytosine and two hydrogen bonds between Adenine and Thymine. Each turn of the duplex consist of 10 base pairs. Both polynucleotide chains are complementary to each other. There is no restriction of the sequence of nucleotides along the length of a DNA strand. The sequence can vary in countless ways. The sequence is specific for different species, organisms and even individuals.

Science Titbits

Watson and Crick assembled the molecular model and published their two-page article on their molecular model of DNA in the journal *"Nature"* in April 1953. Few milestones in the history of biology have as broad an impact as their double helix. They were awarded Nobel Prize in 1962 for their model of DNA.

2.6.4 Concept of Gene

A gene is region of DNA which is made up of nucleotides. It is the physical and functional unit of heredity. Each gene contains the information required to build specific proteins needed in an organism, such as they contain the instructions for our individual characteristics – like eye and hair colour. In order to make proteins, the gene from the DNA is copied into messenger RNA. The mRNA moves out of the nucleus and uses ribosomes to form the polypeptide that finally folds and configures to form the protein.

2.6.5 Ribonucleic Acid (RNA)

RNA is also a polymer of nucleotides. Its detailed chemical nature has already been discussed in previous topics. Unlike DNA, the RNA is generally single stranded and does not form a double helix like DNA. However, some regions of RNA shows a secondary double stranded structure in their complementary regions. There are three major classes of RNA each with a special function in protein synthesis. These RNA are transcribed from DNA template.

Messenger RNA (mRNA)

mRNA consists of a single strand of variable length. Its length depends upon the size of the gene, as well as the protein for which it is taking message. For example, for a protein molecule consisting of 100 amino acids, the mRNA will have the length of 300 nucleotides. Actually every three nucleotides in mRNA encode a specific amino acid, such triplets of nucleotides along the length of mRNA are called **codons** of **genetic codes**. mRNA is about 3 to 4% of the total RNA in the cell. mRNA takes the genetic message from the nucleus to the ribosome in the cytoplasm to form particular protein. This process is known as **translation**.

Ribosomal RNA (rRNA)

Ribosome consists of rRNA and protein. rRNA is transcribed by the genes present on the DNA of the several chromosomes. It is called rRNA because it eventually becomes part of ribosome. The rRNA is packaged with a variety of proteins into ribosomal subunits. The base sequence of rRNA is similar from bacteria to higher plants and animals. rRNA have largest size among the RNA. Approximately, 80% of total RNA contents of a cell are rRNA. It is a part of ribosome where protein synthesis takes place. In other words rRNA provides a platform for protein synthesis.

Transfer RNA (tRNA)

It is the smallest of the RNA molecules and it consists of 75 to 90 nucleotides. A tRNA is a single stranded molecule but it shows a duplex appearance at its some regions where complementary bases are bonded to one another. It shows a flat cloverleaf shape in two dimensional views. Its 5′ end always terminates in Guanine base while the 3′ end is always terminated with base sequence of CCA. Amino acid is attached to tRNA at this end. The nucleotide sequence of the rest of the molecule is variable.

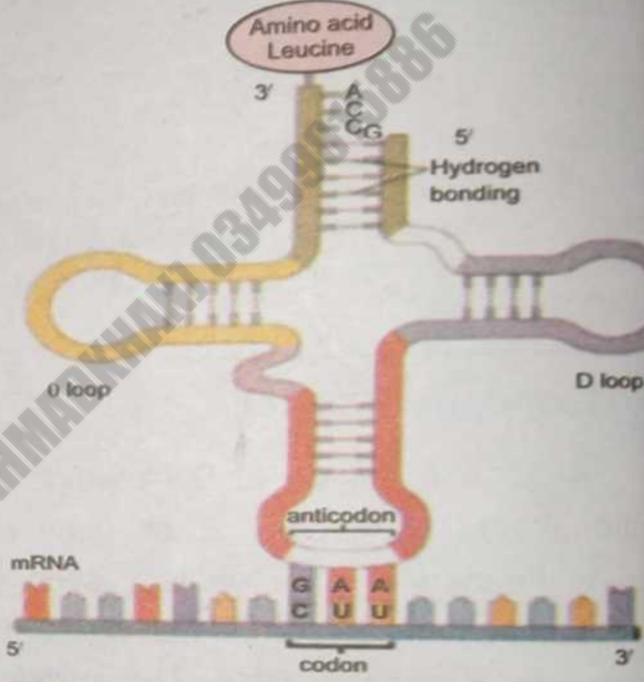


Fig: 2.36: Cloverleaf model of tRNA

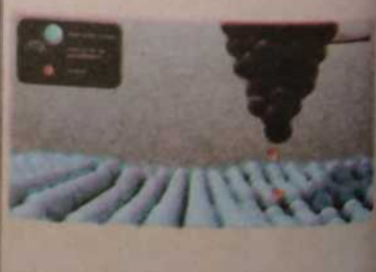
tRNA has three loops. The middle loop in all the tRNA is composed of 7 bases, the middle three of which form the **anticodon**; it is complementary to specific **codon** of mRNA. The D loop recognizes the activation enzyme. Theta (θ) loop recognizes the specific place on the ribosome for binding during protein synthesis. There is at least one tRNA molecule for each of the 20 amino acids found in proteins. Sixty tRNA have been identified. However, human cells contain about 45 different kinds of tRNA molecules, each transports a specific amino acid from cytoplasm to the surface of ribosome for protein synthesis.

Science, Technology and Society Connections

- **Correlate the scanning tunnelling microscope as the latest advancement for seeing the atoms of DNA.**

The Scanning tunneling microscope was invented in 1980. It can allow scientists to view atoms on the surface of a solid. It is a very powerful tool that can be used to resolve features less than a nanometer. The microscope's inventors, Gerd Binnig and Heinrich Rohrer were awarded Nobel Prize in Physics in 1986. Seeman's group worked on the DNA nanotechnology. They constructed molecular building blocks of DNA.


Scanning tunneling microscope


Atoms seen on the surface of a solid

2.7 CONJUGATED MOLECUELS

Molecules when joined by other kinds of molecules are called conjugated molecules. The examples are glyocolipids, glycoproteins, lipoproteins and nucleoproteins.

Glycolipids are complex lipids containing one or more simple sugars in connection with long fatty acids or alcohol. Glycolipids are present in white matter of brain and myelin sheath of nerve fibres and chloroplast membrane.

Glycoproteins are formed when proteins are covalently attached to carbohydrates. Glycoproteins are widely distributed in the cells. They function as hormones, transport proteins, structured proteins and receptors. The blood group antigens contain glycoproteins, which also play an important role in blood grouping.

Lipoproteins are formed by the combination of protein with phospholipids. Phospholipid protein complexes are widely distributed in plant and animal material. They occur in milk, blood, cell nucleus, egg yolk membrane and chloroplasts of plants.

Nucleoproteins consist of simple basic protein and nucleic acid. They are found in chromosomes and ribosomes.

Science Titbits

Why do the nucleotides in DNA have a hydrogen atom at the 2' carbon instead of the hydroxyl group in ribose? The answer is that a hydroxyl group at the 2' position can participate in a reaction that cleaves the phosphodiester bond. Thus, DNA can act as a stable long-term repository for genetic information. RNA is usually degraded within your cells in 30 minutes.

Skills: Analyzing, Interpreting, and Communication

- Draw the Watson—Crick model of DNA
- Illustrate the formation of phosphodiester linkage

Science Technology and Society Connections

- **List the career opportunities in the field of biochemistry.**

Biochemistry, the study of chemical processes that take place in living organisms, is a broad field that offers a wide range of career options. Biochemists can pursue stem cell or genetic research that has the potential to result in dramatic medical or scientific breakthroughs. Some biochemists study the body's immune response to germs and allergens or the effectiveness of drugs in treating a wide array of afflictions. Other biochemists work in the commercial food or agricultural field looking for ways to improve products and crops. The many and diverse applications of biochemistry include pharmacology, genetics, immunology, bioinformatics, environmental science, forensics, toxicological studies and food science. The career options are nearly endless, and still unfolding, as new applications for this exciting field of study continue to evolve.

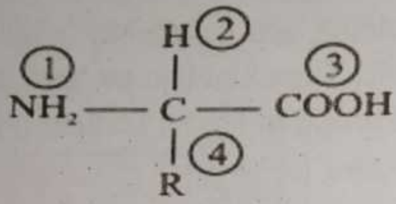
Activity

1. Performing Benedict's test for reducing sugars and confirmation of the presence of starch through Iodine test
2. Confirmation of the presence of proteins through Biuret test
3. Confirmation of the presence of lipids through Emulsion test
4. Demonstration of the presence of nucleic acids in biological materials e.g., onion

Exercise

MCQs

1. Select the correct answer



(i) An amino acid molecule has the following structure:

Which two of the groups combine to form a peptide link between two amino acids?

(A) 1 and 2 (B) 1 and 3 (C) 2 and 3 (D) 2 and 4

(ii) Which class of molecule is the major component of cell membrane

(A) phospholipid (B) cellulose (C) wax (D) triglyceride

(iii) Glycerol is the backbone molecule for

(A) ATP (B) terpenes (C) neutral lipids (D) steroids

(iv) A fatty acid is unsaturated if it

(A) contains hydrogen (B) contains double bonds

(C) contains an acid group (D) all of them

(v) In RNA the nitrogen base that takes the place of thymine is

(A) adenine (B) cytosine (C) guanine (D) uracil

(vi) The ending—ose means a substance is a

(A) sugar (B) lipid (C) protein (D) nucleic acid

(vii) Glycolipids and lipoprotein are important components of

(A) cellular membrane (B) cell wall (C) both of them (D) none of them

(viii) When two amino acids are linked to form peptide linkage .... is removed

(A) hydroxyl (B) water (C) carbon (D) nitrogen

(ix) What is the theoretical number of chemically different dipeptides that may be assembled from two amino acids?

(A) one (B) two (C) three (D) four

(x) A polar molecule is .... in water

(A) soluble (B) insoluble (C) reactive (D) innert

(xi) Which statement correctly describes a property of water?

(A) a relatively large amount of heat is needed to increase its temperature

(B) at normal room temperature, its molecules are bound together by ionic bonds

(C) the highest density of water occurs below its freezing point

(D) water acts as solvent for nonpolar molecules

(xii) Estrogen, vitamin-D and cholesterol are all examples of

(A) glycolipids (B) lipoproteins (C) terpenes (D) steroids

(xiii) Which term includes all others?

(A) carbohydrate (B) starch (C) monosaccharide (D) polysaccharide

(xiv) Choose the pair of terms that correctly completes this sentence: Nucleotide are to ------as --------are to proteins.

(A) nucleic acids; amino acids (B) amino acids; polypeptides

(C) glycosidic linkages; polypeptide linkages (D) polymers; polypeptides

(xv) The enantiomer of D-glucose is

(A) D-galactose (B) L-galactose (C) both of them (D) none of them

Short Questions

2. How would you describe biochemistry?
3. What are bioelements?
4. Describe the chemical composition of protoplasm.
5. What are the four fundamental kinds of biological molecules? Explain.
6. Why is the covalent bond in water polar?
7. Why water is regarded as universal solvent?
8. What is the importance of hydrogen bonding?
9. Why very large amount of heat can increase very little temperature in water?
10. How water protects living things against sudden thermal change?
11. What is the importance of high heat of vapourization of water to animals?
12. Describe classification of carbohydrates.
13. Describe the classification of monosaccharides?
14. Describe the conversion of open chain of ribose into ring chain.
15. Draw and label the ring forms of alpha and beta glucose.
16. Justify that the laboratory-manufactured sweeteners are "left handed" sugars and cannot be metabolized by the "right handed" enzymes.

17. Illustrate the formation and breakage of (a) sucrose (b) maltose (c) lactose.
18. Draw the structural formula of amino acid.
19. Describe the synthesis of peptide bond
20. Describe the four types of structure of proteins.
21. Describe (a) globular proteins (b) fibrous proteins.
22. Describe the classification of lipids
23. What role do lipids play in living organisms?
24. Why phospholipids form a thin layer on the surface of an aqueous solution?
25. What is isoprene unit? Explain.
26. Describe a steroid nucleus.
27. How might an error in the DNA of an organism effect protein function?
28. Define gene is a sequence of nucleotides as part of DNA, which codes for the formation of a polypeptide.
29. Write the differences between:

(a) major and minor bioelements
(b) dimer and polymer
(c) polar and nonpolar covalent bond
(d) polyhydroxy aldehyde and polyhydroxy ketone
(e) alpha and beta glucose
(f) D-glucose and L-glucose
(g) amylase and amylopectin
(h) amylopectin and glycogen
(i) primary and secondary structure of proteins
(j) tertiary and quaternary structure of proteins
(k) purine and pyrimidine
(l) saturated and unsaturated fatty acids
(m) DNA and RNA

Extensive Questions

30. Describe the chemical composition of protoplasm.
31. Distinguish carbohydrates, proteins, lipids and nucleic acids as the four fundamental kinds of biological molecules.
32. Describe and draw sketches of dehydration synthesis and hydrolysis reactions for making and breaking of macromolecule polymers.

33. How the properties of water make it the cradle of life?
34. Distinguish the properties and role of monosaccharides.
35. Write the emperical formula of monosaccharides and classify them.
36. Compare the stereoisomers of glucose.
37. Distinguish the properties and role of disaccharides.
38. Describe glycoside bond in the transport of disaccharides.
39. Distinguish the properties and role of polysaccharides.
40. Describe the properties and roles of starch, glycogen, cellulose and chitin.
41. Justify the significance of the sequence of amino acids through the example of sickle cell haemoglobin.
42. List examples and the roles of structural and functional proteins.
43. Describe the properties and roles of:
    (a) acylglycerol
    (b) phospholipids
    (c) terpenes
    (d) waxes
44. Evaluate the role of the following as important groups of lipids and describe their roles in living organism:
    (a) steroid
    (b) prostaglandins
45. Describe the molecular level structure of nucleotides.
46. Distinguish among the nitrogenous bases found in the nucleotides of nucleic acids.
47. Describe the structure of a mononucleotide (ATP) and a dinucleotide (NAD).
48. Explain the formation of phosphodiester bond.
49. Explain the double helical strucutre of DNA as proposed by Watson and Crick.
50. What is a gene? How gene codes for the formation of a polypeptide?
51. Explain general strucutre of RNA.
52. Explain the structure and role of three types of RNA.
53. Describe the roles of the following conjugated molecules:
    (a) glycolipids
    (b) glycoproteins
    (c) lipoproteins
    (d) nucleoproteins

3

ENZYMES

After completing this lesson, you will be able to

- Describe the structure of enzyme.
- Explain the role and component parts of the active site of an enzyme.
- Differentiate among the three types of co-factors i.e. in organic 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 temperatures 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, pepane.
- 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 rate 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, hydrolyases, isomerases, and ligases).
- Classify enzymes on the basis of the substrates they use (lipases, diastase, amylase, proteases etc).

You got a brief introduction about enzymes in IX-X biology course. There is complete check and balance on the chemistry of cell, which is exhibited through various enzymatic reactions going on within a cell. The concepts developed in this chapter will construct knowledge where you will be able to analyze comprehend and apply that knowledge.

The sum of all the chemical reactions going on in a cell is known as **metabolism**. These reactions have to be carried out very quickly so that their products can be utilized in various life activities in the cells. **Enzymes** are biological catalysts and therefore they speed up the biochemical reaction without being consumed.

> **Science Titbits**
>
> During the early nineteenth century, two French chemists, **Payen** and **Persoz** grounded up barley seeds in water to make a crude mixture that would digest starch. They gave the name **diastase** whatever it was that digested the starch.

Some common properties of enzymes are:

(i) Increase the speed of chemical reaction.
(ii) Required in very small quantity for the reaction.
(iii) Highly sensitive to pH and temperature.
(iv) Either highly specific or slightly less specific.
(v) Can work in *vivo* (living cells) as well as in *vitro* (glassware).
(vi) Some require co-factor for proper activity.
(vii) Lower the need of activation energy.
(viii) Only speed up a reaction and do not affect the equilibrium of the reaction.

3.1 ENZYME STRUCTURE

With exception of ribozymes, all the enzymes are globular proteins which are made up of one or more polypeptides. **Ribozymes** are the enzymes which consist of RNA and are found in ribosomes. For example, peptidyl transferase is a ribozyme which forms peptide bond during protein synthesis.

3.1.1 Shape of Enzymes and Components of an Active Site

Majority of enzymes which are protein in nature can have molecular weights ranging from about 10,000 to over 1 million. Such enzymes have tertiary or quaternary structures. The catalytic activity of an enzyme is located in its **active site** which is a specific charge bearing, three dimensional cavity. The substrate (the reactant which is to be converted into product) molecule is attached to the active site by non-covalent interactions like hydrogen bonding and hydrophobic interactions. Active site consists of 3-12 amino acids which may be scattered in the polypeptide but are brought together in a particular fashion due to secondary and tertiary folding of the protein molecule, e.g., the active site for aldolase consists of glycine, histidine, and alanine amino acids. An active site consists of two functional regions, i.e., binding site and catalytic site. Some amino acids have active site which makes bonds with substrate constitute the **binding site** while the other amino acids which cause conversion of substrate

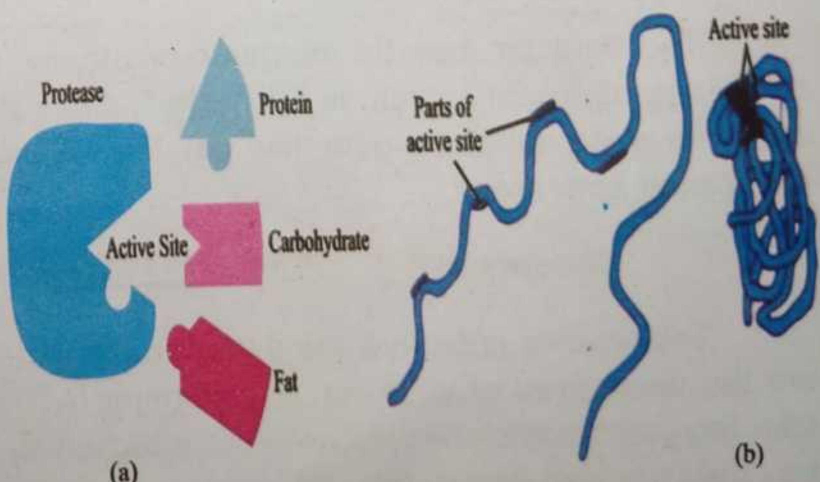


Fig: 3.1: Active site: (a) Which substrate fits the active site? (b) Grouping of amino acids of a polypeptide during the formation of tertiary structure to produce an active site.

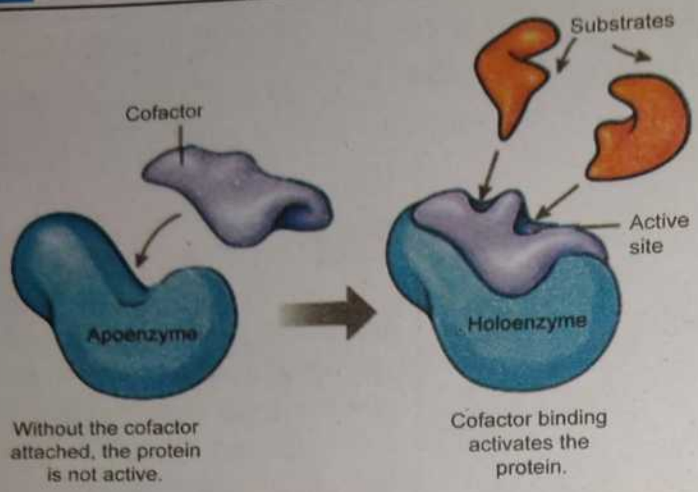


Fig. 3.2 Structure of enzyme

into product (catalysis) constitute the **catalytic site**. The shape of active site is designed according to the substrate therefore only a particular substrate can attach to the active site, however, sometime related substrate can also bind to the active site.

Some enzymes also require a non-protein part, the **cofactor** which is not only responsible for the attachment of substrate to the active site but also participate in catalytic process. The final shape of active site is actually established after the attachment of cofactor. An enzyme which requires a cofactor becomes active only if the cofactor is combined with it. Such an active enzyme is called **holoenzyme**. If the cofactor is not available the remaining protein part of enzyme becomes catalytically inactive and is called **apoenzyme**. On the other hand, the enzymes which do not require cofactor can also show active and inactive states. Pepsin is an example of such enzyme. It is secreted by gastric gland from stomach wall in an inactive state, the **pepsinogen**. In this state, it has an additional polypeptide fragment attached to its active site which does not allow the binding of substrate, hence it remains inactive. When pepsinogen is exposed in HCl (as in stomach cavity) the additional polypeptide fragment is removed and as a result inactive (apoenzyme) pepsinogen is changed into its active (holoenzyme) form, the **pepsin**.

Science Titbits

How are enzymes formed? Enzymes are proteins, so they are formed as per message or base sequence in DNA. Enzymes are synthesized by living cells but they retain their catalytic action even when extracted from cells, i.e., they can act in vitro. These days' enzymes are also being produced by recombinant DNA technology.

3.1.2 Types of Cofactors

The cofactor may be inorganic or organic molecules. The inorganic cofactors are different metallic ions such as Fe^{++}, Mg^{++}, Cu^{++}, Zn^{++}, etc. These are only attached to the enzymes when substrate gets bind i.e., they are detachable cofactors. Such cofactors are also called **activators**.

$$\text{Glucose + ATP} \xrightarrow{\text{Hexokinase} + Mg^{+2}} \text{Glucose-6-phosphate + ADP}$$

The organic cofactors are either co-enzymes or prosthetic groups. The **coenzymes** are the derivatives of vitamins. For example ATP, NAD^+, FAD^+ are common coenzymes. Like inorganic cofactors they are also attached to the enzymes when substrate gets bind i.e., they are also detachable cofactors.

$$\text{Ethyl alcohol} \xrightarrow{\text{Alcohol dehydrogenase} + NAD^+} \text{Acetaldehyde} + NADH_2$$

On the other hand a **prosthetic group** is covalently bonded part of an enzyme which is permanently attached to enzyme and does not detach after the completion of reaction. An iron containing porphyrin ring attached to some enzymes like cytochromes is the example of prosthetic group.

3.2 MECHANISM OF ENZYME ACTION

In an enzyme-catalysed reaction, the substrate first binds to the active site of the enzyme to form an **enzyme-substrate (ES) complex**, then the substrate is converted into **product** while it is attached to the enzyme **(EP complex)**, and finally the product is released, thus allowing the enzyme to start all over again.

$$\underset{\text{enzyme}}{E} + \underset{\text{substrate}}{S} \longrightarrow \underset{\text{enzyme-substrate complex}}{ES} \longrightarrow \underset{\text{enzyme-product complex}}{EP} \longrightarrow \underset{\text{enzyme}}{E} + \underset{\text{product}}{P}$$

Actually, the enzyme can make the local conditions inside the active site quite different from those outside (such as pH, water concentration, charge), so that the reaction is more likely to happen. For example, if a substrate is to be split, a bond might be stretched by the enzyme, making it more likely to break.

3.2.1 Models of Enzyme Action

The mechanism of enzyme action can be explained with the help of two different models. **Emil Fischer** proposed **Lock and key model** (in 1894). According to this model the active site of the enzyme has definite shape and rigid structure. Shape of active site is complementary to the shape of substrate. Therefore, a particular substrate can only bind to the active site. The active site remains unchanged during or after the reaction. Lock and key model assumes that like a particular key opens a particular lock, a specific **enzyme (key)** acts upon a particular **substrate (lock).** Actually, the notched portion of the key is equivalent to the active site on the enzyme. It reflects that enzymes are highly specific in their action and each enzyme can carry out only one particular reaction. The enzymes,

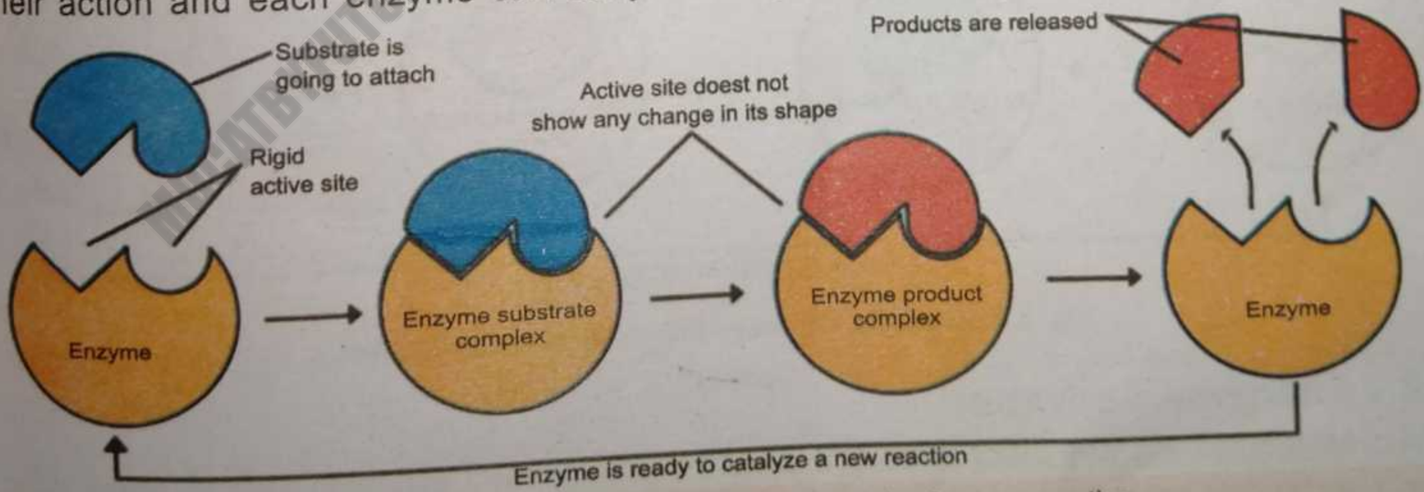


Fig: 3.3: Fischer's "Lock and Key" hypothesis of enzyme action

which work according to this model, are called **non-regulatory enzymes**. However, this model is exercised by a very small number of enzymes, for example sucrase, maltase etc. The ability of enzyme to catalyze one specific reaction is perhaps its most significant property. Although, many enzymes show a broad range of specificity towards the substrate they catalyze. When one enzyme can catalyze only one substrate and essentially no others it is called **absolute specificity** e.g., urease.

$$\text{Urea + Water} \xrightarrow{\text{Urease}} \text{Ammonia + Carbon dioxide}$$

Koshland proposed **Induced fit model** (in 1959). According to this model the active site is flexible; therefore, it is modified as the substrate interacts with enzyme. The amino acids, which makeup the active site are molded into a precise shape which enables the enzyme to perform its catalytic function more effectively. The change which is induced in the shape of active site is responsible for the conversion of substrate into product. As the reaction is completed the active site regains its original shape. This is the flexibility of active site which allows more than one type of related substrates to be attached on active site and therefore, an enzyme can carry out more than one type of related reactions. The example is carbonic anhydrase which can add O_2 to haemoglobin as well as can control the formation of carbonic acid and bicarbonates in blood.

Enzymes, which follow the induced fit mechanism, are called **regulatory** or **allosteric enzymes** for example hexokinase.

$$Hb + 4O_2 \xrightarrow{\text{Carbonic anhydrase}} Hb4O_2 \text{ (Oxyhaemoglobin)}$$

$$CO_2 + H_2O \xrightarrow{\text{Carbonic anhydrase}} H_2CO_3 \xrightarrow{\text{Carbonic anhydrase}} H^+ + HCO^-$$

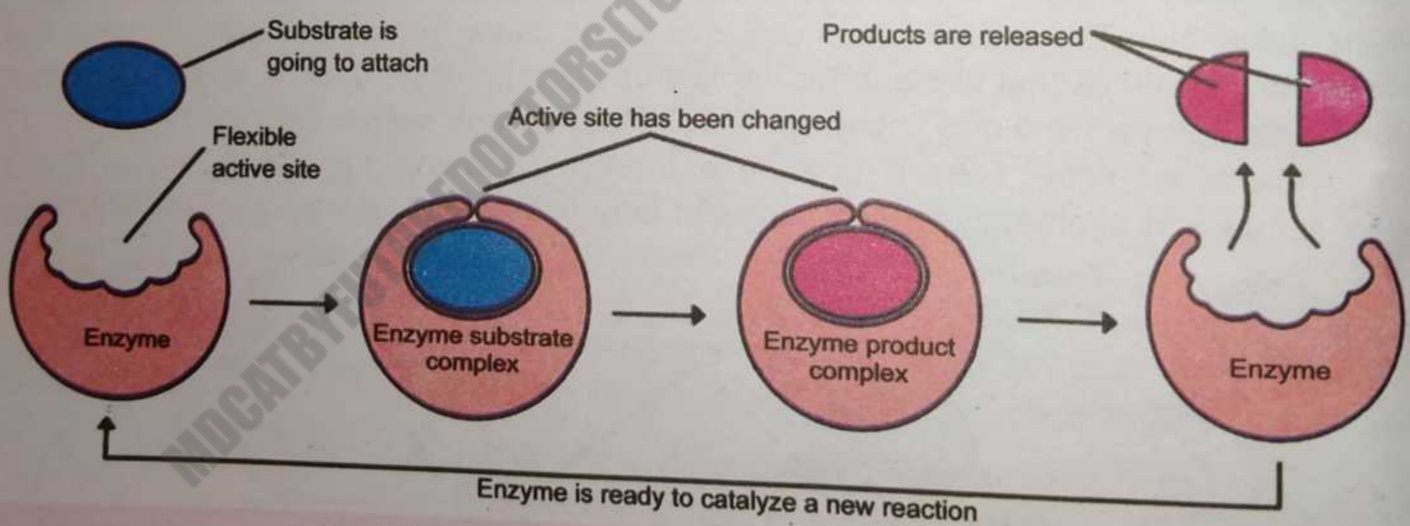


Fig: 3.4: Koshland's "Induced Fit" model of enzyme action

3.2.2 Energy of Activation

Molecules do not react with one another unless they are activated in some way. The energy that must be added to cause molecules to react with one another is called the **energy of activation**. In nonliving system we use heat as energy of activation to increase the number of effective collision between molecules. In living systems large amount of heat cannot be used as energy of activation. Why? All living cells and organisms are mainly composed of temperature sensitive protein molecules. About 1,000 chemical reactions are being carried out in a cell at any time. Energy of activation required for such a large number of reactions cannot be provided by living system.

The living system works in isothermal condition. The excited state of molecules or reactants is achieved by biochemical process. Enzyme (E) reacts with reactant (A) to form an AE transitional complex. The energy level of AE complex reaches to the energy level of reactant B. AE complex then reacts with reactant B to form AB and enzyme (E) is released.

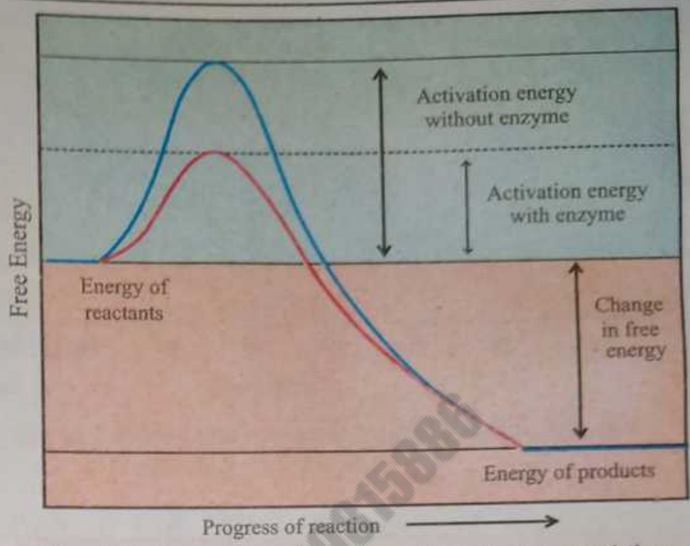


Fig: 3.5: Energy of activation: Enzymes speed the rate of chemical reactions because they lower the amount of energy required to activate the reactants and lower the need of activation energy

$$A + E \longrightarrow AE\ Complex + B \longrightarrow AB + E$$

Enzyme does decrease the energy of activation by changing energy dependent process to energy independent process. Thus the energy of activation is "energy required to break the existing bonds and begin the reaction". An enzyme greatly reduces the activation energy necessary to initiate a chemical reaction.

3.3 FACTORS AFFECTING THE RATE OF ENZYMATIC ACTION

The rate of enzymatic reaction is measured by the amount of substrate changed or amount of product formed, during a period of time. The external conditions which affect rate of enzyme reactions are: temperature, pH, concentration of enzyme and substrate concentration.

3.3.1 Temperature

Heating increases molecular motion. Thus the molecules of the substrate and enzyme move more quickly, so probability of a reaction to occur is increased. Increasing temperature affect the rate of reaction in such a way that an increase of just 10°C in the existing temperature doubles the rate of reaction but this effect remains up to a certain limit. The temperature that promotes maximum activity is called an **optimum temperature**. If the temperature is increased above this level, then a decrease in the rate of the reaction occurs despite the increasing frequencies of collision. This is because the secondary and tertiary structures of the enzyme have been disrupted

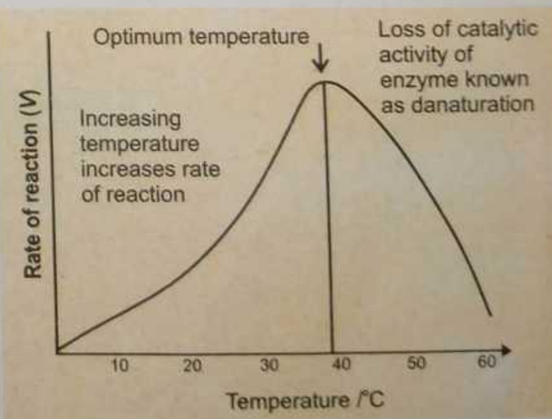


Fig: 3.6 (a): Effect of temperature on the rate of an enzyme controlled reaction

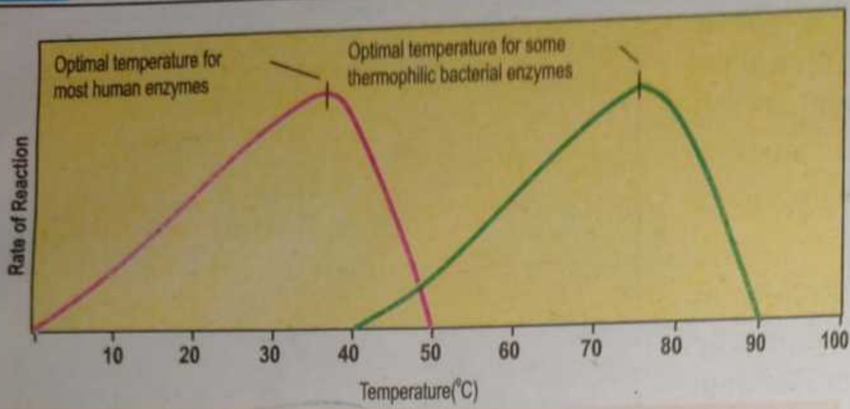


Fig: 3.6 (b): Optimum temperature for human enzymes and thermophilic bacteria

and the enzyme is said to be denatured. The enzyme unfolds and the precise structure of the active site is gradually lost. This temperature which causes denaturation of enzyme is called **maximum temperature.** The bonds which are most sensitive to temperature change are hydrogen bonds. All human enzymes have a optimum temperature of about 37-38°C, but bacteria living in hot springs may have an optimum temperature of 70°C or higher. Such enzymes have been used in biological washing powders for high temperature washes. If temperature is reduced to near or below freezing point, enzymes are inactivated, not denatured. They will regain their catalytic influence when higher temperatures are restored. This temperature where an inactive enzyme becomes active again is called **minimum temperature.**

3.3.2 pH

Every enzyme functions most effectively over a particular pH range. This narrow range of pH at which the maximum rate of reaction is achieved is called **optimum pH**. Enzyme conformation is sensitive to pH changes because pH influences the charges on the amino acid side chains that are involved in maintaining tertiary and quaternary structure of enzyme. Slight change in optimum pH of an enzyme causes ionization of amino acid of the enzyme therefore, they become inactive temporarily. On the other hand, extreme changes in optimum pH alter the ionic charge of the acidic and basic groups of enzyme and therefore disrupts the ionic bonding (denaturation) that helps to maintain the specific shape of the enzyme.

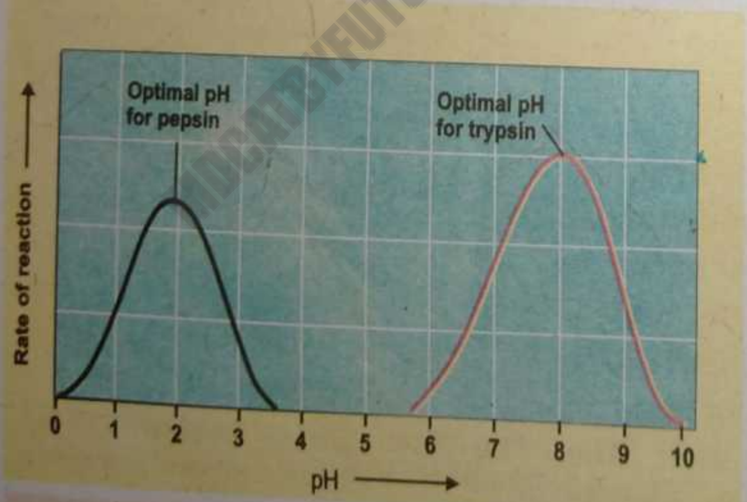


Fig: 3.7: Effect of pH on the rate of enzyme-controlled reaction

The optimum pH values for most enzymes fall in the range of pH 6-8, but there are exceptions. Some enzymes like papain from green papaya act both in acidic and alkaline media. Protein digesting enzyme pepsin is active in acidic medium at pH 2 and trypsin is inactive at this pH but shows maximum activity in alkaline medium at pH 8.

Critical Thinking

Industrial pollution can change the pH of a pond, lake or river to make the water more acidic. How can this affect the metabolic pathways of the plants that live in water?

3.3.3 Enzyme Concentration

Provided that the substrate concentration is maintained at a high level (unlimited availability), and other conditions such as pH and temperature are kept constant, the rate of reaction becomes directly proportional to the enzyme concentration. If there is only one enzyme in the system it can convert hundreds of substrates into products but it takes more time. By increasing concentration of enzyme, numbers of active sites become more available and the rate of conversion of substrate into product becomes fast. Such effect persists till the equilibrium state (when concentration of enzyme and substrate becomes equal), after that further increase in enzyme concentration will have no effect upon rate of reaction.

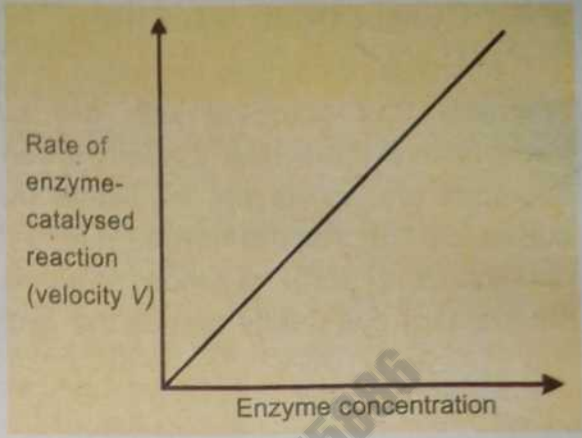


Fig: 3.8: Relationship between Enzyme concentration and the rate of an Enzyme-controlled reaction

3.3.4 Substrate Concentration

When other conditions such as pH and temperature are kept constant and the enzyme concentration is maintained at a higher level (unlimited availability), the increase in substrate concentration (S) increases the velocity (V) of the enzymatic reaction at first. The reaction ultimately reaches a maximum velocity at equilibrium state. The rise in V is decreased progressively with further increase in S. The reaction does not increase by any further rise in substrate concentration. This happens because all the active sites of enzyme molecules are occupied by the substrates (saturation) and no enzyme is left free to bind with additional molecules of the substrate.

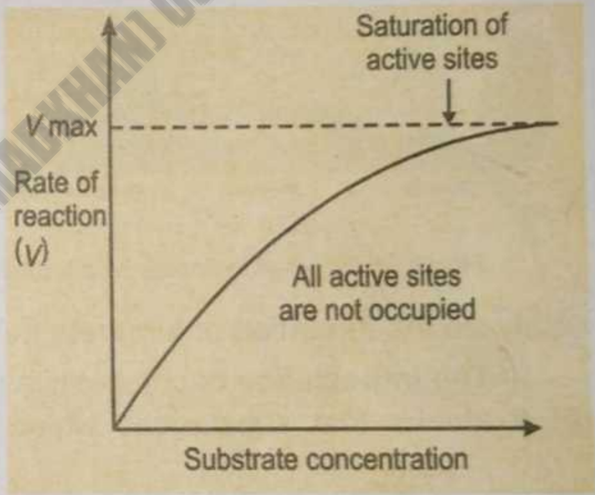


Fig: 3.9: Effect of Substrate concentration on the rate of Enzyme-controlled reaction

3.4 ENZYME INHIBITION

The phenomenon in which an enzyme fails to catalyze a reaction is called **enzyme inhibition** and the molecules which react with enzyme but are not converted into desired products are called **enzyme inhibitors**. In general, the enzyme inhibition is a normal part of the regulation of enzyme activity within cells but sometimes when external factors cause enzyme inhibition; it may become dangerous for life. The molecules which act as inhibitors include poisons, cyanides, antibodies, anti-metabolites, penicillin, sulpha drugs etc. Inhibition may be competitive or noncompetitive.

Science Titbits

Penicillin blocks the active site of an enzyme unique to bacteria. When penicillin is taken, bacteria die but human are unaffected.

3.4.1 Competitive Inhibition

A type of enzyme inhibition in which enzyme activity is blocked by the presence of a chemical that compete with the substrate for binding to the active site is called **competitive inhibition**. Usually a competitive inhibitor is structurally similar to the normal substrate and so fits into the active site of the enzyme. However, it is not similar enough to substitute fully for the normal substrate in the chemical reaction and the enzyme cannot catalyze it to form reaction products. Competitive inhibition is usually temporary, and the inhibitor eventually leaves the enzyme hence it is also called **reversible inhibition**. This means that the level of inhibition depends on the relative concentrations of substrate and i nhibitor, since they are competing for places in enzyme active sites. Therefore, if the concentration of the substrate is increased relative to the concentration of the inhibitor, the active site will usually be occupied by the substrate. An example of inhibitor is **malonate**. Succinate dehydrogenase that catalyzes the formation of fumarate from succinate is competitively inhibited by malonate.

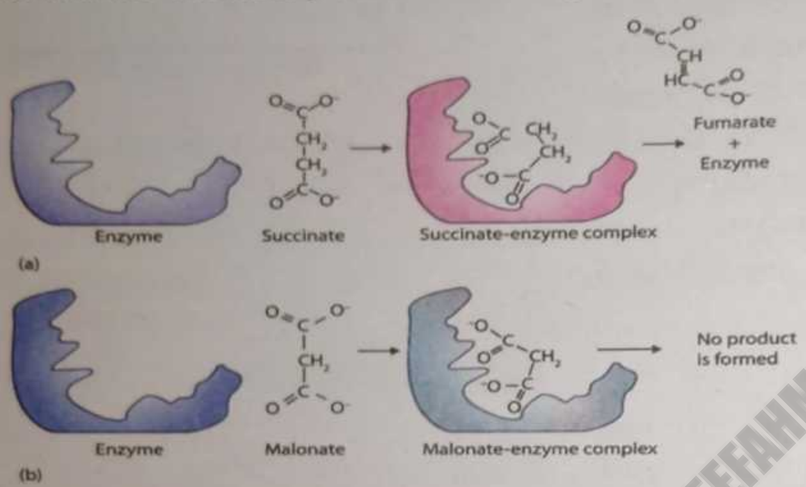


Fig: 3.10: Effect of malonate as competitive inhibitors

The **importance** of competitive inhibitors is: (a) It supports lock and key hypothesis. (b) It shows that substances which are similar to substrate are not acted upon by enzymes. (c) Competitive inhibitors are used as drugs in the control of bacterial pathogens. Antibiotics known as sulphonamides are used to combat bacterial infection.

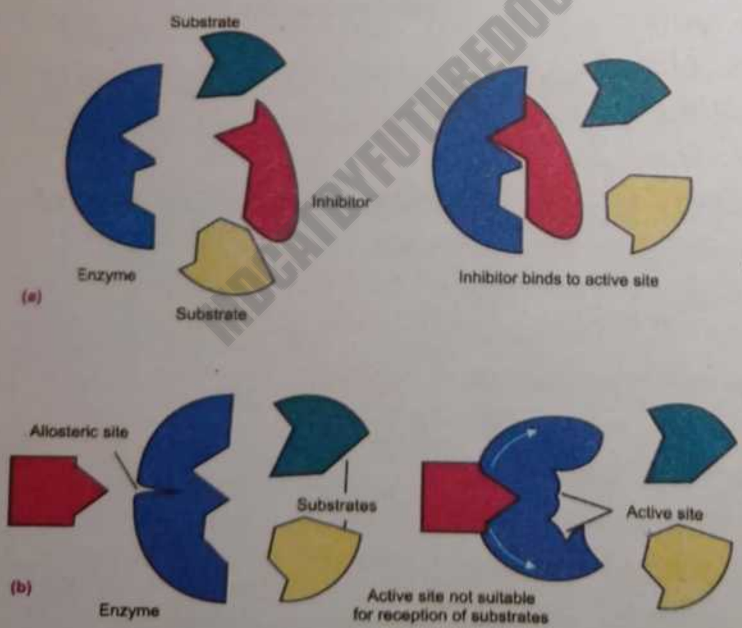


Fig: 3.11: (a) Competitive inhibition (b) Non-competitive inhibition

3.4.2 Non-Competitive Inhibitors

In non-competitive inhibition the inhibitor molecule binds to an enzyme other than active site. The other binding site of enzyme is called **allosteric site**. The non-competitive inhibitors inactivate the enzyme temporarily (reversible inhibition) or they denature the enzyme permanently (irreversible inhibition). **Reversible non-competitive** enzyme inhibitors work not by preventing the formation of enzyme-substrate complexes, but by preventing the formation of enzyme-product complexes. So they prevent the substrate to be converted into product. Feedback inhibition is an example of reversible non-competitive enzyme inhibition

On the other hand, an **irreversible non-competitive** enzyme inhibitor destroys enzyme by altering its shape so that the substrate cannot bind to the active site. The examples of irreversible non-competitive inhibitors include cyanides and salts of heavy metals. **Cyanides** are potent poisons of living organism because they can kill an organism by inhibiting cytochrome oxidase essential for cellular respiration. They block the action of these enzymes by combining with iron which may be present in the prosthetic group. **Ions of heavy metals** such as mercury, silver and copper (Hg^{++}, Ag^{+}, and Cu^{++}) combine with thiol (-SH) groups in the enzyme breaking the disulphide bridges. These bridges are important in maintaining tertiary structure. When these bridges are broken, the enzyme becomes denatured and inactive.

Critical Thinking

Suggest why substrate concentration has no effect on non-competitive inhibition?

3.4.3 Feedback Inhibition

The activity of almost every enzyme in a cell can be regulated by its product. When the activity of an enzyme is inhibited by its own product, it is called feedback inhibition. This is a type of reversible non-competitive inhibition. This phenomenon is a part of normal regulatory mechanism and usually happens during the regulation of metabolic pathways. For example, the amino acid aspartate becomes the amino acid threonine by a sequence of five enzymatic reactions. When threonine, the end product of this pathway, is present in excess, it binds to an allosteric site on enzyme 1 on this pathway and then the active site is no longer able to bind aspartate. When all the threonine is consumed in cellular events, the threonine molecule which is attached to the allosteric site is also removed; the pathway resumes its activity once again.

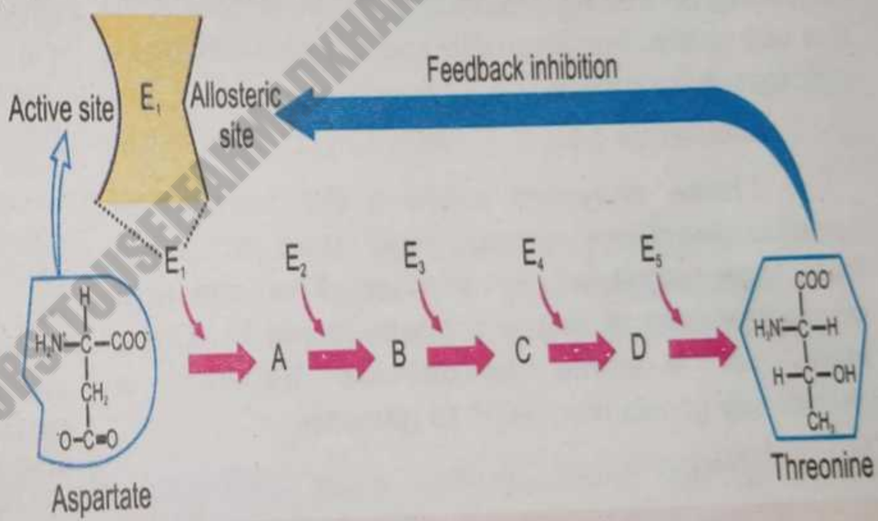


Fig: 3.12: Feedback inhibition

Skills: Analyzing

- **Identify the competitive and non-competitive inhibitors from the given list of chemical (consult any book of Biochemistry or Enzymology).** (Answer is given below)

Competitive inhibitors: Antibodies, antimetabolites, penicillin, iodoacetate, melonate, CoA (high concentration).

Non-competitive inhibitors: Acetaldehyde Di-Isopropyl fluorophosphate (DFP- nerve gas), mercury, silver, copper, cyanide.

3.5 CLASSIFICATION OF ENZYMES

Enzymes can be classified either on the basis of reaction types that they catalyze or on the basis of substrate which are acted upon by the enzyme.

3.5.1 Classification based upon reaction type

A systematic nomenclature and classification of enzymes based on reaction types and reaction mechanism was given by International Union of Biochemistry (in 1961).

On that basis all the enzymes have been classified into six groups:

1. Oxidoreductases
2. Transferases
3. Hydrolases
4. Lyases
5. Isomerases
6. Ligases

1- Oxidoreductases

These enzymes catalyze oxidation/reduction of their substrate and act by removing or adding electron or H^+ ions from or to the substrate. For example **cytochrome oxidase** oxidizes cytochrome.

2- Transferases

These enzymes catalyze the transfer of specific functional group other than hydrogen from one substrate to another. The chemical group transferred in the process is not in a free state, for example **hexokinase** transfers a phosphate group from ATP to glucose.

> **Science Titbits**
>
> **How are enzymes named?**
>
> (a) Enzymes are named by adding "ase" to the name of substrate they act, e.g., proteases, lipases etc. (b) Enzymes are named according to the types of reaction they catalyse, e.g., oxidases, reductases etc. (c) Enzymes are named by taking into consideration both the substrate acted upon and the type of reaction catalysed, e.g., DNA- polymerase. (d) Some enzymes are named as per substance synthesized, e.g., rhodonase catalyses synthesis of rhodonate from hydrochloric acid and sodium thiosulphate.

3- Hydrolases

These enzymes bring about the breakdown of large complex organic molecules into smaller ones by adding water (hydrolysis) and breaking the specific covalent bonds. Examples are proteolytic enzymes which breakdown proteins into peptones and peptides such as **pepsin, renin** and **trypsin**. Other digestive enzymes that work in digestive tract are also the examples of hydrolases.

4- Lyases

These enzymes catalyze the breakdown of specific covalent bonds and removal of groups without hydrolysis. For example **histidine decarboxylase** breaks the covalent bonds between carbon atoms in histidine forming carbon dioxide and histamine.

5- Isomerases

These enzymes bring about intra-molecular rearrangement of atoms in the molecules and thus forming one isomer from another. For example **phosphohexose isomerase** changes glucose 6- phosphate to fructose 6- phosphate.

6- Ligases (Synthetases)

These enzymes bring about joining together of two molecules. The energy is derived by hydrolysis of ATP. For example **polymerases** are responsible for linking monomers into a polymer such as DNA or RNA.

Table 3.1: Classifiation of enzymes based upon reaction type

Sr. No	Enzyme Class	General Scheme of Reaction
1.	Oxidoreductases	$A_{red} + B_{ox} \rightleftharpoons A_{ox} + B_{red}$
2.	Transferases	$A—B + C \rightarrow A + C—B$
3.	Hydrolases	$A—B + H_2O \rightarrow A—H + B—OH$
4.	Lyases	$A—B \rightleftharpoons A + B$ (reverse reaction syntheses)
5.	Isomerases	$A—B—C \rightleftharpoons A—C—B$
6.	Ligases (synthetases)	$A + B + ATP \rightarrow A—B + ADP + Pi$

3.5.2 Classification based upon substrate

Enzymes can be classified on the basis of substrates they use. Some of the examples are: proteases, lipases, carbohydrases and nucleases.

1- Proteases

These enzymes act upon proteins. Examples are: **pepsin** and **trypsin** (both digest large polypeptides into small polypeptides or peptones), **aminopeptidases** and **carboxypeptidases** (both digest peptones into dipeptides) and **erypsin** (digest dipeptides into amino acids)

2- Lipases

These enzymes hydrolyze lipids into fatty acids and glycerols. Examples are **pancreatic lipases**.

3- Carbohydrases

These enzymes cause breakdown of carbohydrates. Examples are:

(a) **amylase** (digest starch or glycogen into maltose)
(b) **cellulase** (digest cellulose into cellubiose, a disaccharide)
(c) **maltase** (digest maltose into glucoses)
(d) **sucrase** (digest sucrose into glucose and fructose)
(e) **lactase** (digest lactose into galactose and glucose)

4- Nucleases

These are involved in the breakdown of DNA and RNA. Examples are:

(a) **RNAases** (digest RNA into ribonucleotides)
(b) **DNAases** (digest DNA into deoxyribo nucleotides).
(c) **ATPases** (cause hydrolysis of ATP in muscles etc.)

Science, Technology and Society Connections

- **List the diagnostic uses of enzymes.**

(a) Aldolase: progressive muscular dystrophy, viral hepatitis and advanced cancer of the prostate
(b) Creatine Phosphokinase: damage to muscle cells.
(c) Gamma-glutamyl Transpeptidase: in assessing liver function.
(d) Lactic Dehydrogenase: in differentiating heart attack, anemia, lung injury, or liver disease.
(e) Lipase: Damage to the pancreas.

Science, Technology and Society Connections

- **Venoms as enzyme inhibitors**

Snake venom is highly modified saliva that is produced by special glands of certain species of snakes. Snake venom is a combination of many toxins (proteins) and different enzymes, use for the purposes like increasing the prey's uptake of toxins. Snake venom inhibits cholinesterase to make the prey lose control of its muscles. Venom is an inhibitor for an essential enzyme cytochrome oxidase in the cells. There are three distinct type of venom that act on the body differently.

(1) Hemotoxic venoms act on the heart and cardiovascular system.

(2) Neurotoxic venom acts on the nervous system and brain.

(3) Cytotoxic venom has a localized action at the site of the bite. Venom occupies the active site of the enzyme or combining with the iron which may present in the prosthetic group or which may be required as an enzyme activator.

Activity

1. Performing of chemical test to demonstrate that enzymes are proteins
2. Performing amylase test on starch with boiled amylase and un-boiled amylase in separate test tubes and confirmation through iodine test

Exercise

MCQs

1. Select the correct answer

(i) The catalytic activity of an enzyme is restricted to its small portion called

(A) active site (B) passive site
(C) regulation site (D) allosteric site

(ii) Which of the following has a coenzyme activity?

(A) NAD^+ (B) Ca^{++}

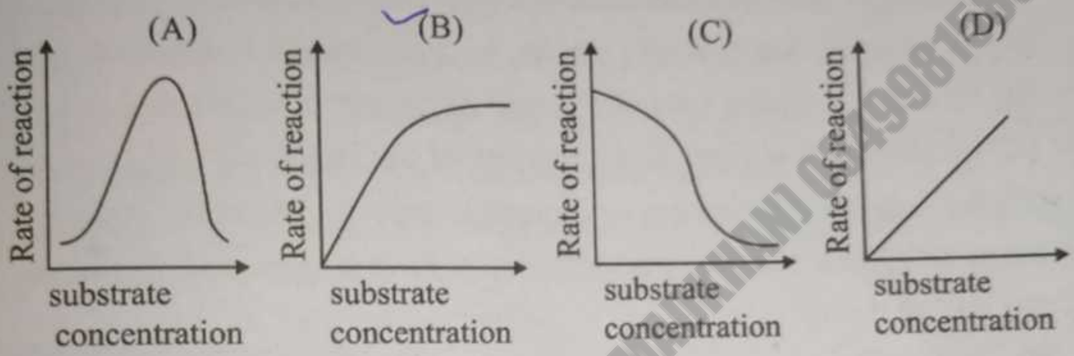
(C) both "a" and "b" (D) none of them

(iii) Non-competitive inhibitors react with enzymes at:

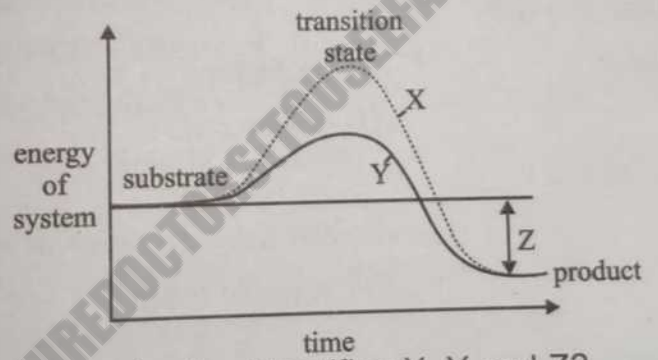
(A) active site (B) allosteric site

(C) both "a" and "b" (D) none of them

(iv) Which graph shows the expected relationship between enzyme activity and substrate concentration?



(v) The graph shows the effect of an enzyme on a reaction.



Which combination identifies X, Y and Z?

	X	Y	Z
A	catalyzed reaction	uncatalyzed reaction	activation energy
B	catalyzed reaction	uncatalyzed reaction	energy lost during reaction
C	uncatalyzed reaction	catalyzed reaction	energy gained by product
D	uncatalyzed reaction	catalyzed reaction	overall energy change

(vi) Combination of apoenzyme and coenzyme produces

(A) prosthetic group (B) holoenzyme

(C) enzyme (D) isoenzyme

(vii) The specificity of enzyme is due to their

(A) surface configuration (B) pH

(C) hydrogen bonding (D) high molecular weight

(viii) An essential feature of a competitive inhibitor is its ability to
(A) activate an operator gene (B) combine with prosthetic group
(C) modify a substrate (D) occupy an active site

(ix) The reaction rate of salivary amylase with starch decreases as the concentration of chloride ions is reduced. Which of the following describe the role of the chloride ions?
(A) allosteric inhibitors (B) cofactors
(C) coenzyme (D) competitive inhibitor

(x) How does an enzyme increase the rate of a reaction?
(A) by bringing the reacting molecules into precise orientation
(B) by increasing the rate of random collisions of molecules
(C) by shifting the point of equilibrium of the reaction
(D) by supplying the energy required to start the reaction

(xi) Many enzymes are secreted in inactive form to protect
(A) cell proteins (B) mitochondria
(C) cell membrane (D) cell DNA

(xii) Erypsin is an example of?
(A) carbohydrases (B) proteases
(C) lipases (D) nucleases

(xiii) Ribozymes consist of:
(A) only protein (B) protein + none protein part
(C) only RNA (D) none of them

Short Questions

2. What are ribozymes?
3. What is the structure of enzyme?
4. Explain the enzyme pepsin which does not require cofactor.
5. What is prosthetic group? Give an example.
6. What is the mechanism of enzyme action?
7. What is the role of free energy of activation in a chemical reaction?
8. List the external conditions which affect rate of enzyme reaction.
9 Compare the optimum temperatures of enzymes of human and thermophilic bacteria.
10. Describe the range of pH at which human enzymes function.

11. What are enzyme inhibitors? Name the molecules which act as enzyme inhibitors.
12. What is the importance of competitive enzyme inhibitors?
13. Describe cyanides as irreversible non-competitive inhibitor.
14. Describe ions of heavy metals as irreversible non-competitive inhibitor.
15. Write the difference between:
    (a) binding site and catalytic site of an enzyme
    (b) apoenzyme and holoenzyme
    (c) prosthetic group and coenzyme
    (d) inorganic cofactor and organic cofactor
    (e) lock and key model and Induced fit model of enzyme action
    (f) competitive and noncompetitive enzyme inhibitors
    (g) reversible non-competitive enzyme inhibitors and irreversible non-competivie enzyme inhibitors

Extensive Questions

16. Write the properties of enzymes.
17. Explain the role and component parts of the active site of an enzyme.
18. What are cofactors? Describe the two types of cofactors by giving examples.
19. Explain the mechanism of enzyme action through induced fit model.
20. Explain the mechanism of enzyme action through lock and key model.
21. Explain how an enzyme catalyzes specific reactions.
22. Explain through graph how an enzyme speeds up reaction by lowering the energy of activation.
23. Describe the effect of temperature on the rate of enzyme action.
24. Describe how the concentration of enzyme affects the rate of enzyme action.
25. Explain the effect of substrate concentration on the rate of enzyme action.
26. Describe enzymatic inhibition, its types and its significance.
27. Explain feedback mechanism with reference to enzymes.
28. Classify enzymes on the basis of reactions catalyzed.
29. Classify enzymes on the basis of the substrate they use.

4

BIOENERGETICS

After completing this lesson, you will be able to

- Explain the role of light in photosynthesis.
- Identify the two general kinds of photosynthetic pigments (carotenoids and chlorophylls).
- Describe the roles of photosynthetic pigments in the absorption and conversion of light 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, narrating the experimental work done, the role of water in photosynthesis.
- Describe the events of non-cyclic photophosphorylation and outline the cyclic photophosphorylation.
- Explain the Calvin cycle (the regeneration of RuBP should be understood in outline only).
- Draw the molecular structure of chlorophyll, showing the porphyrin head and the phytol tail.
- Draw the Z-scheme for explaining the events of the light-dependent reactions.
- Extract the leaf pigments and separate them by paper chromatography.
- Explain the process of anaerobic respiration in terms of glycolysis and conversion of pyruvate into lactic acid or ethanol.
- Outline (naming the reactants and products of each step of) the events of glycolysis.
- Illustrate the conversion of pyruvate to acetyl-CoA.
- Outline (naming the reactants and products of each step of) the steps of Krebs cycle.
- Explain the passage of electron 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.
- Justify the importance of G3P in photosynthesis and respiration.
- Outline the cellular respiration of proteins and fats and correlate these with that of glucose.
- Draw the flow charts showing the events of glycolysis and Krebs cycle.
- Illustrate the net energy output during glycolysis, oxidation of pyruvate and Krebs cycle.
- 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 C_4 photosynthesis as an adaptation evolved in some plants to deal with the problem of photorespiration.

Living things cannot grow, reproduce, or exhibit any of the characteristics of life without a ready supply of energy. All metabolic reactions involve energy transformations. So the quantitative study of energy relationships in biological system is called **bioenergetics**. Biological energy transformations obey the laws of thermodynamics. You have got an introduction about bioenergetics in IX-X biology course.

This chapter deals with the most fundamental bioenergetics processes i.e., photosynthesis and respiration. You already have the general concept of these processes. The detailed learning would foster the skills of analysis and evaluation. This chapter also develops the basic concepts of photorespiration, the process that reduces plants productivity.

4.1 PHOTOSYNTHESIS

Chemically photosynthesis is a "redox" process in which CO_2 (an oxidized form of carbon) is reduced into glucose (a reduced form of carbon). Water acts as reducing agent which is oxidized into oxygen during this process. Bio-energetically photosynthesis can be defined as an energy conversion process in which energy poor molecules i.e., CO_2 and H_2O are transformed into energy rich molecule such as glucose. The extra energy is absorbed in the form of sunlight by the photosynthetic pigments.

The overall reaction of photosynthesis can be summarized as follows:

Reduction

$$\underset{\text{Carbon dioxide}}{6CO_2} + \underset{\text{Water}}{12H_2O} \xrightarrow[\text{Chlorophyll}]{\text{Light}} \underset{\text{Glucose}}{C_6H_{12}O_6} + \underset{\text{Oxygen}}{6O_2} + \underset{\text{Water}}{6H_2O}$$

Oxidation

This process involves the interaction of sunlight, pigments, water and carbon dioxide.

4.1.1 Role of Light

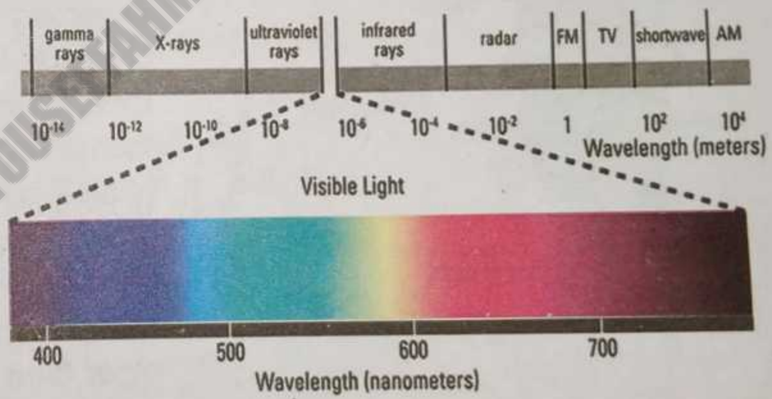


Fig. 4.1 Electromagnetic spectrum

Sunlight is an electromagnetic form of energy. The full range of electromagnetic radiation in the universe is called **electromagnetic spectrum.** Visible light is only a small part of the spectrum between 380ηm to 750ηm which is not only seen by naked eye but is also effective for the process of photosynthesis.

The effectiveness of a particular wavelength of light for the process of photosynthesis primarily depends upon its absorption in plant body. As different wavelengths (colours) of visible light are differently absorbed by various photosynthetic pigments, therefore, each wavelength has its own effectiveness for the process of photosynthesis. If a plant is illuminated in different colours of light one by one, the rate of photosynthesis is measured and the data obtained in this

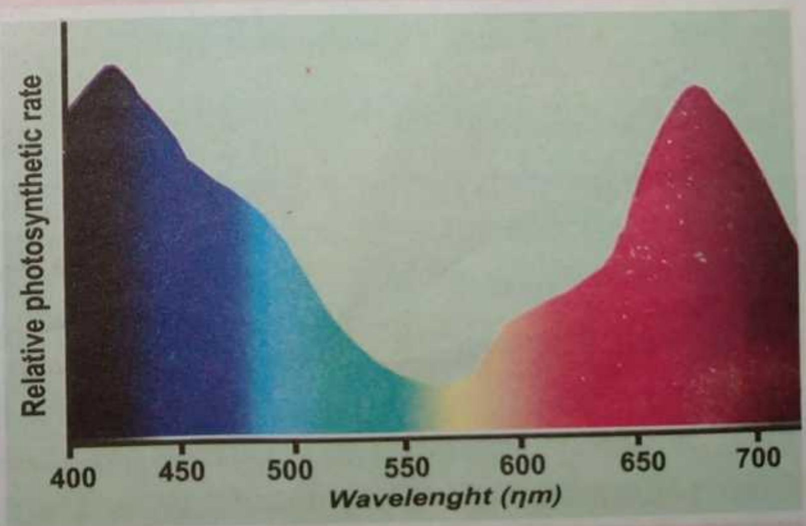


Fig. 4.2 Action spectrum of photosynthesis

way is plotted in a graph, you will see that the rate of photosynthesis will be variable in different colours of light. Such a graph which shows the effectiveness of different wavelength of light for the process of photosynthesis is called **action spectrum**. Analysis of action spectrum indicates that blue (430ηm) and red (670ηm) wavelengths of light are the most effective for the process of photosynthesis.

4.1.2 Role of Photosynthetic Pigments

Pigment is any substance that absorbs light energy. All the wavelengths which are absorbed by a pigment are disappeared. A particular pigment shows only those wavelengths which are reflected back. All the pigments that take part in photosynthesis are embedded in thylakoid membranes (grana lamellae) within chloroplasts. Higher plants have two major group of pigments i.e., chlorophyll and carotenoids.

> **Science Titbits**
> The rate of photosynthesis is directly proportional to the CO_2 consumed or O_2 released therefore; it can be measured by measuring the amount of CO_2 consumed or by measuring the amount of O_2 released during the process in a specific time.

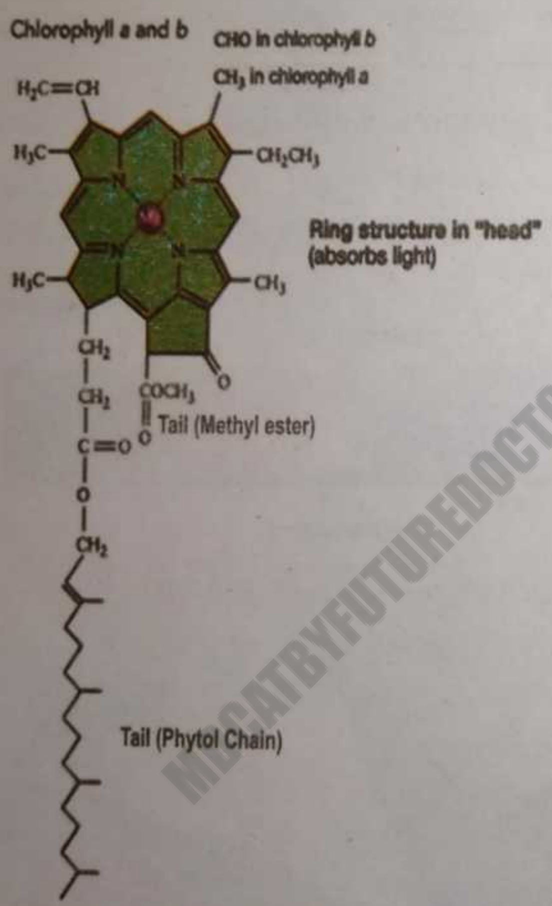


Fig 4.3: Structure of chlorophyll

Chlorophyll

Chlorophylls absorb mainly violet, blue, orange and red wavelengths. Green and yellow are least absorbed and reflected. Two major types of chlorophyll are Chlorophyll-a and Chlorophyll-b. Chlorophyll-a is a bluish green pigment which is found in all photosynthetic organisms except photosynthetic bacteria. Chlorophyll-b is yellowish green pigment which is also found in all photosynthetic organisms except brown, red algae and photosynthetic bacteria. Algae also have some other form of chlorophylls i.e., Chl-c, Chl-d and Chl-e while photosynthetic bacteria have yet another type of chlorophyll i.e., bacteriochlorophyll.

Molecular formula of chlorophyll a and b:

Chlorophyll a = $C_{55} H_{72} O_5 N_4 Mg$

Chlorophyll b = $C_{55} H_{70} O_6 N_4 Mg$

A molecule of chlorophyll consists of a head and two tails. The head is composed of a **porphyrin ring** with Mg in the centre. The porphyrin ring further consists of four pyrrole rings (each pyrrole ring contains four carbons and one nitrogen atom). The nitrogen atoms of **pyrrole rings** interact with central Mg atom. The pyrrole rings also contain different groups around them. The only difference between chlorophyll-a and chlorophyll-b is that chlorophyll-a has methyl group ($-CH_3$) on 2nd pyrrole ring whereas, chlorophyll-b has aldehyde group (-CHO) at this point. The head of chlorophyll is hydrophilic in nature. It is exposed on the surface of thylakoid membrane. It is light absorbing part of chlorophyll.

The two side chains in the chlorophyll molecule are called tails. Side chains are phytol and methyl ester. **The chlorophyll tails** are hydrophobic in nature. They are embedded into the thylakoid membranes and serve to anchor the chlorophyll molecule in the membrane.

Carotenoids

Carotenoids are terpenoid lipids, which are yellow, orange, red or brown pigments. They absorb light strongly in the blue-violet range. They are seen in leaves before leaf fall, present in some flowers and fruits. The carotenoids act as accessory pigment along with chlorophyll-b as they absorb light energy and then transfer it to the chlorophyll-a. Therefore, they protect the chlorophyll-'a' from excess of light. They also attract insects, birds and other animals for pollination and dispersal.

There are two types of carotenoids: carotenes and xanthophylls. The **carotenes** are orange red pigments, composed of isoprenoid units and are found in all photosynthetic eukaryotes. The most widespread and important carotene is β (beta) carotene. **Xanthophylls** are yellow in colour and are also composed of isoprenoid units. Lutein is widely distributed xanthophylls which is responsible for yellow colour of foliage in autumn.

4.1.3 Absorption Spectrum

The absorption of different colours of light by a particular pigment can be determined by the help of spectrophotometer. The data of spectrophotometer is represented by a graph. Such a graph which shows the absorption of different colours of light by a particular pigment is called **absorption spectrum** of the pigment.

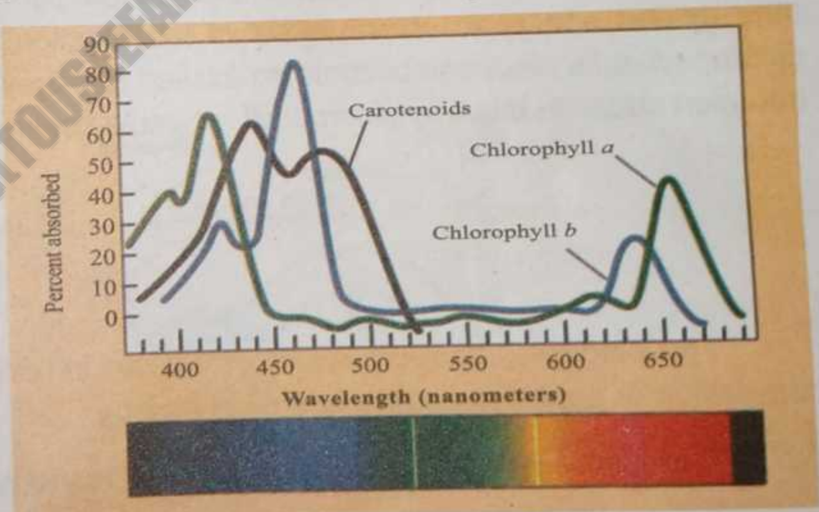


Fig: 4.4: Absorption spectra of different pigments

The absorption spectra of different pigments indicate that they absorb different wavelengths of visible light and these wavelengths are not absorbed at the same rate. The main photoreceptors are chlorophyll a and b and both show more absorption in violet blue (400ηm to 470ηm) and orange-red (630ηm to 660ηm) regions of the visible spectrum. On the other hand carotenoids show more absorption at 430ηm to 500ηm.

4.1.4 Arrangements of Pigments (Photosystems)

For efficient absorption and utilization of light energy, the photosynthetic pigments are arranged in the form of clusters in thylakoid membranes. These clusters are called **photosystems**. The peripheral part of photosystem is called **antenna complex** which consists of accessary pigments such as chlorophyll-b and carotenoids. The central part of photosystem is called **reaction centre** which contains only chlorophyll-a and associated proteins. Since chlorophyll-a generally has an optimal absorption wavelength of 660ηm, it associates with different proteins in each type of photosystem to slightly shift its optimal wavelength, producing two distinct photosystem types i.e., photosystem-I (PS-I) and photosystem-II (PS-II). The chlorophyll-a in the reaction centre of PS-I can absorb maximum 700ηm wavelength of light, hence called P700. Similarly, the chlorophyll-a in the reaction centre of PS-II can absorb maximum 680ηm wavelength of light, hence called P680. The photosystems are named for the order in which they were discovered and not for the order in which they occur in the thylakoid membrane.

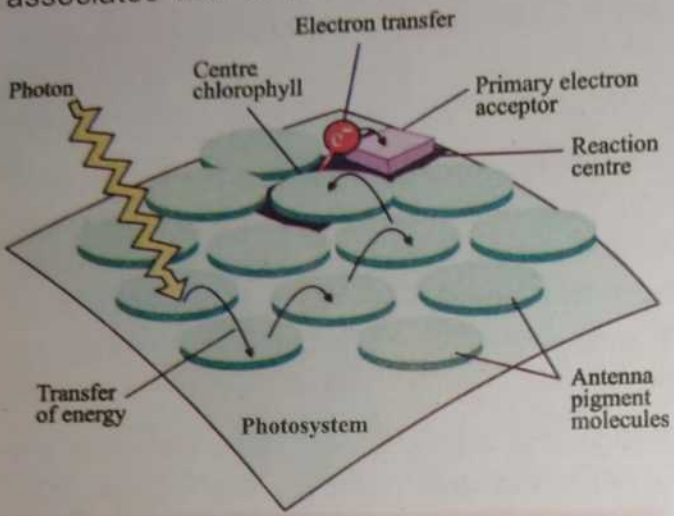


Fig: 4.5: Structure of photosystem

As chlorophyll-a can only absorb light of a narrow wavelength, it works with the pigments of antenna complex to gain energy from a larger part of the spectrum. The pigments absorb light of various wavelengths and pass along their gained energy to chlorophyll-a of the reaction centre. When the energy reaches the chlorophyll-a its electrons become so excited that they escape and move to a nearby electron transport chain. In this way chlorophyll molecule becomes oxidized.

$$\underset{\text{(reduced form)}}{\text{chlorophyll}} \xrightarrow{\text{light energy}} \underset{\text{(oxidized form)}}{\text{chlorophyll}} + \underset{\text{electron}}{e^-}$$

The electron transport system plays an important role in generation of ATP by the conversion of light energy into chemical energy.

4.1.5 Role of Carbon Dioxide in Photosynthesis

Carbon dioxide acts as carbon source for the synthesis of organic compounds in photosynthesis. Plants are therefore known as autotrophs because they use inorganic compounds for the synthesis of their organic compounds. Carbon dioxide is utilized in the dark or light independent reaction (Calvin cycle) of photosynthesis. Air contains about 0.03 to 0.04 percent of carbon dioxide. Land plants use this atmospheric carbon dioxide for photosynthesis. Dissolved carbon dioxide, bicarbonates and carbonates are present in water, which are used by aquatic photosynthetic organisms as carbon source.

4.1.6 Role of Water in Photosynthesis

Water is one of the raw materials for photosynthesis. Water acts as hydrogen and electron donor in photosynthesis. It replaces the electron lost by the P680 during photosynthesis. $2H^+$ ions are taken up the $NADP^+$ to form NADPH. The oxygen which is produced is released in atmosphere.

This role of water in photosynthesis was first reported by **Van Niel** in 1930. He hypothesized that plants split water as a source of hydrogen, releasing oxygen as a byproduct. This observation was based on investigations of photosynthesis in bacteria that make carbohydrates from carbon dioxide, but do not release oxygen.

Neil's hypothesis was confirmed in 1940, when for the first time ^{18}O in biological research was used. In first experiment water was made of ^{18}O. The water tagged ^{18}O was added to an alga suspension. The oxygen, evolved during photosynthesis, was found to be radioactive. It was separated and identified. In another experiment carbon dioxide with tagged ^{18}O was added. The oxygen evolved contained none of the isotopes. Thus the source of evolved oxygen was proved to be water. In the following summary, red denotes labelled atoms of Oxygen ^{18}O.

$$\underset{\text{Carbon dioxide}}{6CO_2} + \underset{\text{Water}}{12H_2O} \xrightarrow[\text{Chlorophyll}]{\text{Light}} \underset{\text{Glucose}}{C_6H_{12}O_6} + \underset{\text{Water}}{6H_2O} + \underset{\text{Oxygen}}{6O_2}$$

$$\underset{\text{Carbon dioxide}}{6CO_2} + \underset{\text{Water}}{12H_2O} \xrightarrow[\text{Chlorophyll}]{\text{Light}} \underset{\text{Glucose}}{C_6H_{12}O_6} + \underset{\text{Water}}{6H_2O} + \underset{\text{Oxygen}}{6O_2}$$

4.1.7 Mechanism of photosynthesis

The process of photosynthesis has been divided into two phases. The first phase is called light dependent phase (light reaction) because it can take place only in the presence of light. The light-dependent phase occurs in the thylakoid membranes. In this phase light energy is used to make ATP (assimilating power) and NADPH (reducing power); whereas, water and oxygen are supposed to be input and output respectively. The second phase of photosynthesis is called the light independent phase (dark reaction) because it can take place whether light is present or not. This phase actually requires the products of light reaction i.e., ATP and NADPH. Since these products are available in day therefore, dark reaction also occurs in day time. In this phase CO_2 acts as input which is converted into glyceraldehyde-3-phosphate (G3P), the output of this phase. The ATP is hydrolyzed to

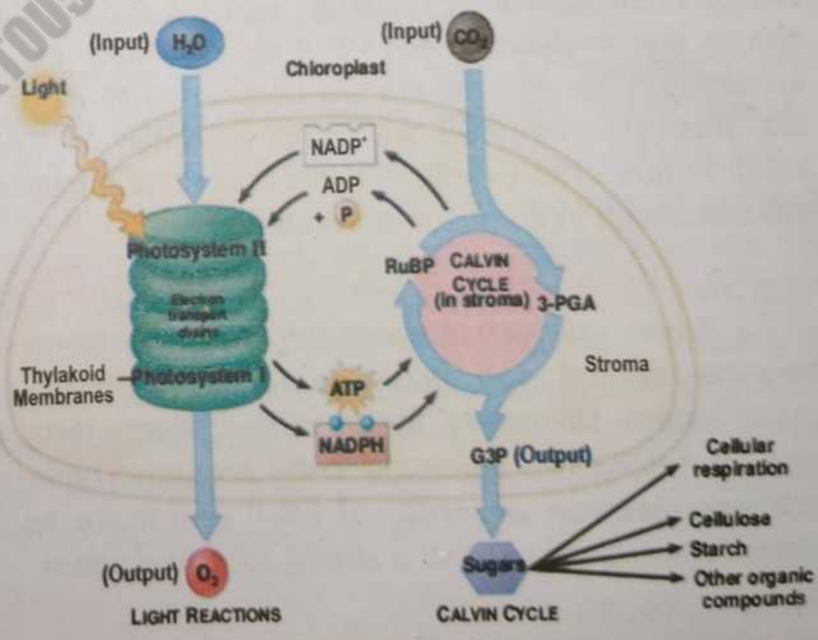


Fig: 4.6: An overview of photosynthesis

ADP and Pi (H_3PO_4) and its energy is incorporated in this phase; whereas, NADPH provides energized electron and hydrogen for the formation of G3P, which is an energy rich molecule.

4.1.8 Light Dependent Phase (Light Reaction)

Light dependent phase of photosynthesis involves the absorption of light by the photosystems, excitation and flow of electrons through an electron transport chain, chemiosmotic synthesis of ATP, and reduction of $NADP^+$ to NADPH. The flow of excited electrons through an electron transport chain during light reaction is of two different types i.e., non-cyclic and cyclic. In non-cyclic electron flow, the excited electrons after leaving a

$$ADP + Pi \longrightarrow ATP$$

particular photosystem do not comeback; these electrons after losing their energy are incorporated into another molecule. On the other hand, in cyclic electron flow, the excited electrons after leaving a particular photosystem finally comeback to their photosystem again. The most important event in light reaction is the production of ATP.

This production of ATP during light reaction is called **photophosphorylation** and the mechanism is called **chemiosmosis.** There are two types of photophosphorylation.

(a) Non-cyclic photophosphorylation

It is predominant pathway of light reaction in higher plants that occurs in routine. In this process both photosystems i.e., PS-I and PS-II are utilized and two electron transport chains are involved. When PS-II absorbs light, its excited electrons after flowing through an electron transport chain are transferred to PS-I. Similarly, the excited electrons which are liberated from PS-I are finally accepted by $NADP^+$. Therefore it is called non-cyclic electron flow. The events of non-cyclic photophosphorylation are continuous but here they are discussed in steps for convenience.

Absorption of light by PS-II and excitation of its electrons

When just two photons strike the antenna complex of PS-II, the two electrons become excited and begin to move along the atoms of different pigments within photosystem. Ultimately, the absorbed energy reaches the reaction centre of PS-II (P680) and causes its two electrons to be excited. These excited electrons are captured by the **primary electron acceptor** of PS-II and leave two "electron holes" in the photosystem behind making chlorophyll a strong oxidizing agent.

Photolysis of water

The electron holes of photosystem must be filled so that in the presence of water splitting enzyme reactions can proceed. When water reacts with oxidized state of chlorophyll in photosystem, it breaks up into $2H^+$ ions, $2e^-$ and $\frac{1}{2}O_2$. Since this breakdown occurs in the presence of sunlight therefore, it is termed as photolysis of water. The electrons released from water are used to fill the "electron holes" of PS-II.

$$H_2O \xrightarrow{\text{Photolysis of water}} 2H^+ + 2e^- + \tfrac{1}{2}O_2$$

Electron flow from PS-II to PS-I

The excited/energized electrons which have been released from PS-II and captured by primary electron acceptor now begin to flow to PS-I through an electron transport chain. The electrons move from primary electron acceptor to the **plastoquinone (PQ)**. From PQ the electrons flow through a complex of the **cytochromes (Cyt)** which consist of **Cyt-b$_6$** and **Cyt-f**.

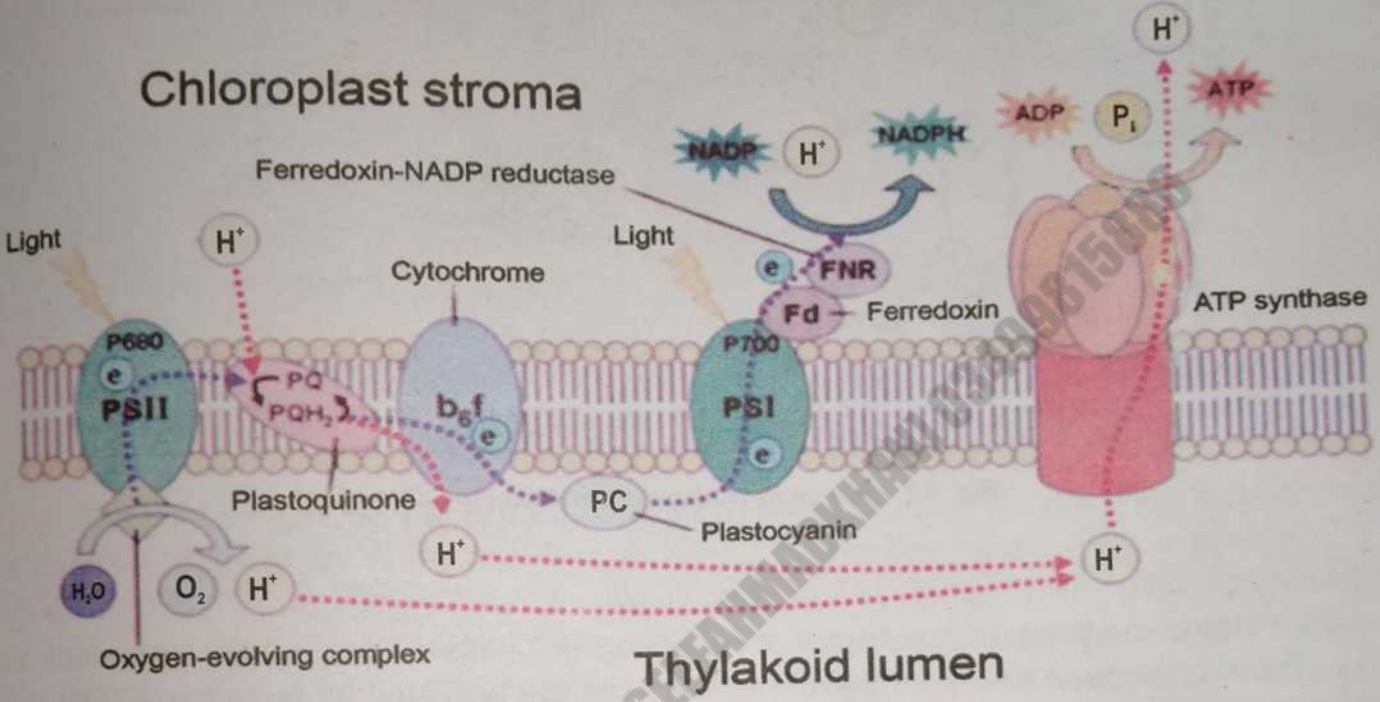


Fig: 4.7: Chemiosmotic synthesis of ATP during light reaction

The cytochrome complex is not only an electron carrier but it also works as proton pump. The electron flow through the cytochrome complex stimulates it to pump the protons from stroma to the thylakoid inner space. In this way the energy of flowing electrons is transformed into a gradient of protons (H^+) in the thylakoid inner space. The proton gradient activates an enzyme in thylakoid membrane called **ATP synthase** which not only moves the protons back into the stroma but also catalyzes a reaction in which ADP and Pi are combined to form ATP (photophosphorylation). This whole mechanism which involves flow of electron, pumping of protons and generation of ATP by thylakoid membranes is called **chemiosmosis**. This ATP, generated by light reactions will provide chemical energy for the synthesis of sugar during Calvin cycle. The energized electrons after losing their energy, move from cytochrome complex to the **plastocyanin (PC)** and finally incorporated into the PS-I

Absorption of light by PS-I and excitation of its electrons

On the other hand, when P700 in the reaction centre of PS-I molecule absorbs two photon of light, electrons are boosted to a higher energy level. P700 molecule passes these excited electrons to a primary electron acceptor of PS-I, creating "electron holes". The electron holes of P700 are filled by the pair of electrons received from the P680 (photosystem II) via electron transport chain.

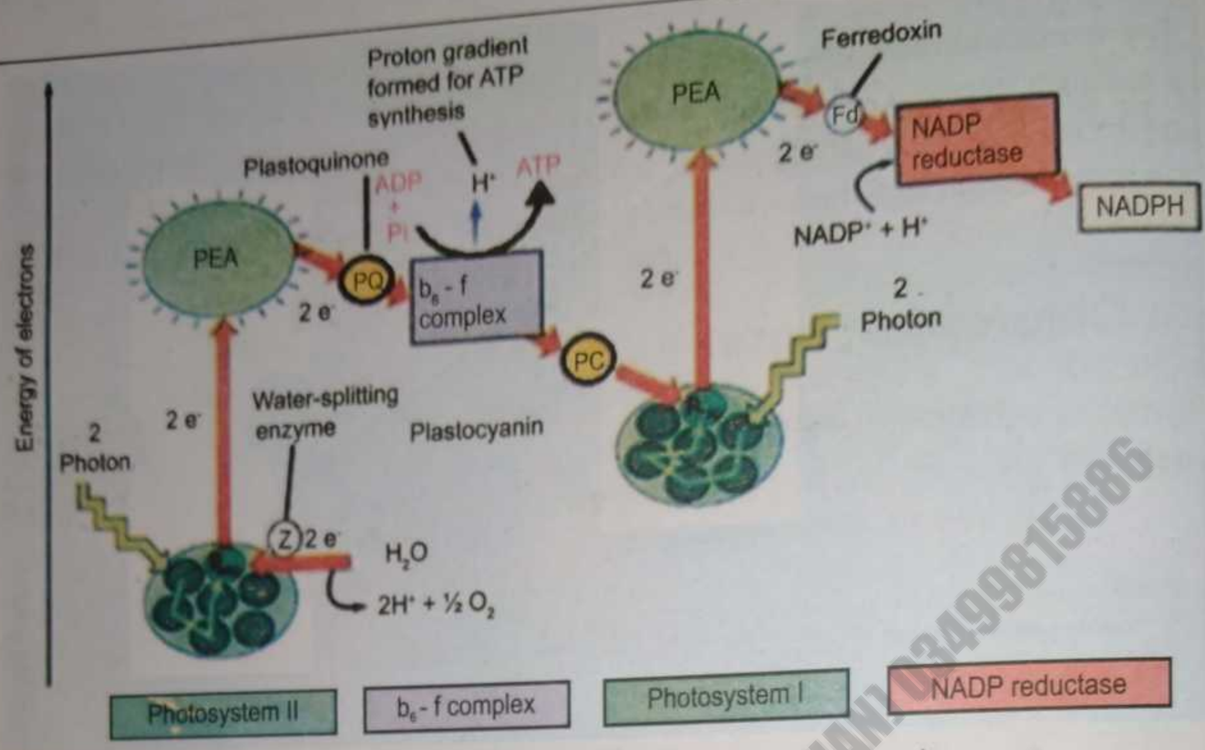


Fig: 4.8: Non-cyclic photophosphorylation (Z Scheme)

Electron flow from PS-I to $NADP^+$

The primary electron acceptor of photosystem I passes the photoexcited electrons to a second electron transport chain. The electrons are accepted by **ferredoxin (Fd)**. It is an iron containing protein. An enzyme called **NADP reductase** (flavoprotein enzyme) transfers the electrons from Fd to $NADP^+$. $NADP^+$ combines with electrons and hydrogen ions to form NADPH (reduced). The NADPH will provide reducing power for the synthesis of sugar in the Calvin cycle.

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

The path of electron transport through the two photosystems during non-cyclic photophosphorylation is known as **Z-Scheme** due to its conceptual zigzag shape.

(b) Cyclic photophosphorylation

The rise in NADPH and deficit of ATP may stimulate a temporary shift from a non-cyclic to cyclic electron flow until ATP supply catches up the demand. In this mechanism only PS-I is utilized. It absorbs energy in the form of photons. When energy reaches the **reaction centre** of PS-I the electrons are boosted up to higher energy level. Such excited electrons are first captured by primary electron acceptor of PS-I, then they move through an electron transport chain containing ferridoxin, cytochrome b_6-f complex and plastocyanin. When electrons are passed from cytochrome b_6-f complex an ATP is generated by chemiosmosis. Finally, the electrons after losing the energy return back to P700 chlorophyll in PS-I reaction centre. There is no production of NADPH, no occurrence of photolysis of water and therefore, no release of cxygen.

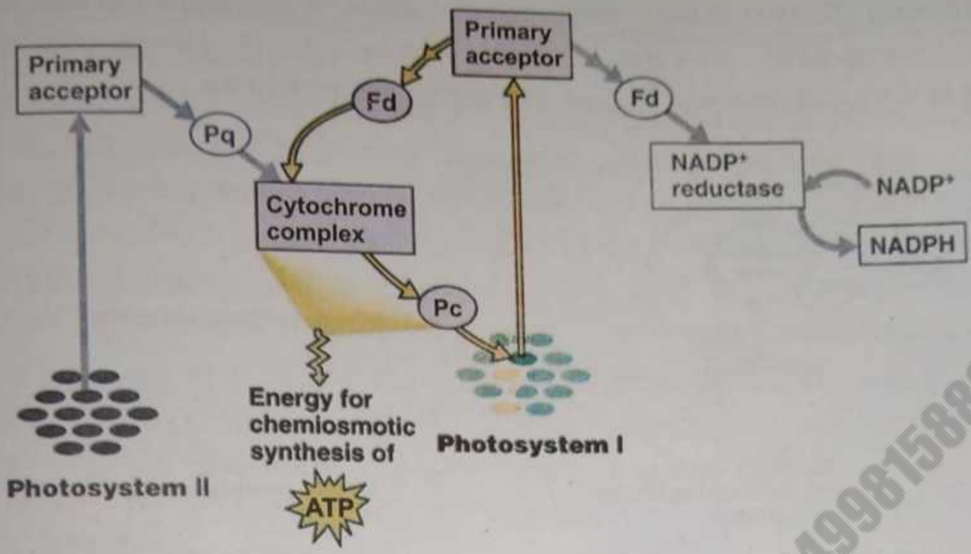


Fig: 4.9: Cyclic photophosphorylation

4.1.9 Light Independent Phase (Dark Reaction)

The light independent phase (dark reaction) takes its name from the fact that light is not directly required for these reactions to occur. This phase requires the availability of NADPH, ATP (the products of light reaction) and CO_2. In this phase of photosynthesis, NADPH is used to reduce carbon dioxide while ATP is used to incorporate energy. Finally, CO_2 is converted into a phosphorylated triose carbohydrate i.e., glyceraldehyde-3-phosphate (G3P) which are later on used to make glucose. Dark reaction generally involves a complicated metabolic pathway, the Calvin cycle or C3 pathway. However, in some plants, in addition to Calvin cycle another metabolic pathway is also involved, called **C4 pathway.** The plants in which only Calvin cycle occurs during dark reaction are called **C3 plants**.

Calvin cycle

Calvin cycle term is applied to the series of metabolic reactions in which CO_2 is reduced to produce G3P. (These reactions have been explored by **Melvin Calvin** and co-workers at the University of California. Melvin Calvin won the Nobel Prize in 1961 for this work). The Calvin cycle can be divided into three phases, carbon fixation, reduction and regeneration of carbon dioxide acceptor i.e., RuBP.

Carbon fixation

One of the key substance in this process is a five carbon phosphorylating sugar called **ribulose bisphosphate (RuBP)**. It is generally referred as **CO_2 acceptor** because it is capable of combining with carbon dioxide with the help of Ribulose bisphosphate (RuBP) carboxylase/oxygenase also known as **RuBisCO**. Three intermediate molecules of six carbons are formed during this reaction. These molecules are unstable and exist for such a short time that, they cannot be isolated. Each six carbon breaks down to form two molecules of 3-phosphoglycerate (3-PGA), a phosphorous containing compound with three carbon atoms. Since, the carbon of inorganic compound (CO_2) becomes the part of organic compound (RuBP) during this phase, hence, it is called **carbon fixation**. As the first stable compound in the Calvin cycle is a three carbon compound (3-PGA) that is why Calvin cycle is also known as **C3 pathway**.

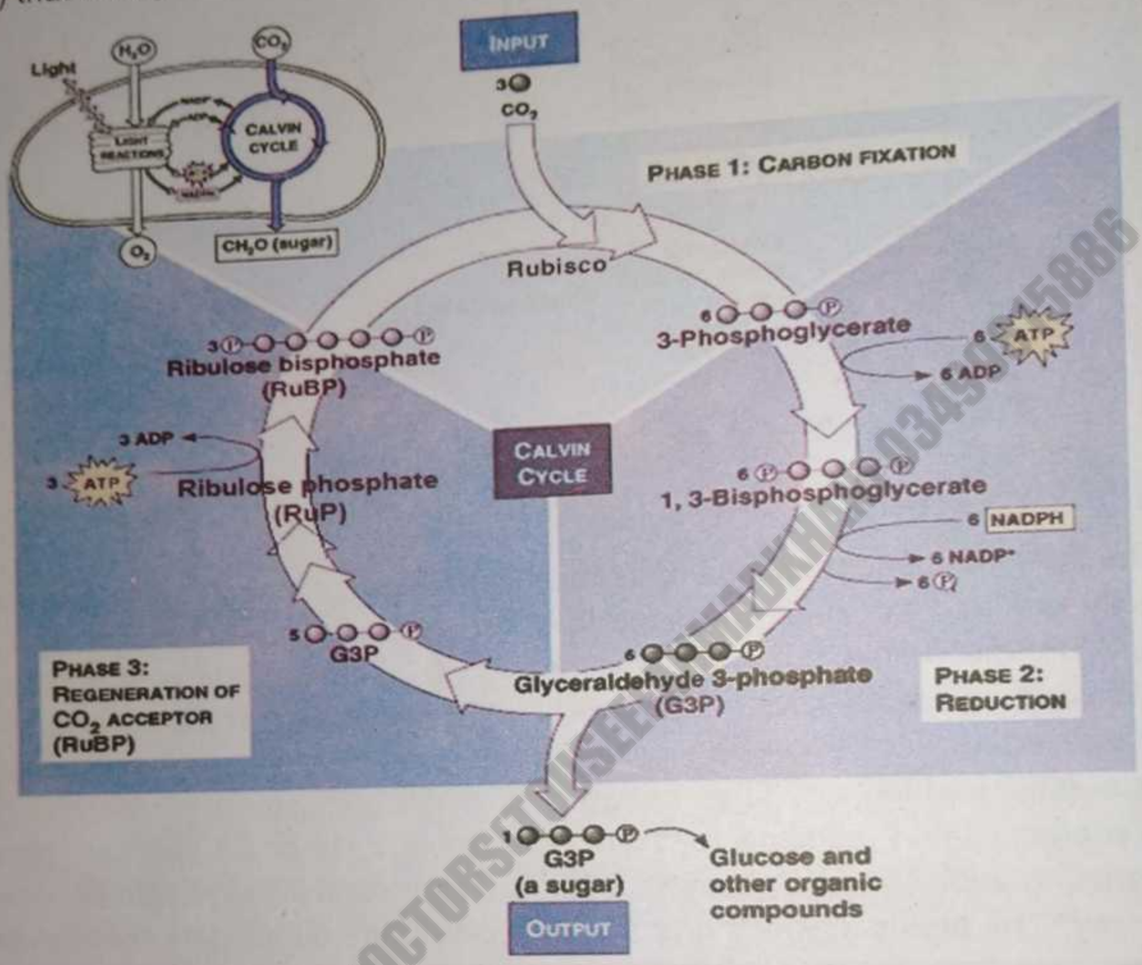
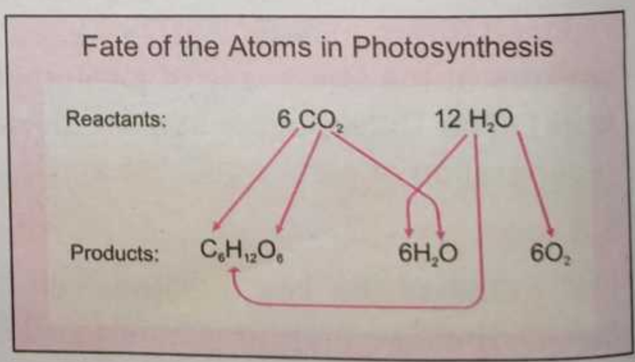


Fig 4.10: Calvin cycle

Reduction



In this phase six molecules of 3-phosphoglycerate (3-PGA) react with six ATP molecules, a phosphate from each ATP is transferred to each 3-PGA. In this way, 3-PGA molecules are changed into 1,3-Bisphosphoglycerate. These molecules are then reduced by the hydrogen of NADPH and finally glyceraldehyde 3 phosphate (G3P) molecules are produced. During this reduction process a phosphate group from each 1,3-Bisphosphoglycerate molecule is also given off. There are total six molecules of G3P are produced in this phase but only one molecule is released from the cycle while rest of the five molecules are used to regenerate the CO_2 acceptor molecules in the next phase.

Regeneration of CO_2 acceptor

Five molecules of G3P from the previous phase are used to regenerate the RuBP (CO_2 acceptor) in this phase. These five molecules each containing three carbon atoms undergo a series of reactions in which three molecules of ribulose phosphate (RuP) each containing five carbon atoms are produced. When three molecules of RuP react with three molecules of ATP, a phosphate group from each ATP is transferred to each RuP. Ultimately RuP are converted into RuBP which again participate in the next cycle.

The whole process of Calvin cycle indicates that there are three molecules of CO_2, six molecules of NADPH (reducing power) and nine molecules of ATP (assimilating power) are used to release just one molecule of G3P form the cycle. However, in order to produce a glucose molecule, two molecules of G3P are required. The overall process of Calvin cycle can be represented as:

$$3CO_2 + 6NADPH + 9ATP \longrightarrow G3P + 3H_2O + 9ADP + 9Pi + 6\,NADP^+$$

4.2 CELLULAR RESPIRATION

In biological systems oxidation-reduction is a chemical reaction usually involves the removal of hydrogen atom from one molecule and the gain of hydrogen atom by another molecule. Cellular respiration is a series of complex oxidation-reduction reactions by which living cells obtain energy through the breakdown of organic matter.

4.2.1 Kinds of Cellular Respiration

There are two kinds of respirations: aerobic respiration and anaerobic respiration. Aerobic respiration takes place in the presence of abundant atmospheric oxygen, whereas, anaerobic respiration occurs in the absence of oxygen. The organic molecule that generally undergoes breakdown in cellular respiration in order to release energy is glucose, therefore, glucose is supposed to be **respiratory fuel**. The initial breakdown of glucose in both aerobic and anaerobic respirations is quite same, in which it is broken down into two molecules of **pyruvates**. This common step of aerobic and anaerobic respirations is called **glycolysis**. The pyruvates undergo in different respiratory pathways depending upon the availability of oxygen and the kind of organism. If oxygen is available, the further breakdown of pyruvates takes place aerobically and the final products are carbon dioxide and water with the release of large amount of energy i.e., 36 ATPs (in eukaryotes) or 38 ATPs (in prokaryotes). If oxygen is absent, then the pyruvates are broken down anaerobically and the final products are either lactic acid or ethanol and carbon dioxide with release of very small amount of energy i.e., just 2 ATPs.

4.2.2 Mechanism of Anaerobic Respiration

Anaerobic respiration takes place in many microorganisms (bacteria, yeast), muscle cells of vertebrates and in the cells of higher plants. Anaerobic respiration is incomplete breakdown of glucose in the absence of oxygen. It is also known as **fermentation**. There are two pathways of anaerobic respiration depending upon the nature of final products i.e., lactic acid fermentation and alcoholic fermentation.

Lactic acid fermentation

It consists of **glycolysis** followed by the **reduction** of pyruvate by NADH to lactic acid. The pathway operates anaerobically because after NADH transfers its electron to the pyruvate, it is "free" to return and pick up more electrons during the earlier reaction of glycolysis. The overall equation can be represented as:

$$C_6H_{12}O_6 + 2NAD^+ \longrightarrow 2C_3H_4O_3 + 2NADH + 2H^+$$
$$2C_3H_4O_3 + 2NADH + 2H^+ \longrightarrow 2C_3H_6O_3 + 2NAD^+$$

Lactic acid fermentation occurs in anaerobic bacteria and in the muscles of mammals as well as human during strenuous exercise when oxygen supply is exhausted. The accumulation of lactic acid causes muscles fatigue i.e., muscles become unable to contract and begin to ache.

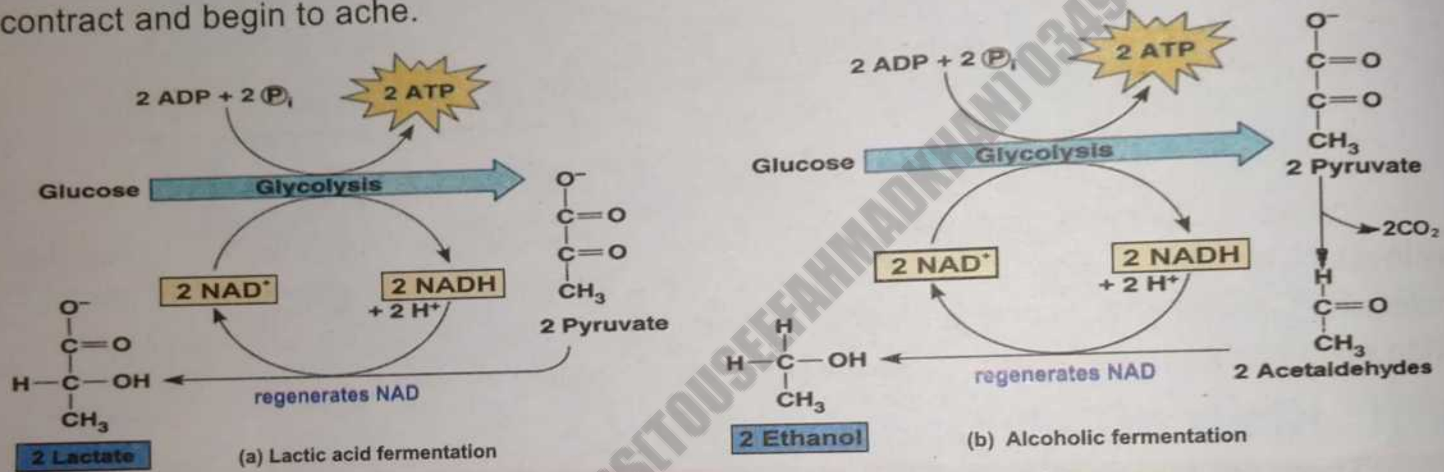


Fig: 4.11 Anaerobic respiration

Alcoholic fermentation

Alcoholic fermentation is found in yeast. It consists of **glycolysis** followed by the **decarboxylation** of pyruvate to acetaldehyde then **reduction** of acetaldehyde by NADH to ethyl alcohol or ethanol. This pathway also operates anaerobically because after NADH transfers its electron to the acetaldehyde, it is "free" to return and pick up more electrons during the earlier reaction of glycolysis. The overall equation can be represented as:

$$C_6H_{12}O_6 + 2NAD^+ \longrightarrow 2C_3H_4O_3 + 2NADH + 2H^+$$
$$2C_3H_4O_3 + 2NADH + 2H^+ \longrightarrow 2C_2H_5-OH + 2CO_2 + 2NAD^+$$

4.2.3 Mechanism of Aerobic Respiration

Aerobic respiration is a catabolic process which involves complete oxidative breakdown of organic food (especially glucose) into carbon dioxide and water with release of great deal of energy in the form of ATPs. It is predominant respiratory pathway in most of the organisms. Aerobic respiration is completed in four phases: glycolysis, oxidation of pyruvates, Krebs cycle and respiratory electron transport chain.

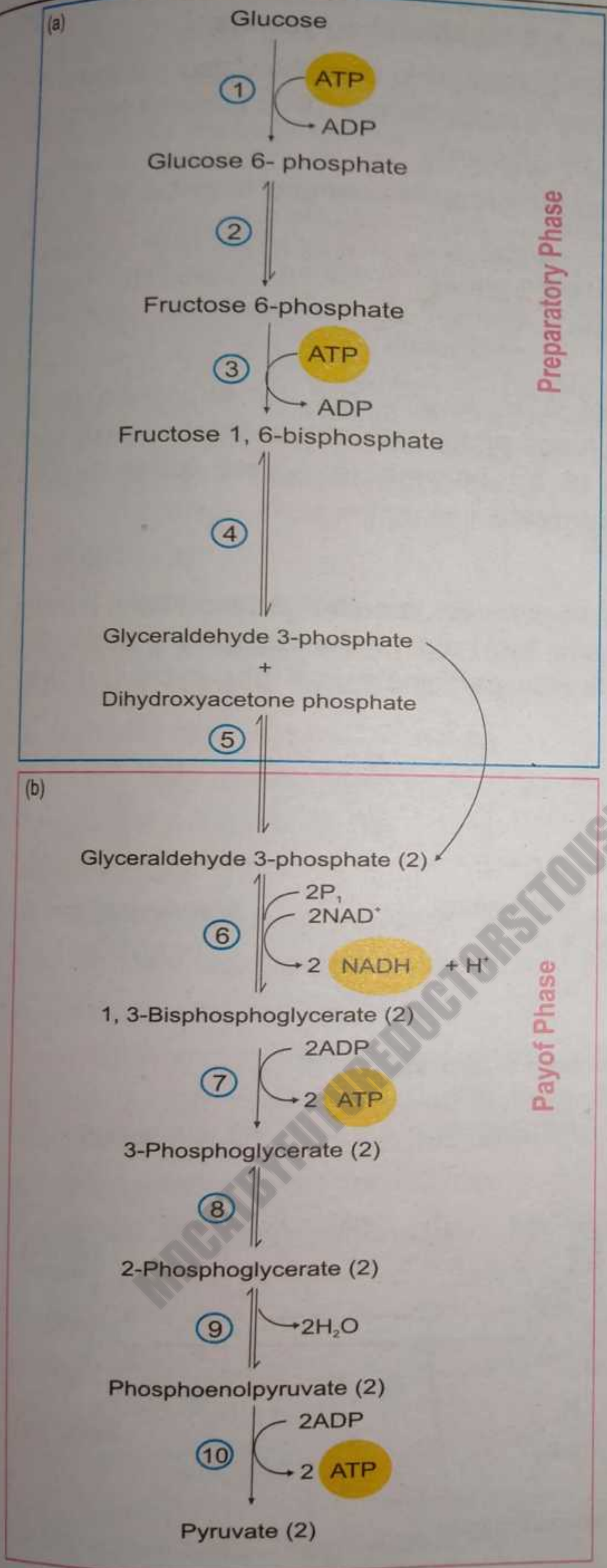


Fig: 4.13: Glycolysis

Glycolysis

Glycolysis is the process of breakdown of glucose or similar hexose sugar into two molecules of pyruvates through a series of enzymatic reactions releasing some energy (as ATP) and reduced coenzymes (as NADH). It occurs in the cytoplasm. It is completed in two phases i.e., preparatory phase and oxidative phase. **Preparatory phase** is an investment phase in which two ATPs are consumed. Its end products are two molecules of G3P. On the other hand **oxidative phase** is **pay off phase** in which not only ATPs are produced through substrate level phosphorylation but it also produces NADH which upon further oxidation in respiratory electron transport chain yields more ATPs. The whole glycolysis pathway takes place in the following sub steps.

1. Phosphorylation: When glucose reacts with ATP, a phosphate group from ATP is transferred to glucose. In this way glucose is phosphorylated to **glucose-6-phosphate**.

2. Isomerization: Glucose-6-phosphate is changed to its isomer **fructose-6-phosphate.**

3. Phosphorylation: When fructose-6-phosphate reacts with another ATP, it is phosphorylated to **Fructose-1, 6-bisphosphate.**

4. Splitting: Now fructose-1, 6-bisphosphate splits up to form one molecule each of 3-carbon compounds, **glyceraldehyde 3-phosphate** (G3P) and **dihydroxyacetone 3-phosphate.**

5. Isomerization: The dihydroxyacetone 3-phosphate is ultimately changed into its isomer, the **glyceraldehyde 3-phosphate** (G3P). In this way preparatory phase is completed. Next phase of glycolysis is proceeded by two molecules of G3P, therefore, the remaining reactions occur twice.

6. Dehydrogenation and Phosphorylation:

NADH and accepts inorganic phosphate (Pi) to form **1, 3-bisphosphoglycerate.**

7. Formation of ATP: The direct synthesis of ATP from organic phosphorylated substrate is called **substrate level phosphorylation.** In this step a molecule of ATP is formed from 1, 3-bisphosphoglycerate which is changed into **3-phosphoglycerate.**

8. Isomerization: In this step position of phosphate group is changed from C3 to C2 of phosphoglycerate to form 2-phosphoglycerate.

Glycolysis is also called EMP pathway because it was discovered by three German scientists Embden, Meyerhof and Parnas.

9. Dehydration: In this step, 2-phosphoglycerate undergoes dehydration and is converted into **phosphoenol pyruvate** (PEP).

10. Formation of ATP: Again a molecule of ATP is produced by **substrate level phosphorylation** when phosphoenol pyruvate loses phosphate group which is taken up by the ADP to form ATP in the presence of an enzyme (**pyruvate kinase**). The phosphoenol pyruvate is finally converted into **pyruvate.**

4.2.4 Oxidation of Pyruvate

Pyruvates are produced in cytosol. Because pyruvate is a charged molecule, it must enter the mitochondrion via active transport with the help of the transport protein. On entering the mitochondria, pyruvates do not directly participate in Krebs cycle but they

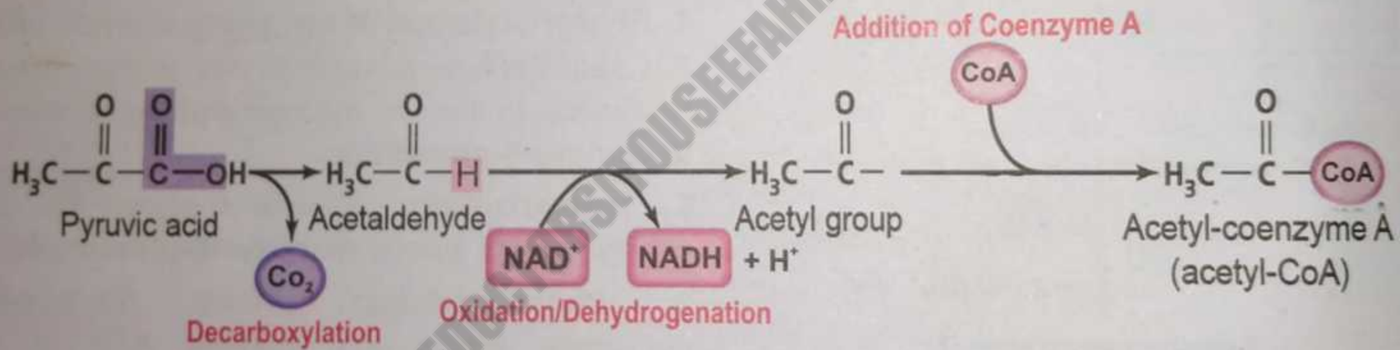


Fig: 4.14 Pathway of oxidation of pyruvate

undergo an intermediate phase, called **oxidation of pyruvate** or **link reaction** as it links the pathway of aerobic respiration that occurs outside the mitochondria with that occurs inside the mitochondria.

The oxidation of pyruvate takes place in three steps. First, it undergoes **decarboxylation** in which a molecule of CO_2 is removed from pyruvate to form **acetaldehyde**. Then NAD^+ removes hydrogen from acetaldehyde. As a result of this oxidation/ dehydrogenation a 2C fragment acetyl and NADH are produced. Finally, acetyl group is combined with coenzyme-A to form **acetyl CoA.**

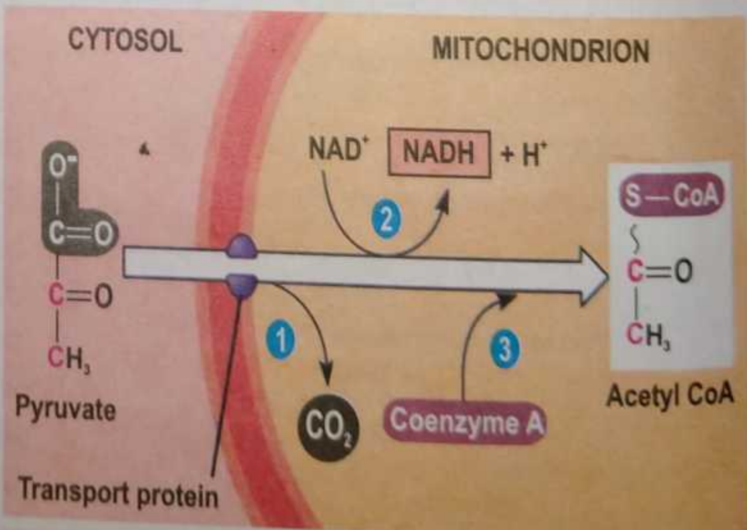


Fig: 4.15 Site of oxidation of pyruvate: Conversion of pyruvate to acetyl CoA, the junction between glycolysis and the citric acid cycle.

Science Titbits

A complex oxidation-reduction involves NAD or NADP. NAD and NADP act as intermediate in cellular reactions involving electron transfer. Many of the electrons removed from reduced carbon compounds in various enzyme-catalyzed reactions are transferred to NAD to produce NADH. When a molecule of NAD or NADP gains electrons and becomes reduced, a hydrogen ion combines with it as well. Thus the reduced form is symbolized as NADH or NADPH. In fact, another hydrogen ion becomes closely associated with each reduced molecule. Technically it is more accurate to represent the reduced form as $NADH + H^+$ or $NADPH + H^+$. For convenience, these reduced forms i.e., $NADH + H^+$ and $NADPH + H^+$ can be represented as $NADH_2$ and $NADPH_2$ respectively.

4.2.5 Krebs Cycle

This cycle was discovered by British scientist **Sir Hans Krebs**, therefore, called **Krebs cycle.** It is also called **Citric acid cycle** or **Tri carboxylic acid** (TCA) cycle because the first compound which is formed in the cycle is **citrate** (citric acid) that contains three carboxylic acid groups.

The Krebs cycle comprises following nine steps.

1. Synthesis

Acetyl CoA (2-carbon compound) and a water molecule combine with oxaloacetate (4-carbon compound) to form a 6-carbon compound called **citrate** (citric acid). It is the first product of Krebs cycle. CoA is liberated.

2. Dehydration

Citrate undergoes reorganization by the removal of a water molecule. The resulting compound is **cis-aconitate**.

3. Hydration

Cis-aconitate is converted into **isocitrate** with the addition of water. Actually, citrate and isocitrate are isomers of each other.

4. Oxidative decarboxylation

This is a two-step process, which involves oxidation/ dehydrogenation of isocitrate, followed by the **decarboxylation** to form **alpha-ketoglutarate**. The hydrogen and electrons which are released from isocitrate are taken up by NAD^+ to form NADH while the carboxyl group is released in the form of CO_2.

5. Oxidative decarboxylation and addition of CoA

α-Ketoglutarate again undergoes oxidative decarboxylation. The hydrogen and electrons which are released from **α-ketoglutarate** are taken up by NAD^+ to form NADH while the carboxyl group is released in the form of CO_2. Then, it combines with coenzyme A to form **succinyl CoA**.

6. Formation of ATP

Coenzyme A is removed from Succinyl CoA to form **succinate**. The reaction releases sufficient energy which is used to combine GDP and Pi forming GTP. GTP reacts with ADP to form ATP while GTP is again converted into GDP. In this way a molecule of ATP is generated in this reaction.

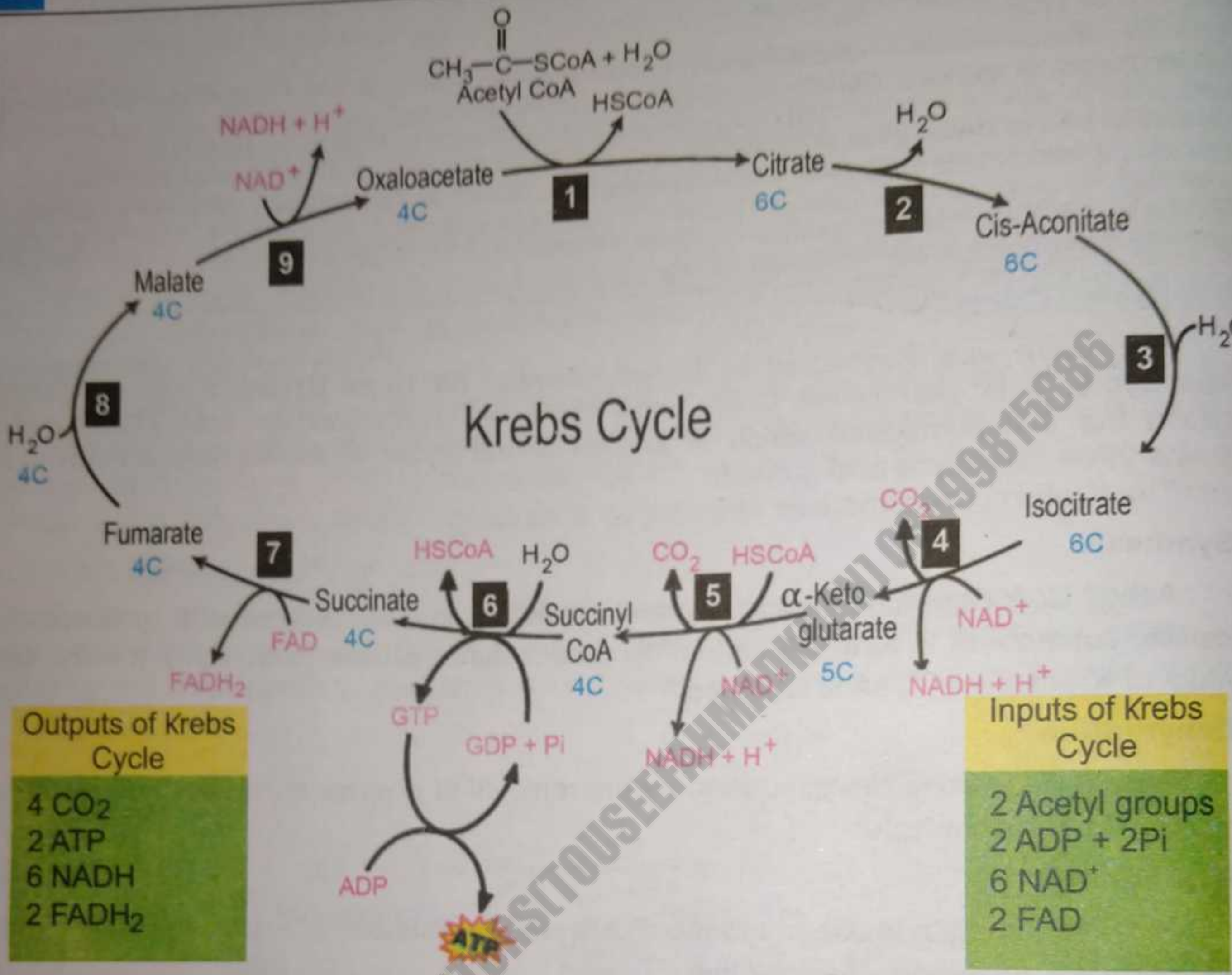


Fig: 4.16 Krebs cycle (Citric acid cycle or TCA cycle)

7. Dehydrogenation/oxidation

Succinate undergoes dehydrogenation/oxidation to form **fumarate.** The hydrogen and electrons which are released from succinate are taken up by FAD to form $FADH_2$.

8. Hydration

A molecule of water gets added to fumarate to form **malate.**

9. Dehydrogenation/oxidation

Malate undergoes dehydrogenation/oxidation to produce **oxaloacetate**. The hydrogen and electrons which are released from malate are taken up by NAD^+ to form NADH. Oxaloacetate picks up another molecule of acetyl CoA to repeat the cycle.

4.2.6 Electron Transport Chain (ETC)

After Kreb's cycle most of the energy of glucose is in the form of NADH and $FADH_2$. These two molecules enter into the electron transport chain. In this chain, the reduced NADH and $FADH_2$ are oxidized and their electrons are passed along a series of oxidation reduction reaction to the final acceptor i.e., molecular oxygen.

Components of electron transport chain

The components of electron transport chain include: (1) **NADH- dehydrogenase complex (I)**, (2) **FADH-dehydrogenase complex (II)** (3) **coenzyme Q** (4) **Cytochrome reductase complex (III)** (5) **Cytochrome-c** (6) **Cytochrome oxidase complex (IV).**

Passage of electron flow

NADH is oxidized when it reacts with **NADH- dehydrogenase complex (I)**. Electrons now move to the **co-enzyme Q**. If $FADH_2$ is to be oxidized through ETC, it also hands over its electrons to coenzyme Q, via **FADH dehydrogenase complex (II).**

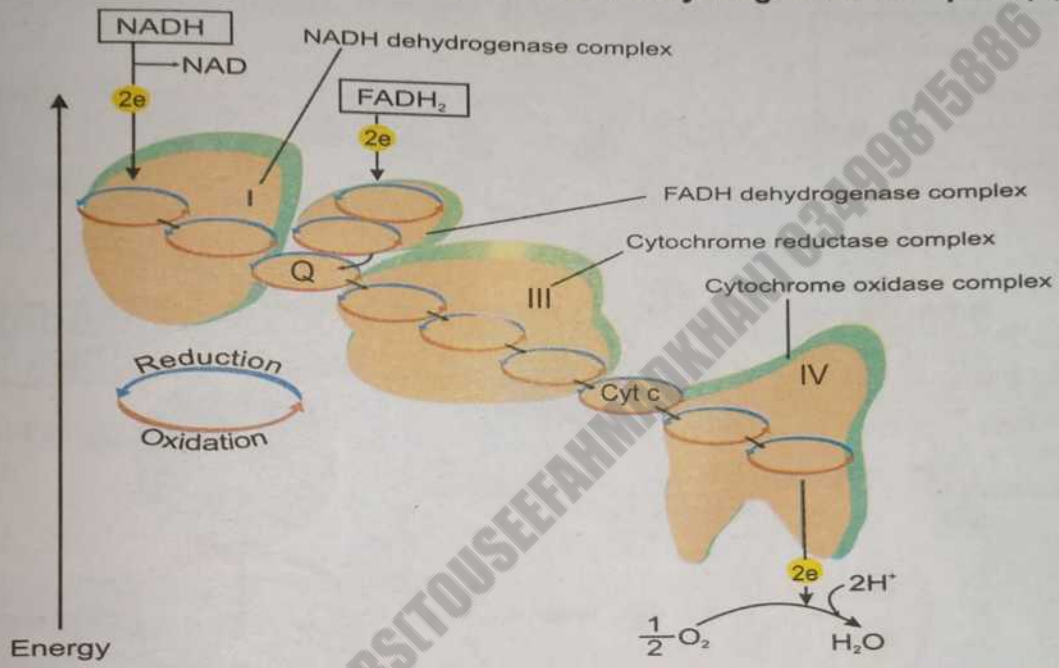


Fig: 4.17 Sequence of electron carriers in respiratory ETC

The flowing electrons from coenzyme **Q** are now transferred to **cytochrome reductase complex (III)** which hands over its electron to **cytochrome c**. Like co-enzyme Q, cytochrome c is also mobile carrier of electrons. Cytochrome c delivers the electrons to **cytochrome oxidase complex (IV).**

Finally, the electrons are transferred to oxygen. The oxygen is the ultimate acceptor of electrons. It becomes reactive. Each oxygen atom also picks up a pair of hydrogen ions from the aqueous solution forming water.

Science Titbits

Ubiquinone is not a protein, but a small molecule soluble in lipids and insoluble in water Cytochromes literally means "cell colour". The reduced cytochromes are pink in colour. They are protein plus pigment molecules containing iron. They can gain or lose an electron.

Energy released during passage of electrons from one carrier to the next is used to pump protons (H^+) from the mitochondrial matrix to the inter membrane space. There are three such sites, corresponding to three enzymes present in the electron transport chain i.e. NADH-dehydrogenase complex (I), cytochrome reductase complex (III) and cytochrome oxidase complex (IV).

The electron transport chain makes no ATP directly. Its function is to ease the fall of electrons from food to oxygen releasing energy in manageable amounts. How does the mitochondrion couple this electron transport chain and energy to ATP synthesis? The answer is a mechanism called chemiosmosis.

4.2.7 Chemiosmosis and Oxidative Phosphorylation

Oxidative phosphorylation is the synthesis of ATP molecules with the help of energy liberated during oxidation of reduced co-enzymes (NADH, $FADH_2$) produced in respiration. The enzyme required for this synthesis is called ATP synthetase.

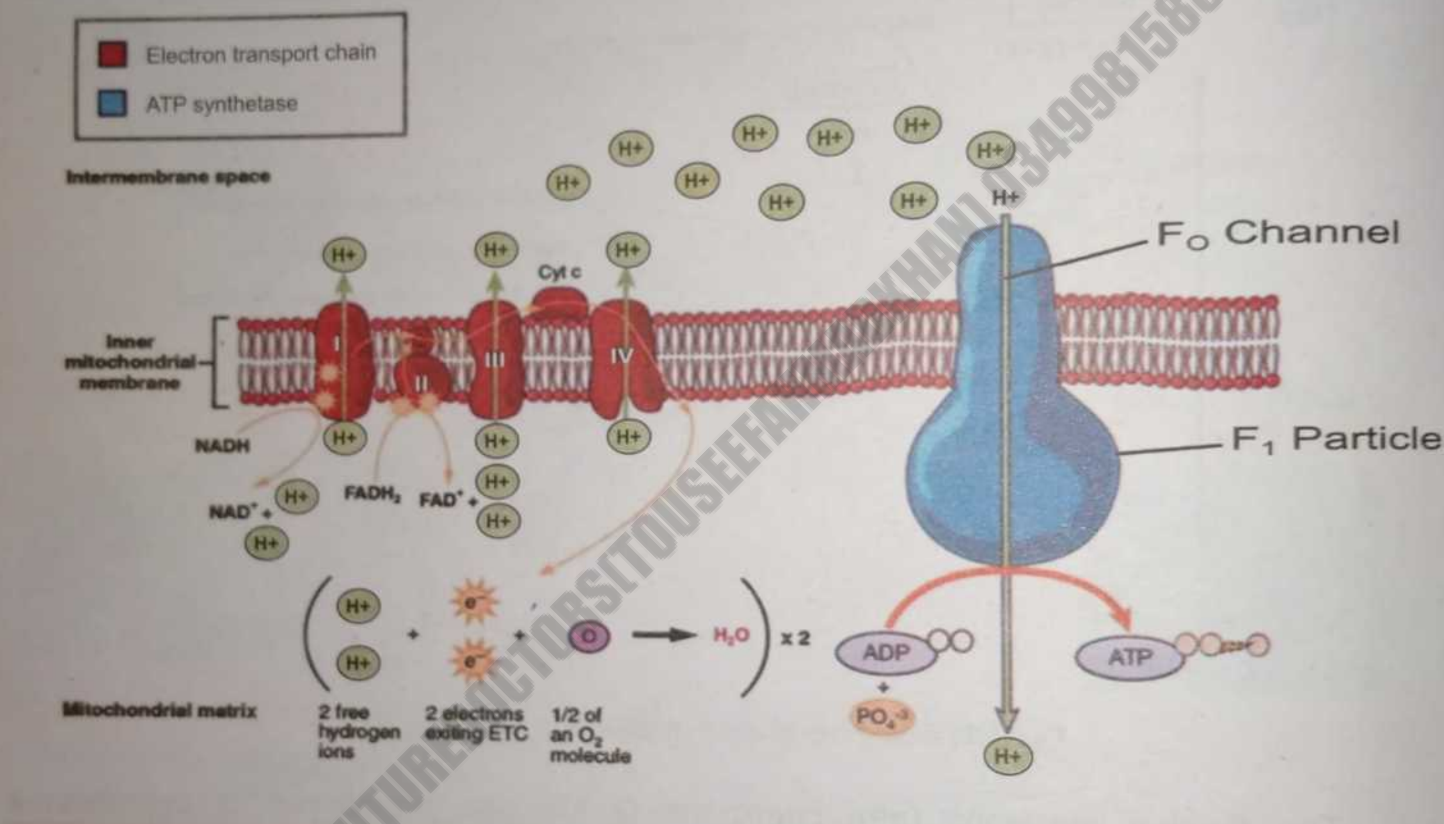


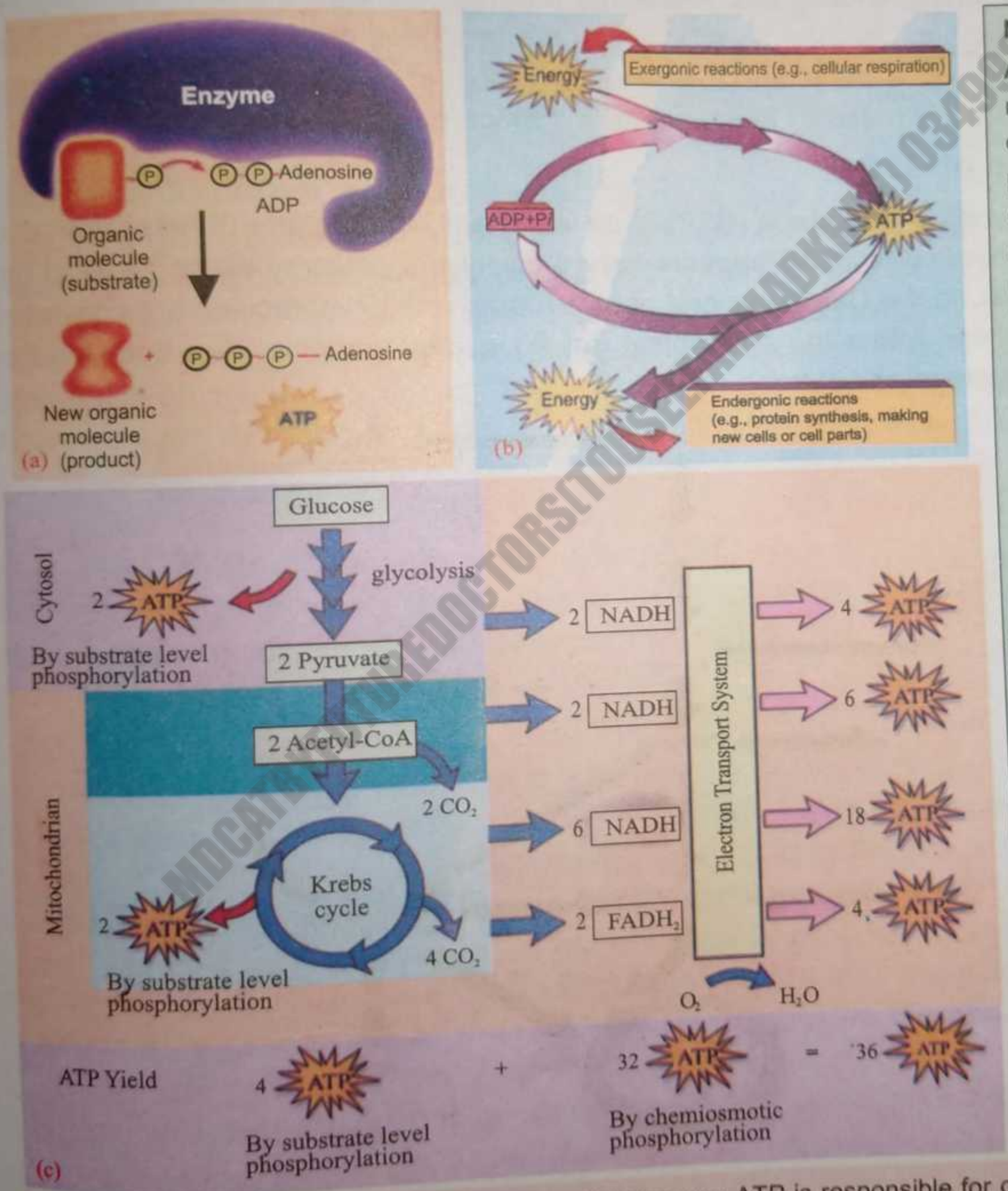
Fig: 4.18: Mechanism of chemiosmosis in respiratory electron transport chain

It is located in the inner mitochondrial membrane. It consists of two parts i.e., F_0 and F_1. F_0 is embedded in the membrane and involves in the movement of protons from inter-membrane space to mitochondrial matrix. F_1 or elementary particle is a head like part which is projected from the surface of membrane towards matrix. It catalyzes ATP synthesis by the combination of ADP and Pi. ATP-synthetase becomes active in ATP formation only when a proton gradient having higher concentration of H^+ or protons on the F_0 side as compared to F_1 side is established. The flow of protons through the F_0 channel induces F_1 particles to function as ATP-synthetase i.e., the energy of the proton gradient is used in attaching a phosphate to ADP by high energy bond. This produces ATP. Oxidation of one molecule of $NADH_2$ produces 3 ATP molecules while a similar oxidation of $FADH_2$ forms 2 ATP molecules. The theory of ATP production by this mechanism is called **chemiosmosis.**

4.2.8 Substrate Level Phosphorylation

The prime objective of cellular respiration is to generate ATPs. There are two ways to do this during aerobic respiration: chemiosmosis and substrate level phosphorylation, the former we have already discussed.

As far as substrate level phosphorylation is concerned, you are already familiar that the addition of inorganic phosphate to any organic molecule is called **phosphorylation** but, when phosphate is enzymatically transferred from an organic substrates molecule it is called **substrate level phosphorylation.** However, it accounts for only a small percentage of the ATP that a cell generates. It occurs at three occasions during aerobic respiration.



Note:
Actually, the two molecule of the NADH of glycolysis are produced in cytoplasm. These cannot be taken up by mitochondria because the mitochondrial membrane is impermeable for NADH. Therefore, at the time of their uptake only the energized electrons of NADH are transferred inside the mitochondrion by a complex mechanism. These electrons are received by two molecules of FAD^+ in the mitochondrial matrix to produce two molecule of $FADH_2$. Hence, four ATP molecules are produced instead of six. So, eukaryotes yield two less number of ATP than prokaryotes.

Fig:4.19: (a)Substrate level phosphorylation. (b) Because ATP is responsible for coupling many endergonic and exergonic reactions it is an important link between anabolism and catabolism in living cells. (c) ATP Budget in aerobic respiration

In glycolysis, substrate level phosphorylation occurs, when 1,3-bisphosphoglycerate is converted into 3-phosphoglycerate (7th reaction) and when phosphoenol pyruvate is converted into pyruvate (10th reaction). There are four ATPs produced by this mechanism during glycolysis but two of them are supposed to be consumed in preparatory phase so net product by substrate level phosphorylation is 2 ATP.

In Krebs cycle, substrate level phosphorylation occurs when succinyl CoA is converted into succinate. There are two molecules of ATP produced at this occasion. Since, ATP can be synthesized directly from the organic substrates of exergonic reactions (energy releasing reactions e.g., cellular respiration), therefore, it is said that substrate level phosphorylation couples the exergonic reactions with the synthesis of ATP. These ATP are then used to drive endergonic reactions (energy storing reaction e.g., protein synthesis). In this way, out of total 36 ATP which are produced during aerobic respiration in most of human cells, 4 ATP are the result of substrate level phosphorylation and remaining 32 ATP are produced by chemiosmosis through electron transport chain.

4.2.9 Importance of G3P

Glyceraldehydes 3-phosphate (G3P) is an important intermediate of respiration and photosynthesis. In respiration, G3P appears during glycolysis pathway which leads to the formation of pyruvate. In the Calvin cycle of photosynthesis, G3P molecules are converted into glucose phosphate within the chloroplast. Glucose phosphate is then converted to glucose, fructose, sucrose and starch.

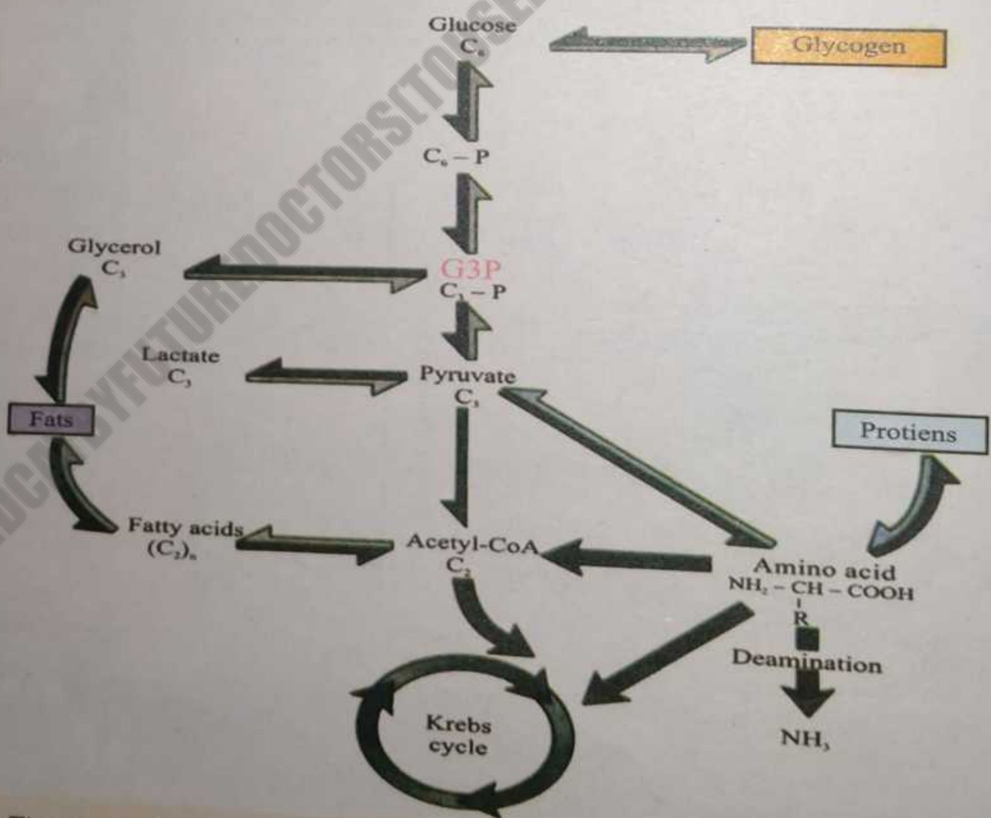


Fig: 4.20: The matabolic pool concept: When they are used as energy sources carbohydrates, fats and proteins enter degradative pathways at specific points. Degradation produces metabolites that can be used for synthesis of other compounds.

4.2.10 Cellular Respiration of Fats and Proteins

When a fat is used as an energy source, it breaks down to glycerol and three fatty acids. As figure 4.20 indicates, glycerol is converted to G3P, a metabolite in glycolysis. The fatty acids are converted to acetyl-CoA, which enters the Krebs cycle. An 18-carbon fatty acid results in nine acetyl-CoA molecules.

The hydrolysis of **proteins** results in amino acids whose R-group size determines whether the carbon chain is oxidized in glycolysis or the Krebs cycle. The carbon chain is produced in the liver when an amino acid undergoes deamination, i.e., the removal of the amino group. The amino group becomes ammonia (NH_3), which enters the urea cycle and becomes part of urea.

4.3 PHOTORESPIRATION

The respiratory activity that occurs in green cells in the presence of light resulting in release of carbon dioxide is termed as **photorespiration**. It needs oxygen and produce CO_2 and H_2O like aerobic respiration. However ATP is not produced during photorespiration.

4.3.1 Mechanism of Photorespiration

When the CO_2 levels inside the leaf drop to around 50 ppm (part per million), ribulose bisphosphate carboxylase/oxygenase (RuBisCO) starts to combine O_2 with RuBP instead of CO_2. The net result of this is that instead of producing two 3C molecules of phosphoglycerate (PGA), only one molecule of PGA and a toxic 2C molecule called **phosphoglycolate** are produced. The plant must get rid of the phosphoglycolate. First it immediately gets rid of the phosphate group, converting the molecule to **glycolate**.

$$RuBP + O_2 \longrightarrow \text{Phosphoglycolate} + \text{Phosphoglycerate} \longrightarrow \text{Glycolate}$$

The glycolate is then transported to the peroxisome and there converted to **glycine**. The glycine is then transported into the mitochondria where it is converted into **serine**. The serine is then used to make other organic molecules.

$$\text{Glycolate} \longrightarrow \text{Glycine}$$

$$2\ \text{Glycine} \longrightarrow \text{Serine} + CO_2$$

Effect of temperature on the activities of RuBisCO

Photorespiration is related to the functioning of the enzyme ribulose bisphosphate (RuBP) **carboxylase/oxygenase**. It is often called **RuBisCO** because it can have an oxygenase activity in addition to carboxylase activity. Its activity depends upon the relative concentration of O_2 and CO_2 in leaves. Photorespiration starts when the CO_2 levels inside a leaf become low. This happens on hot dry days when plant begins to secrete abscisic acid which causes closing of stomata to prevent excess water loss. If the plant continues CO_2 fixation in photosynthesis when its stomata are closed, the CO_2 will be used up and the O_2 released from photosynthesis will be prevented to release out of plant body. In this way, ratio of O_2 in the leaf will increase relative to CO_2 concentrations.

Disadvantages and Evolution of Photorespiration

Photorespiration costs the plant energy and results in the net loss of CO_2 fixation from the plant. Thus, it reduces the rate of photosynthetic process. In most plants, photorespiration reduces the amount of carbon fixed into carbohydrate during photosynthesis by 25 percent. Photorespiration is not essential for plant. It is also observed that if photorespiration is inhibited chemically, the plant can, still grow. Furthermore, some plants are naturally resistant to photorespiration. Then why photorespiration exists? The common simple answer to this question is that the active site of RuBisCO is evolved to bind both carbon dioxide and oxygen. Originally it was not a problem as there was no oxygen in the atmosphere at the time of establishment of earth so the carbon dioxide binding activity was the only one used. The photorespiration started when the oxygen began to accumulate in the atmosphere.

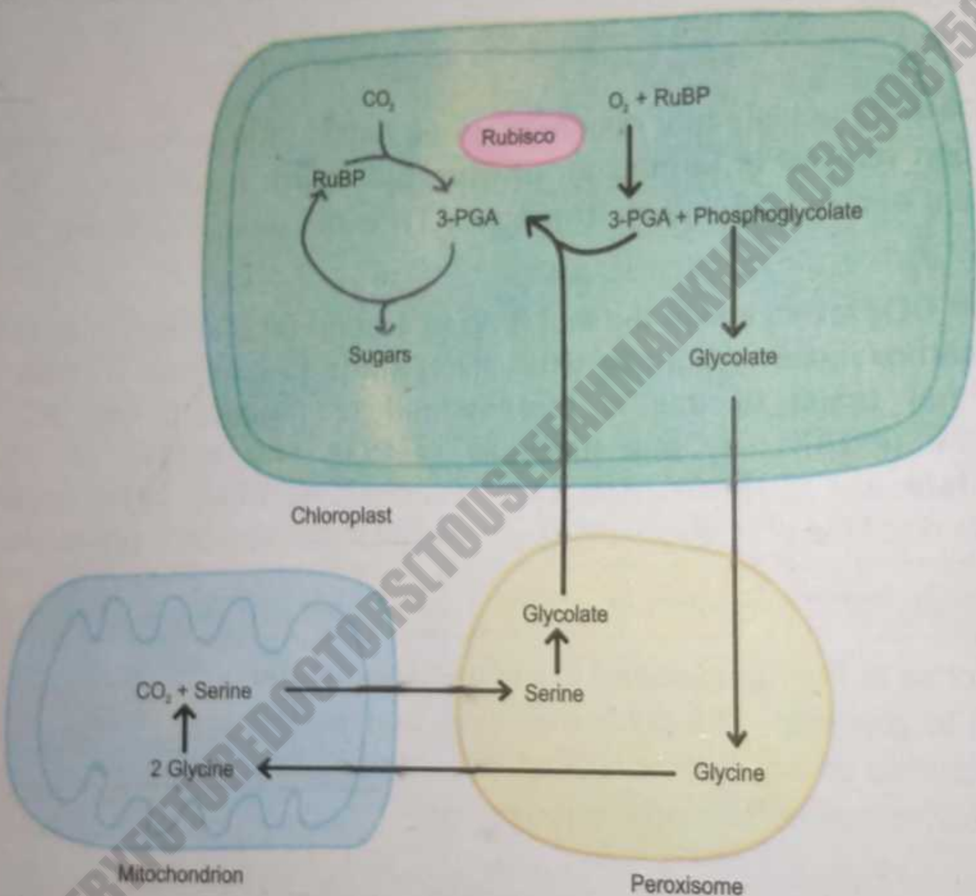


Fig: 4.21: Schematic representation of pathway involved in photorespiration in chloroplast, peroxisomes and mitochondria

Science, Technology and Society Connections

- **Analyze the impact of photorespiration on the agriculture yield in the tropic climates.**

Photorespiration decreases net photosynthesis because a portion of CO_2 fixed in photosynthesis escapes from the leave after it is fixed. Under certain conditions, up to 5% of the photosynthetic potential is lost in photorespiratory metabolism. Thus photorespiration reduces dry matter production and agricultural yield in tropical climate.

4.3.2 C_4 photosynthesis: An adaptation to the problem of photorespiration

Some plants which grow in tropical climate have an adaptation to the problem of photorespiration. They have an additional metabolic pathway in light independent phase of photosynthesis beside Calvin cycle. This metabolic pathway is called Hatch-Slack cycle of C_4 pathway in which **phosphoenol pyruvate** (PEP) carboxylase is used instead of RuBisCO to fix CO_2 to phosphoenol pyruvate (a C_3 molecule), and the result is **oxaloacetate**, a C_4 molecule. It takes place in cytoplasm of mesophyll cells.

$$PEP + CO_2 \xrightarrow{\text{PEPcarboxylase}} \text{Oxaloacetate}$$

As the first product of CO_2 fixation is a 4-carbon compound oxaloacetate, so the plants are called C_4 plants e.g., maize, sugarcane, sorghum, etc. Oxaloacetate is then transported to the chloroplasts of mesophyll cells. It is then converted to another 4-C compound, the **malate**, with the help of NADH, produced in the photochemical phase. The malate is then transported to the chloroplasts of bundle sheath cells. Here malate is converted to **pyruvate** (C_3) with the release of CO_2. Thus concentration of CO_2 increases in the bundle sheath cells. These cells contain enzymes of Calvin cycle. Because of high concentration of CO_2, RubisCO participates in Calvin cycle and not in photorespiration. Sugar formed in Calvin cycle is transported into the phloem. Pyruvate generated in the bundle sheath cells re-enters mesophyll cells and regenerates phosphoenol pyruvate (PEP) by consuming one ATP.

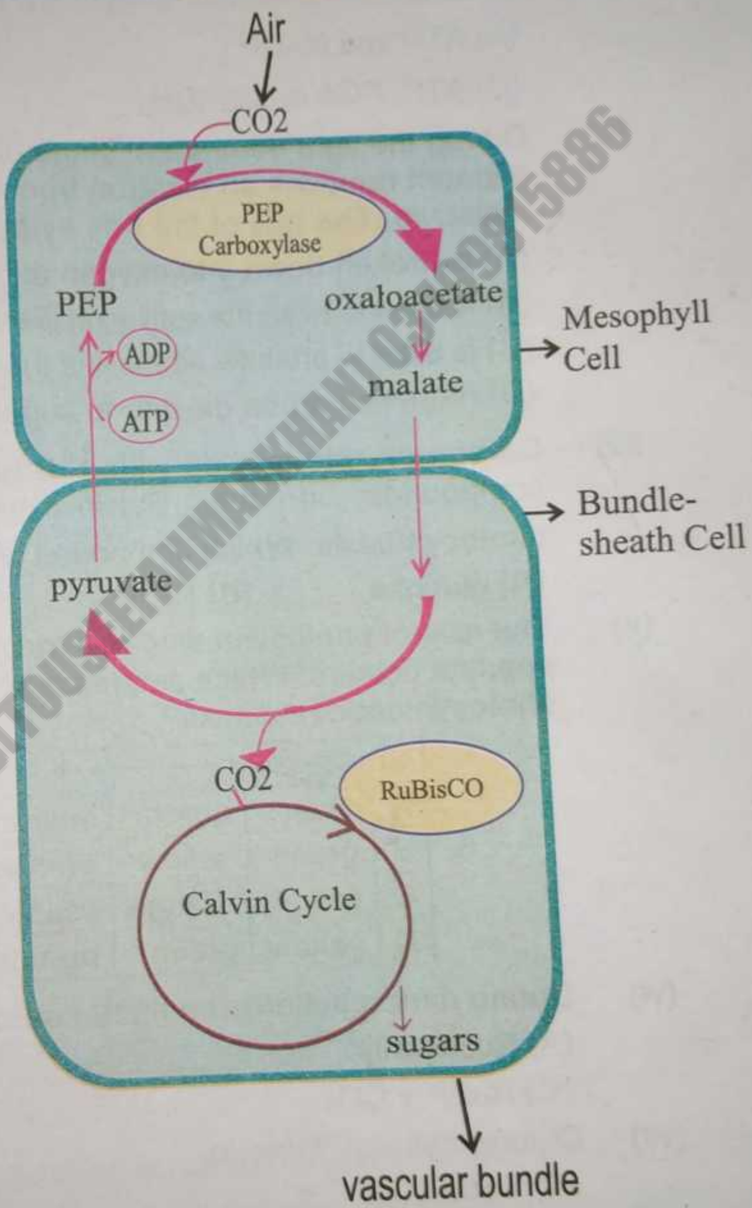


Fig. 4.22: C_4 photosynthesis

Exercise

MCQs

1. **Select the correct answer**

(i) Removal of the source of carbon dioxide from photosynthesizing chloroplasts results in rapid changes in the concentration of certain chemicals. Which one of the following represents the correct combination of concentration changes?

	ATP	Ribulose bishposphate	Phosphoglyceric acid (PGA)
A	decreases	decreases	increases
B	decreases	increases	no change
C	increases	increases	decreases
D	increases	no change	decreases

(ii) What are the products of the light reactions in photosynthesis?
(A) ATP and NADP
(B) ATP, $NADPH_2$ and oxygen
(C) ATP, PGA and $NADH_2$
(D) ATP, PGA and oxygen

(iii) During the light dependent stage of photosynthesis, the photoactivated pigment removes an electron from the hydroxylation derived from the water molecule. The fate of the free hydroxyl radical is that it
(A) is broken down into oxygen and a free radical of hydrogen
(B) is used to raise the activation level of chlorophyll by donating a positive charge
(C) is used to produce adenosine triphosphate from adenosine diphosphate
(D) reduces carbon dioxide to sugar

(iv) Carbon dioxide labeled with ^{14}C has been used to identify the intermediate compounds in the Calvin cycle, the light-independent stage in photosynthesis. Which compound would be the first to contain the ^{14}C?
(A) glucose (B) PGA (C) RuBP (D) starch

(v) The rate of photosynthesis of a freshwater plant is measured using five spectral colours. Which sequence of colours would give an increasing photosynthetic response?

	Smallest →			Largest response	
A	blue	green	yellow	orange	red
B	green	yellow	orange	red	blue
C	red	orange	yellow	green	blue
D	yellow	green	orange	blue	red

(vi) During dark reactions the three carbon atoms of 3-PGA are derived from
(A) RuBP only
(B) CO_2 only
(C) RuBP + CO_2
(D) RuBP + CO_2 + PEP

(vii) Chlorophyll is soluble in
(A) water
(B) organic solvent
(C) water and organic solvent
(D) not in any solvent

(viii) Photorespiration takes place only in
(A) root
(B) mitochondria
(C) green parts of the plant
(D) all cells of the plant

(ix) In C_4 plants, fixation of CO_2 occurs in
(A) palisade tissue
(B) cortex of stem
(C) spongy mesophyll and bundle of sheath
(D) phloem tissue

(x) ATP synthesis during light reactions is

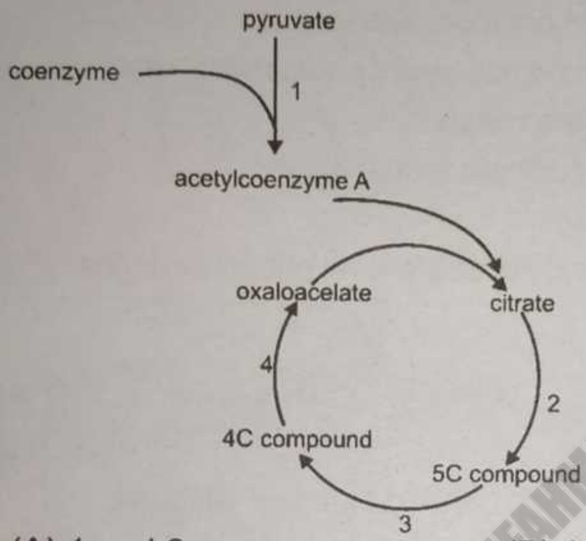
(A) oxidative (B) photolysis

(C) substrate phosphorylation (D) photophosphoryation

(xi) In C_3 plants first stable product of photosynthesis during dark reaction is

(A) PGA (B) G3P (C) RuBP (D) oxaloacetate

(xii) The diagram shows the Krebs cycle. At which numbered stages does decarboxylation take place?



(A) 1 and 2 (B) 1, 2 and 3

(C) 1, 3 and 4 (D) 1, 2, 3 and 4

Short Questions

2. What is electromagnetic spectrum?
3. Explain 'action spectrum' of photosynthesis.
4. What are the types of chlorophyll?
5. What is the importance of carotene?
6. Describe 'absorption spectrum' in photosynthesis.
7. What is photosystem? Explain.
8. What is the role of carbon dioxide in photosynthesis?
9. How it was confirmed that 'plants split water as a source of hydrogen releasing hydrogen as a byproduct?
10. What is the importance of G3P?
11. What is the effect of temperature on the activities of RuBisCO?
12. What are the disadvantages of photorespiration?
13. How photorespiration evolved?
14. Write the differences between:

(a) chlorophyll a and chlorophyll b
(b) carotene and xanthophyll
(c) action spectrum and absorption spectrum
(d) absorption spectrum of chlorophyll a and b
(e) antenna complex and reaction centre
(f) photosystem I and photosystem II
(g) light dependent reaction and light independent reaction of photosynthesis
(h) oxidative phosphorylation and photophosphorylation
(i) cyclic photophosphorylation and non-cyclic photophosphorylation
(j) C_4 carbon fixation and C_3 carbon fixation
(k) lactic acid fermentation and alcoholic fermentation
(l) Calvin cycle and Krebs cycle
(m) oxidative phosphorylation and substrate level phosphorylation

Extensive Questions

15. What is photosynthesis? Explain the role of light in photosynthesis.
16. Describe the structure of chlorophyll.
17. Write a note on the photosynthetic pigment carotene.
18. Explain the arrangement of photosystems.
19. Describe the role of water in photosynthesis.
20. Describe the mechanism of photosynthesis.
21. Explain in detail the light dependent phase of photosynthesis?
22. Explain in detail the light independent phase of photosynthesis?
23. Describe cyclic photophosphorylation.
24. Describe Calvin cycle.
25. Describe the kinds of cellular respiration.
26. Give an account of 'Glycolysis'.
27. Explain oxidation of pyruvate.
28. Explain Krebs cycle.
29. Explain electron transport chain.
30. Explain chemiosmosis and oxidative phosphorylation.
31. Describe substrate level phosphorylation.
32. Give an account of photorespiration in plants.
33. Explain that C_4 photosynthesis is an adaptation to the problem in photorespiration.

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SECTION 2

Biodiversity

Various types of plants and animals

5

ACELLULAR LIFE

After completing this lesson, you 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 bases of their hosts and structure.
- Explain the structure of a model bacteriophage, and HIV.
- Draw labeled diagrams of bacteriophage, flu virus and HIV.
- Justify why a virus must have a host cell to parasitize in order to complete its life cycle.
- Explain how a virus survives inside a host cell, protected from the immune system.
- Determine the method a virus employs to survive/ pass over unfavorable 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.
- Make a list of the sequences involved in the lytic life cycle of a bacteriophage.
- Explain the life cycle of HIV.
- Justify the name of the virus *i.e.,* "Human Immunodeficiency Virus" by establishing T-helper cells as the basis of immune system.
- Reason out the specificity of HIV on its host cells.
- List the symptoms of AIDS.
- Explain 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 virus 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.
- List the diseases caused by prions and viroids.

You have got a very brief introduction of biodiversity in IX-X biology course. This chapter deals with nature of virus, prions and viroids as acellular level of organization and the role they play in the economy of a country by causing preventable and fatal infectious diseases.

5.1 VIRUSES-DISCOVERY AND STRUCTURE

You must have heard about influenza, bird flu, polio, swine flu, dengue fever etc. All these and many other diseases are caused by the infectious agents called **viruses**. The viruses are pathogens, which cause diseases in animals and plants.

Viruses are not cells; they are not capable of independent replication. They cannot synthesize their own energy and proteins. They are too small to be seen under the light microscope.

5.1.1 History and Discovery of Virus

The word virus is derived from a Latin word "venom" meaning 'poison'. In past, the term virus was associated with infectious diseases which have unknown cause. The first evidence about the existence of virus came when (in 1884) **Charles Chamberland**, who worked with **Louis Pasteur**, found that the causative agents of rabies could pass through the porcelain filter (pore sizes of 100 – 1000 nm). However such filters could be used to completely remove all bacteria or other cells known at the time from a liquid suspension.

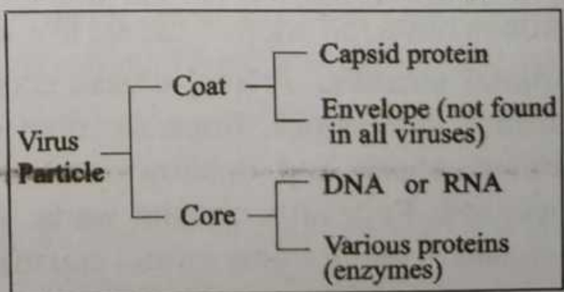
Tobacco mosaic disease was thought to be caused by bacteria. **Iwanowsky** (in 1892) extracted the juice from the leaves of tobacco having tobacco mosaic disease. In order to remove bacteria the juice was passed through porcelain filter. He then rubbed the filtered juice on the leaves of healthy plants, expecting no disease to develop, but the healthy leaves soon showed the symptoms of the disease.

By 1900, similar disease producing substance had been discovered in both plants and animals. The name filterable viruses were given to these substances. **W. M. Stanley (in** 1935) crystallized the infectious particle, now known as tobacco mosaic virus (TMV). Subsequently many other viruses actually have been seen with the help of the electron microscope. The study of virus is called **virology**.

5.1.2 Characteristics of viruses

They show the characteristic of both living and nonliving things. The **living characteristics** of viruses are: (1) Viruses occur in different varieties or strains. (2) They have their own genetic material in the form of either DNA or RNA that can undergo mutation. (3) They reproduce using the metabolic machinery of the host cell they infect. (4) They enter the cells of living organism and cause disease i.e., intracellular obligate parasite. (5) They get destroyed by ultraviolet rays.

The **nonliving characteristics** of viruses are: (1) They lack cellular structure, coenzyme and enzyme system and do not have metabolic activity of their own. (2) They can be crystallized and stored in bottles. (3) They do not respire. Viruses behave as nonliving, inert infectious particles outside the host.



5.1.3 General Structure of a Virus

Viruses have a very simple structure. A complete viral particle is called **virion**. Primarily, it can be divided into two parts i.e., **core** and **coat**.

The core is inner part of virion which consists of viral genome and various proteins (enzymes). **Genome** is the genetic material, which is either DNA or RNA, which may be single stranded or double stranded. **Core proteins** include one or more enzymes that facilitate the virus in its mode of action within host body. For example; all single stranded RNA viruses have the enzyme to convert single stranded RNA genome into double stranded RNA genome. Retroviruses and hepatitis B virus contain the enzyme reverse transcriptase to convert single stranded RNA genome into double stranded DNA genome.

The **coat** is the outer covering of viral particle which consists of capsid and envelope. The **capsid** is the protective coat of protein surrounding the core. Capsid is composed of identical repeating subunits called **capsomers (capsomeres)**. The number of capsomers is specific to a particular kind of virus. For example: Herpes virus has 162 capsomers in its capsid while adenovirus that causes common cold contains 252 capsomers in its capsid. There are two forms of symmetry in virus capsid. When the capsomers are arranged in 20 triangles, it is called **icosahedral** (polyhedral or spherical). When the capsomers are arranged in a hollow coil that appears rod shaped, it is called **helical**. A few viruses have an additional lipoprotein **envelope** around the capsid which is derived from the cell surface membrane of the host and also contain virally encoded proteins. The viral envelope is often covered with **glycoprotein spikes** that help them to recognize the host cell.

Bacteriophage capsid (Extra Reading Material)
In a bacteriophage capsid there are 12 vertices and 20 faces. Two types of capsomeres constitute the icosahedral capsid: pentagonal (pentons) at the vertices and hexagonal (hexons) at the faces. There are always twelve pentons, but the number of hexons varies among virus groups. HIV capsid forms an unusual cone-shaped structure, with twelve of the pentameric rings and over a hundred hexamers. The number of capsomere in polio virus is 32.

5.1.4 Classification of Virus

Virus classification is either based upon host organisms or on other structural characters such as morphology, genome type and mode of action in the host. The internationally agreed system of virus classification is based on the structure and composition of the virus particle (virion). In some cases, the mode of replication is also important in classification.

Classification of viruses based upon host

Viruses can be classified on the basis of their hosts e.g., bacteriophage virus, plant viruses and animal viruses.

David Baltimore, a Nobel Prize-winning biologist, devised the Baltimore classification system, which places viruses into one of seven groups, based on their mode of replication, and genome type.

Bacteriophage virus: It attacks bacteria. It is a DNA virus with a polyhedral head and a tail.

Plant viruses: More than 2,000 types of viral plant diseases are known. Most plant viruses discovered till to date including tobacco mosaic virus (TMV), having an RNA genome. Many viruses have rod shaped capsid like TMV e.g., potato yellow dwarf virus.

Animal viruses: Animal viruses occur as parasites in animals. Viruses cause foot and mouth disease in livestock. Rous sarcoma virus causes cancer in animals. In many viral infections viruses attack and destroy certain cells in the human body causing the symptoms and diseases. Papovirus causes warts. Poxivirus causes small pox. Picornovirus causes polio, hepatitis A etc. Paramyxovirus causes measles, mumps.

Classification of viruses based upon structure

(i) **On the bases of capsid** viruses are classified as:

(a) helical capsid e.g., tobacco mosaic virus.

Critical Thinking
Why antibiotics do not work against viruses?

(b) polyhedral capsid e.g., Adenoviruses.
(c) enveloped viruses e.g., Influenza viruses.
(d) complex capsid e.g., Bacteriophage.

(ii) **On the bases of genomes** viruses are classified as:
(a) Double-stranded (dsDNA) e.g. smallpox virus.
(b) Single -stranded DNA (ssDNA) e.g., mild rash virus.
(c) Double-stranded RNA (dsRNA) e.g., diarrhea virus.
(d) Single-stranded RNA (ssRNA); serves as mRNA e.g., Rubella virus.
(e) ssRNA; template for mRNA synthesis e.g., Influenza virus.
(f) ssRNA; template for DNA synthesis., HIV.

Science, Technology and Society Connections

- **Describe the limitations of the vaccine for the common cold/flu virus.**

Although we can often refer to the causative agent of cold as "the cold virus" there are actually more than 200 viruses that cause cold. Developing a vaccine against the infection is not practical.

5.2 PARASITIC NATURE OF VIRUS

Viruses are parasitic in nature. They are highly specific to their host. Bacteriophage infects only bacteria, the tobacco mosaic virus infects only tobacco plants and rabies virus infects only mammals. Some human viruses even specialize in a particular tissue. HIV will enter only certain types of white blood cells, the poliovirus reproduces in spinal nerve cells, and hepatitis viruses infect only liver cells. Human cold viruses infect only the cells lining the upper respiratory tract. Actually viruses have protein spikes on their surfaces which help them to attach with specific receptors on the host cells. The specificity of attachment determines the **host range** of the virus. Some viruses have a narrow range, whereas others have quite a broad range. For example, poliovirus can enter the cells of only humans and other primates whereas rabies virus can enter all mammalian cells.

5.2.1 Viruses must require host cell to complete life cycle

A virus must have a host cell to parasitize in order to complete its life cycle because viruses are obligate intracellular parasites, which means they cannot multiply outside a living cell. Viruses infect all sorts of cells, from bacterial cells to human cells. An isolated virus is unable to reproduce or do anything else except infect an appropriate host cell. Viruses lack metabolic enzymes, ribosomes, etc., for making proteins. Therefore they need host cell to complete their life cycles

5.2.2 Survival of viruses inside a host cell

However, host body has a strong defence against viruses but viruses respond the host immune system by inhabiting the actions carried out by immune system (discussed in chapter 13) and by changing their own genetic constitution so rapidly that vaccines or antibodies of host against them become ineffective. These are different ways that how a virus survives inside a host cell, protected from immune system.

5.2.3 Viruses can pass unfavourable conditions outside the host

Viruses unlike other "living" organisms do not need food to survive. They remain dormant or inactive outside the host body. Being tiny, they are not threatened by the other microorganisms. Their only concern would be the pH and temperature, as these would denature the protein. The virulence of the virus outside the host is maintained for a certain period of time and the time period depends on what virus is or pH and temperature of the medium. Viruses outside the host are nonliving. It can be said that they go under dormant period as they do not have any metabolic activity outside living host, however, the genome of the virus remains viable for long time (in inactive form) outside the host.

Non-enveloped viruses can in fact survive for long periods outside the host (up to several days) whereas enveloped viruses survive for shorter time periods. This is because many enveloped viruses rely on the proteins on the surface of the membrane to attach to the host cell, this envelope is generally sensitive to degradation to sunlight and normal cleaning procedures.

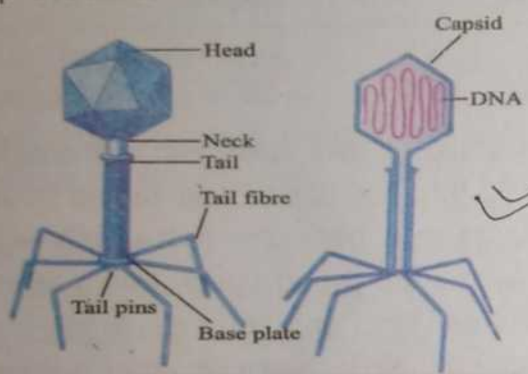


Fig. 5.1: Structure of bacteriophage

Science Titbits

Since the prophage contains genes, it can confer new properties to the bacteria. When a cell becomes lysogenized, occasionally extra genes carried by the phage get expressed in the cell. These genes can change the properties of the bacterial cell. This process is known as lysogenic conversion or phage conversion. *Clostridium botulinum*, a causative agent of food poisoning, makes several different toxins, 2 of which are actually encoded by prophage genomes.

5.3 BACTERIOPHAGE

The bacteriophage or simply phage is the virus that attacks upon bacteria.

5.3.1 Structure of Bacteriophage

It is generally a tadpole shaped virus. It consists of head, neck and tail. The **head** is icosahedral in shape. The inner core of head consists of a single stranded DNA genome. Below the head is narrow **neck** or collar which separates head and tail. The **tail** is a hollow tube made up of proteins through which the nucleic acid passes during infection. The tail is surrounded by a contractile sheath, which contracts during infection of the bacterium. At the end of the tail a **base plate** is present which possesses about six tail fibres around it and several **tail pins** or spikes at its lower surface. The **tail fibres** and tail pins are involved in the binding of the phage to the bacterial cell. At the bottom of core tube of tail, an enzyme, the **lysozyme** is present which is released upon contraction of tail. It digests the portion of host cell wall so that core tube can be penetrated into the host cell during infection.

5.3.2 Life cycle of bacteriophage

Bacteriophages or phages show two types of life cycles i.e., **Lytic cycle** and **Lysogenic cycle**. The life cycle of bacteriophage comprises two main steps i.e., infection process and replication within the host cells. The initial steps in the infection process such as adsorption, penetration and genome injection are quite similar in both cycles but mode of replication is much different in lytic cycle or lysogenic cycle.

5.3.3 Infection Process

The common steps of infection process of bacteriophages to their host are as under:

Adsorption

The first step in the infection process is the adsorption of the phage to the bacterial cell. This step is mediated by the tail fibres and tail pins/spikes. Phages attach to specific receptors on the bacterial cell.

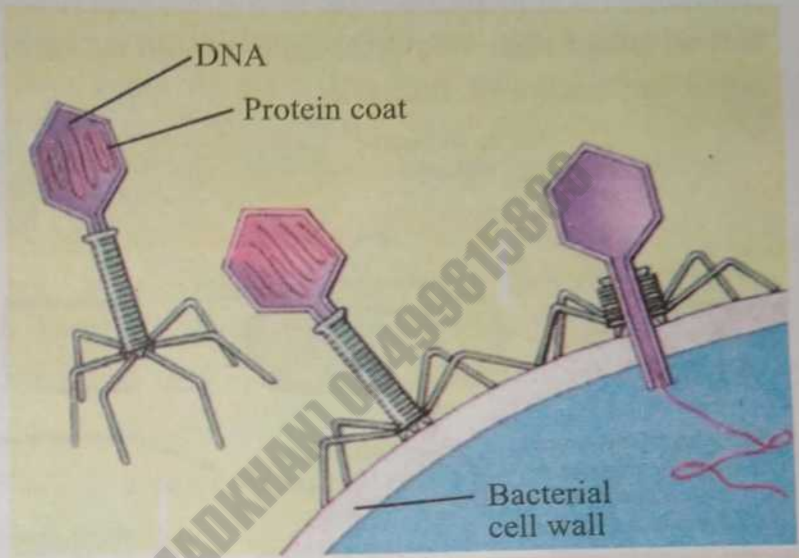


Fig. 5.2: Insertion of core into the bacterium

Penetration

The binding of the phage to the bacterium results in the contraction of the sheath and release of lysozyme that digest the portion of bacterial envelope; as a result the hollow core tube is pushed through the bacterial envelope. This insertion of core tube is called **penetration**.

Genome injection

The penetration of core results into the injection of viral DNA in the bacterial cytoplasm whereas, the remainder of the phage remains on the outside of the bacterium.

5.3.4 Replication of Bacteriophage in Lytic Cycle

The bacteriophage that performs lytic cycle is called **lytic** or **virulent phage** because it immediately causes lysis (breakdown) of its host cell after its own multiplication. It develops **Master-Slave relationship** with the host cell because host genomic DNA is immediately disintegrated by the virally encoded DNA digesting enzyme (DNAase). Since viral DNA is already undergone certain chemical modification therefore, such enzymes do not affect it. The disintegration of host DNA enables the viral DNA to take over the control of the whole metabolic machinery of its host. In lytic cycle the subsequent steps are **synthesis of phage components**, **assembly**, **maturation**, **lysis** and **release**.

Soon after the disintegration of host DNA phage specified mRNAs and proteins are began to produce. Structural proteins (head, tail) that comprise the phage as well as the proteins needed for lysis of the bacterial cell are separately synthesized. Nucleic acid is then packaged inside the head and then tail is added to the head. The assembly of phage components into mature infective phage particle is known as maturation. Within 20 to 25 minutes, approximately 200 phage particles are produced. In lysis and release phase the bacteria begin to lyse due to the accumulation of the phage lysis protein i.e., lysozyme and intracellular phage particles are released into the medium.

5.3.5 Replication of Bacteriophage in Lysogenic Cycle

The bacteriophages that perform lysogenic cycle are called **lysogenic** or **temperate phages**. These phages can either multiply via the lytic cycle or enter a dormant state in the cell. Such phages develop **Host-Guest relationship** because in this case the phage DNA actually integrates into the host chromosome and is replicated along with the host chromosome and passed on to the daughter cells. This integrated state of phage DNA is termed **prophage**. This process is known as **lysogeny** and the bacteria harboring prophage are called **lysogenic bacteria**.

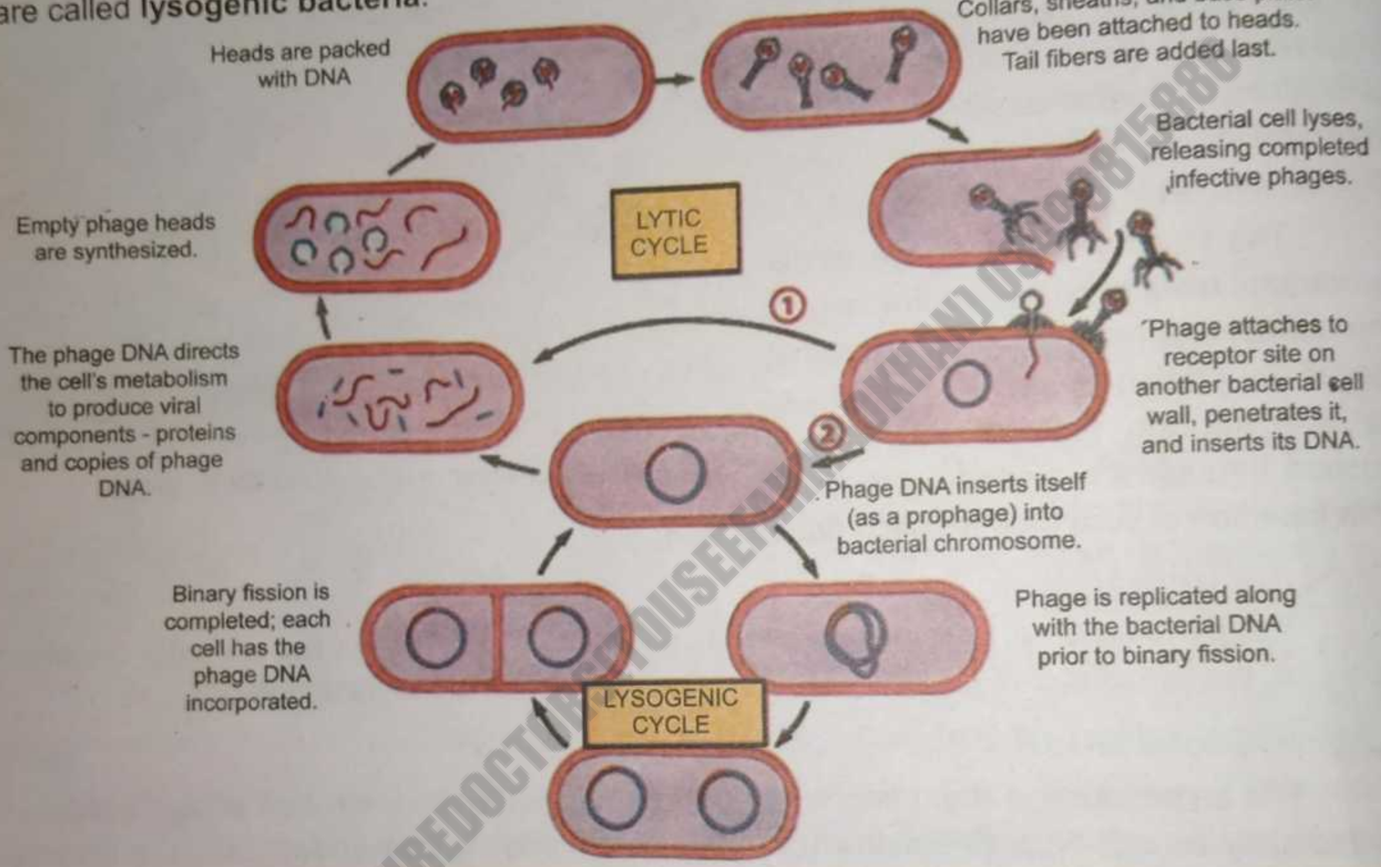


Fig. 5.3: Lytic and lysogenic life cycle of bacteriophage

The lysogenic state of a bacterium can get terminated anytime when it is exposed to adverse conditions. This process is called **induction**. Conditions that favour the termination of the lysogenic state include: desiccation, exposure to UV or ionizing radiation, exposure to mutagenic chemicals, etc. The separated phage DNA then initiates lytic cycle resulting in cell lysis and releases of phages. Such phages are then capable of infecting new susceptible cells and render them lysogenic.

5.3.6 Usage of Bacteriophages in Genetic Engineering

Genetic engineering is the field of biotechnology in which alteration in genetic material of an organism is carried out such as transfer of gene from one organism to another. Several biological tools have been used in genetic engineering to accomplish the required task. The bacteriophages have also been used in number of ways in different approaches of genetic engineering. Some of them are outlined below:

a) Beside bacterial plasmids the phage DNA has also been used as **vector** in genetic engineering techniques such as development of **genomic library** (a collection of bacteria or bacteriophage clones which contains multiple copies of all the genes of an individual's genome).

b) **Phage therapy** is the application of genetically engineered phages that can kill pathogenic bacteria. Phage therapy has advantages over conventional antibiotic therapy. As phages are fairly narrow in their spectrum of activity, meaning that with phage treatment it is possible to kill bacterial pathogens while avoiding harming of normal bacterial flora, i.e., our good bacteria.

c) Bacteriophages have been used for many years as tools for the treatment of bacterial infections but recently a new application in the area of **antibacterial nanomedicines** has been discovered in which bacteriophages can be formulated as targeted drug-delivery vehicles.

5.4 HUMAN IMMUNODEFICIENCY VIRUS

Human immunodeficiency virus (HIV) is the causative agent of acquired immune deficiency syndrome or AIDS. It was identified (in 1984) by research team from Pasture Institute in France and National Institute of Health in USA. The virus was named HIV (in 1986).

5.4.1 Structure of Human Immunodeficiency Virus

Human Immunodeficiency Virus (HIV) is a **retrovirus**. It is spherical in shape. The outer covering is a lipoprotein **envelope** which consists of two layers of lipids; different proteins are embedded in the viral envelope, forming **"spikes"** consisting of the outer **glycoprotein (gp) 120** and the **transmembrane gp41**. The lipid membrane is borrowed from the host cell during the budding process (formation of new particles). gp 120 is needed to attach to the host cell, and gp41 is critical for the cell fusion process. Beneath envelope another protein shell is present which is made up of **matrix proteins**. It lies between the envelope and capsid. The HIV capsid is somewhat conical shaped which is composed of capsomers. The viral core contains two single strands of **HIV RNA** and the enzymes needed for HIV replication, such as reverse transcriptase, integrase and protease. The **reverse transcriptase** enzyme is used to convert viral RNA genome into viral DNA genome, integrase enzyme is used to incorporate viral DNA into host DNA while the protease enzyme is used to break large structural proteins into smaller units. These structural proteins are encoded by three out of the nine virus genes.

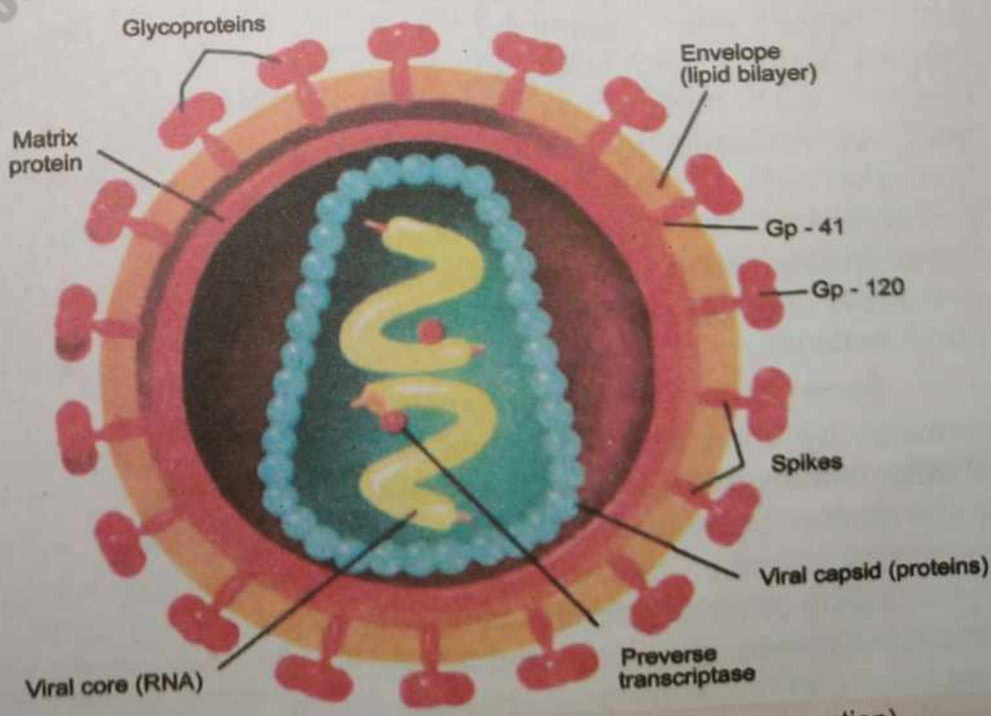


Fig: 5.4: Human immunodeficiency virus (HIV) (cross section)

5.4.2 Life Cycle of HIV

The primary hosts of HIV are helper T lymphocytes (CD4 or T4 cells). In addition macrophages and certain brain cells may also be affected. Following steps are involved in the life cycle of HIV. (1) The initial step in the life cycle of HIV is adsorption/attachment which is characterized by the binding of the virion glycoprotein 120 envelope proteins to the CD4 proteins (a receptor) on the surface of T4 cells. (2) Next the fusion of the viral envelope with the cell membrane takes place and the virion enters the cell by endocytosis. Once inside the host cell, the HIV particle sheds its protective coat i.e., **uncoating** occurs. This leaves the single stranded viral RNA in the cytoplasm along with viral enzymes. (3) The enzyme called **reverse transcriptase** synthesizes a single stranded DNA complementary to virus RNA therefore, called **complementary DNA** (cDNA). (4) After reverse transcription the viral genomic RNA is disintegrated by the ribonuclease (RNAase) enzyme. (5) The single stranded cDNA is replicated to form double stranded cDNA. (6) The double stranded cDNA then integrates into the host cell DNA. Integration is mediated by a virus encoded enzyme integrase. (7) The integrated DNA is now called **provirus**. (8 and 9) Viral mRNA is transcribed from the proviral DNA by the host cell RNA polymerase. During **transcription** not only viral mRNAs for different protein are formed but viral genomic RNA is also produced. (10) The viral mRNAs are **translated** by host ribosomes into several large proteins, which are then cleaved by the virus-encoded protease to form the virion structural proteins. (11) The viral components are assembled and **mature virions** are produced. (12) Finally, the mature virions are gradually **released by budding off** from the host cell and enclosing a portion of host cell membrane around them. In this way host cell size is decreased enough that it becomes non-functional.

Since, helper T cells regulate immunity by enhancing the response of other immune cells so, the decrease in the number of helper T cells causes deficiency of the human immune system. The virus affects the human immune system, therefore, the virus has been named Human Immunodeficiency Virus (HIV).

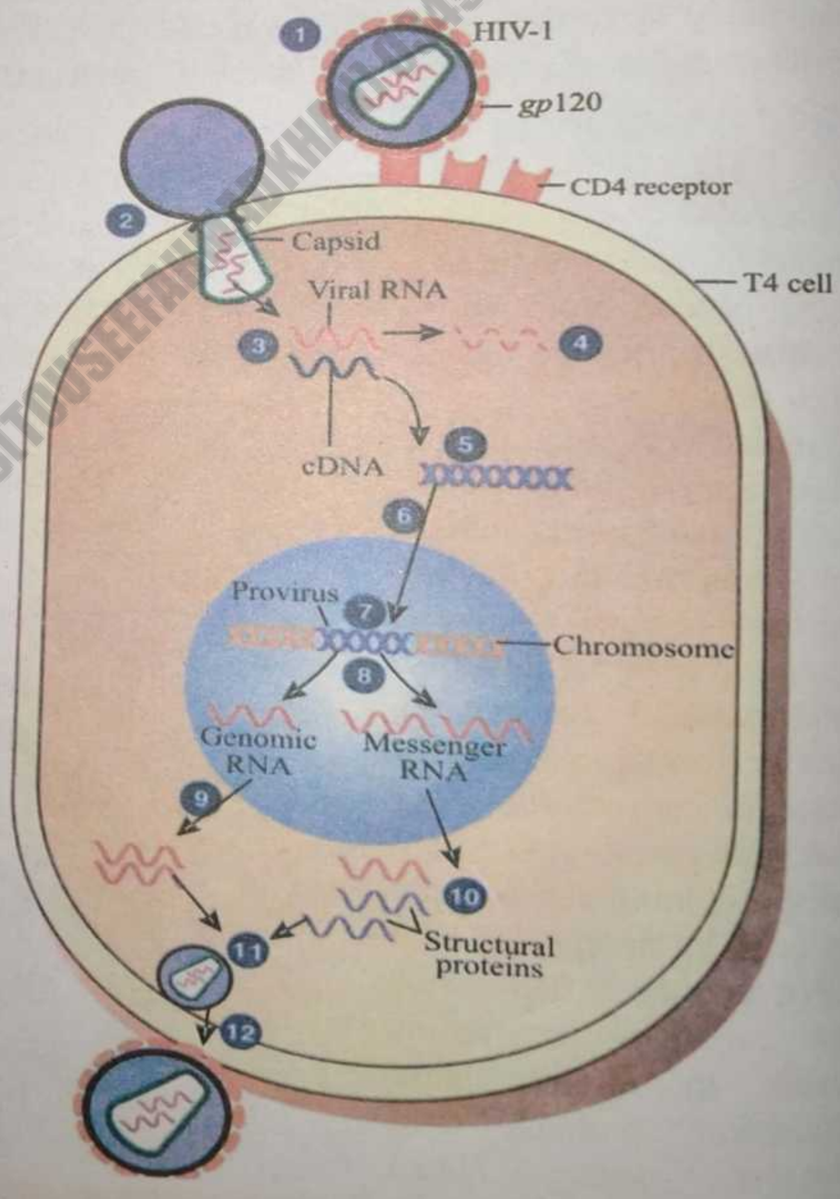


Fig. 5.5: Life cycle of HIV 1. Attachment/ adsorption. 2. Penetration. 3. Reverse transcription. 4. Breakdown of viral genomic RNA. 5. Replication. 6. Integration. 7. Provirus. 8. and 9. Transcription. 10. Biosynthesis of protein. 11. Maturation. 12. Release.

5.4.3 Symptoms of AIDS

An HIV infection can be divided into 3 stages: Asymptomatic carrier, AIDS Related Complex (ARC), Full Blown AIDS. In **asymptomatic carrier** symptoms that may include are fever, chills, aches (continued pain), swollen lymph glands and an itchy rash. These symptoms disappear and there are no other symptoms for nine months or longer. Although the individual exhibit no symptoms during this stage, he or she is highly infectious. The standard HIV blood test for the presence of antibody becomes positive during this stage.

The most common symptoms of **AIDS related complex** are swollen lymph glands in the neck, armpit or groin that persist for months. Other symptoms include night sweats, persistent cough, flu, and persistent diarrhoea, loss of memory and depression.

The **full blown AIDS** is the final stage. In it there is severe weight loss and weakness due to persistent diarrhoea and usually one of several opportunistic infections.

Fig. 5.6: This photograph shows the multiple wounds of the skin cancer on the arm of a patient with AIDS.

5.4.4 Opportunistic Diseases

HIV does not cause any disease nor kills any person. It only destroys T-cells of immune system. The decrease in the human immune system results in the inability of the body to fight diseases. Due to weak defence system a person suffering from AIDS is attacked by diseases called opportunistic diseases, e.g., skin cancer, fungal infection, viral infection, gastrointestinal diseases, respiratory diseases, nervous system and eye diseases.

5.4.5 Treatment of AIDS

HIV is treated using a combination of medicines to fight HIV infection. This is called **antiretroviral therapy** (ART). ART is not a cure, but it can control the virus so that HIV positive person can live a longer, healthier life and reduce the risk of transmitting HIV to others. ART is a highly effective treatment for HIV infection, preventing progression of the disease in the vast majority of recipients. When ART is accessible and started early in the course of infection, the lifespan of HIV-positive people is typically very close to that of comparable HIV-negative people. But ART can have toxicities, is often costly, and requires strict daily pill taking that can lessen quality of life. Because of the limitations of ART, a cure for HIV infection remains a vital goal for research.

5.4.6 Control Measures Against the Transmission of HIV

AIDS can be controlled by preventing transfer of body fluid (blood, serum, semen, etc.,) from patient to unaffected person. The following behavior of precautionary measure will prevent AIDS: (1) Do not use used syringes and needles. (2) For blood transfusion, blood must be used after proper screening for HIV. (3) Do not share toothbrushes, blades and towels with anyone. Special cares to be taken at barber's shop or hair cutting saloons, beauty salons. (4) Surgical instruments must be properly sterilized. (5) AIDS is primarily a sexually transmitted disease. Refrain from immoral sexual activities and follow Islamic teachings to pass healthy, neat and clean life. (6) Mother having HIV should not feed their babies. Shaking hands, hugging, coughing or sneezing and swimming in the same pool do not transmit HIV. One cannot get AIDS from inanimate objects such as toilets, door knobs, telephones, office machines and house hold furniture. AIDS is not transmitted by mosquitoes and other insects.

Skills: Interpreting and Recording

- **Predict from the given data the incidence and prevalence of AIDS over a period of next five months.**

HIV FACT SHEET NOVEMBER 2016

GLOBAL HIV STATISTICS

- 18.2 million people were accessing antiretroviral therapy (June 2016)
- 36.7 million people globally were living with HIV (end 2015)
- 2.1 million people became newly infected with HIV (end 2015)
- 1.1 million people died from AIDS-related illnesses (end 2015)
- 78 million people have become infected with HIV since the start of the epidemic (end 2015)
- 35 million people have died from AIDS-related illnesses since the start of the epidemic (end 2015)

People living with HIV

- In 2015, there were 36.7 million people living with HIV.

New HIV infections

- Worldwide, 2.1 million people became newly infected with HIV in 2015.
- New HIV infections among children have declined by 50% since 2010.
- Every year since 2010, around 1.9 million adults have become newly infected with HIV.

Skills: Interpreting and Recording

- **Make a list of factors responsible for the spread of AID**

Source: www.unaids.org/en/resources/fact-sheet

HIV/AIDS in Pakistan: Nearly 100,000 people in Pakistan living with HIV/AIDS, but only 15,370 registered. The number of new HIV infections in Pakistan grew at an average of 17.6 percent per year between 2005 and 2015, making it the highest increase in the world. The highest number of 1,278 Aids patients and HIV carriers were in Sindh, followed by 558 in Punjab, 522 in Islamabad, 468 in the NWFP, 215 in Baluchistan and 31 in Azad Kashmir

Courtesy: The Express Triubne, Islamabad. 12th May 2016 and The Dawn, Islamabad 28th December 2016

5.5 VIRAL DISEASES

In this section we will describe causative agent, symptoms, treatment, transmission and prevention of hepatitis, herpes, polio and cotton leaf curl disease.

5.5.1 Hepatitis

Hepatitis is generally characterized as inflammation of liver including other symptoms. It is generally caused by viral infection or rarely due to toxicity of drugs and certain other causes. It may present in acute (recent infection, relatively rapid onset) or chronic (slowly progressing) forms. The most common causes of viral hepatitis are Hepatitis A, Hepatitis B, Hepatitis C, Hepatitis D, and Hepatitis E.

Hepatitis "A"

Cause: Hepatitis A (also called infectious hepatitis) is caused by HAV. **Transmission:** HAV is transmitted by the fecal-oral route. **Symptoms:** The typical symptoms are fever, loss of appetite, nausea, vomiting and jaundice. Dark urine, pale feces are also seen. **Treatment:** No antiviral therapy is available. **Prevention:** Active immunization with a vaccine containing inactivated HAV is available. Observation of proper hygiene.

Hepatitis "B"

Cause: Hepatitis B (also called serum hepatitis) is caused by HBV. **Symptoms:** It is similar to hepatitis A. **Transmission:** The three main modes of transmission are via blood, sexual contact and prenatally from mother to newborn. **Treatment:** Alpha interferon is effective against HBV. **Prevention:** Vaccine is highly effective in preventing hepatitis "B". All blood transfusion should be screened.

Hepatitis "C"

Cause: Hepatitis C is caused by Hepatitis C virus. **Transmission:** It is only transmitted via blood. **Symptoms:** Symptoms are just like hepatitis B. **Treatment:** A combination of alpha interferon and ribavirin is the treatment choice for chronic hepatitis C. **Prevention:** No vaccine is available. Blood transfusion should be screened as preventive measure.

Hepatitis "D"

Cause: The only human disease known to be caused by a **viroid** is hepatitis D. **Transmission:** The hepatitis D viroid can only enter a human liver cell if it is enclosed in a capsid that contains a binding protein. It obtains this from the hepatitis B virus. The viroid then enters the blood stream and can be transmitted via blood or serum transfusions. **Symptoms:** As in hepatitis B but more severe. **Treatment** and **Prevention:** Same as HBV.

Hepatitis (Extra Reading Material)

Hepatitis F virus (HFV) is a hypothetical virus linked to hepatitis. Several hepatitis F virus candidates emerged in the 1990s; none of these reports have been substantiated.

Another potential viral cause of hepatitis that is probably spread by blood and sexual contact was initially identified as Hepatitis G virus. There is very little evidence that this virus causes hepatitis, as it does not appear to replicate primarily in the liver. It is now classified as GB virus C.

Hepatitis "E"

It is caused by HEV. **Transmission:** Like HAV, it is also transmitted by the fecal-oral route. **Treatment** and **Prevention:** There is no antiviral treatment and vaccine. Observation of proper hygiene.

5.5.2 Herpes Simplex

Herpes simplex is a superficial viral infection characterized by one or more painful, fluid-filled sores or blisters (an elevation of the skin) appear on the skin or epithelium of outer openings of the body. Tingling, itching, or burning may be felt on the skin before the blisters appear. Blisters break open and often ooze fluid and form a crust, before healing. The sores can last from 7 to 10 days. There are two primary types of herpes i.e., oral herpes and genital herpes.

Oral Herpes

Cause: It is caused by herpes simplex virus type-1. **Transmission:** HSV Type-1, is transmitted primarily through oral secretions (saliva) or physical contact with sores on the skin. It can also be spread by sharing objects such as toothbrushes or eating utensils. **Symptoms:** Most blisters appear on the lips or around the mouth. Sometimes blisters form on the face or on the tongue. **Treatment:** Antiviral drugs are used to treat herpes. **Prevention:** Avoid contact with affected area of the patient.

Genital Herpes

Cause: It is caused by herpes simplex virus type-2. **Transmission:** In general, a person can only get HSV type 2 infection during sexual contact with someone who has a genital HSV-2 infection. **Symptoms:** In genital herpes the sores typically occur on the penis, vagina, buttocks, or anus. **Treatment**: Antiviral drugs are used to treat Herpes. **Prevention**: Avoid contact with affected area of the patient.

5.5.3 Poliomyelitis

Cause: It is caused by polio virus which is also an enterovirus. **Transmission**: Polio virus is transmitted by the fecal oral route. **Symptoms**: It replicates in the oropharynx and intestinal tract and spread to blood and central nervous system where virus replicates in the motor neurone located in the spinal cord. Death of these cells results in paralysis of the muscles innervated by theses neuron. The motor nerve damage is permanent. **Treatment**: There is no antiviral therapy. Physiotherapy for the affected muscles is important. **Prevention**: Polio can be prevented by the killed (Salk vaccine, or injectable polio vaccine or IPV) and the live, attenuated (weakened) vaccine (sabin vaccine or, oral polio vaccine or OPV).

5.5.4 Cotton Leaf Curl Disease

Cotton leaf curl disease (CLCuD) is a serious disease of cotton. **Cause:** Begomoviruses. **Transmission:** This disease is transmitted by the whitefly. **Symptoms:** The symptoms are initially characterized by a deep downward cupping of the youngest leaves. This is followed by development of cup-shaped, leaf-like structures. **Treatment** and **Prevention:** Control of CLCuD is mainly based on insecticide treatments against the insect vector.

Fig. 5.7: Cotton leaf curl disease

Fig. 5.8: *Whitefly*

Table 5.1: Losses due to cotton leaf curl disease, in Punjab, Pakistan

Year	Affected Area (000 ha)			Loss in Production (000 balse)	Loss in Pak Rupees (million)
	Partial	Complete	Total		
2006-07	1686.4	25.21	1711.63	1231.7	14063
2007-08	1432.8	2.5	1435.29	953.5	13778
2008-09	1440.1	40.25	1480.35	1115.7	16079
2009-10	1693.5	43.39	1956.62	1840.1	44160
2010-11	1341.8	28.33	1370.12	1164.90	48457
2011-12	569.6	0.00	569.60	482.20	11815

Production loss in bales calculated on the survey reports conducted by the PWQC, Punjab.
Economic loss estimated on the basis of annual average lint prices at Multan Market Committee
Courtesy: Mr. Tariq Mehmood, Director, CCRI, Multan

Skills: Interpreting and Communication.

- Collect and Compare the number of fatalities caused by hepatitis, herpes and polio combined with the total fatalities caused by AIDS.
- National AIDS Control Programme, Ministry of health – Government of Pakistan. www.nacp.gov.pk.
- Give reasons in favour of the statement "prevention is better than cure" and present the arguments in class.

5.6 PRIONS AND VIROIDS

The idea of an infectious agent that did not use nucleic acids and proteins together was considered impossible, but pioneering work by Nobel Prize-winning biologist **Stanley Prusiner** has convinced the majority of biologists that such agents do indeed exist. Prions and viroids are such agents which are acellular infectious particles like viruses but are even simpler and smaller than viruses.

5.6.1 Prions

Prions, so-called because they are proteinaceous, are infectious particles, smaller than viruses, that contain no nucleic acids (neither DNA nor RNA). Electron microscopy reveals filaments rather than virus particles. Prions are much **more resistant** to inactivation by ultraviolet light and heat than are viruses. Prions are composed of a single protein. This protein is encoded by a **single cellular gene**.

Fatal neurodegenerative diseases, such as Kuru in humans and in cattle mad cow disease were shown to be transmitted by prions.

5.6.2 Viroids

Viroids are plant pathogens that consist of a short, circular, single-stranded RNA without a protein coat or envelope. Viroid RNA does not code for any protein. The replication mechanism involves an enzyme RNA polymerase II, which synthesizes new RNA using the viroid's RNA as template. Some viroids are ribozymes, having catalytic properties which allow self-cleavage. The only human disease known to be caused by a viroid is hepatitis D. They cause several plant diseases, e.g., in potato, coconut, apple, peach, etc.

Science, Technology and Society Connections

- Suggest ways to rid human civilization of viruses.

Science, Technology and Society Connections

- Interpret how viral infections cause global economic loss.

Activity

1. Correlate the social and cultural values of a country with prevalence of AIDS.
2. List the factors responsible for the spread of AIDS.

Exercise

MCQs

1. Select the correct answer

(i) Viruses are considered nonliving because

(A) do not mutate
(B) they do not locomote
(C) cannot reproduce independently
(D) have nucleic acid

(ii) Which of these are found in all viruses?
(A) envelope, nucleic acid, capsid
(B) DNA, RNA and proteins
(C) proteins and nucleic acid
(D) protein, carbohydrate, lipids

(iii) Which step in the lytic cycle follows attachment of virus and release of DNA into the cell?
(A) production of lysosome
(B) disintegration of host DNA
(C) assemblage
(D) DNA replication

(iv) Which of these is a true statement?
(A) viruses carry with them their own ribosome for protein formation
(B) new viral ribosomes form after viral DNA enters the cell
(C) viruses use the host ribosomes for their own needs
(D) viruses do not need ribosomes for protein formation

(v) Which part of an animal virus is not reproduced in multiple copies?
(A) envelope (B) protein (C) capsid (D) ribosome

(vi) RNA retroviruses have a special enzyme that
(A) disintegrates host DNA
(B) polymerises host DNA
(C) transcribe viral RNA to DNA
(D) translates host DNA

(vii) Which of the following illness is caused by a retrovirus?
(A) typhoid (B) malaria (C) AIDS (D) sleeping sickness

(viii) The HIV primarily infects
(A) plasma cells
(B) helper T cells
(C) all white blood cells
(D) red blood cells

(ix) Poliomyelitis affects
(A) motor neuron (B) sensory neuron (C) brain (D) muscles

(x) HIV attaches to
(A) CD4 protein (B) nucleoprotein (C) lipoprotein (D) glycoprotein

(xi) Hepatitis D is caused by
(A) bacteria (B) virus (C) prions (D) viroids

Short Questions

2. What are the living and nonliving characteristics of viruses?
3. Give the classification of viruses based on their hosts.
4. What are the parasitic natures of virus?
5. Justify why a virus must have a host cell to parasitize in order to complete its life cycle.

6. Explain how a virus survives inside a host cell, protected from immune system.
7. Determine the method a virus employs to survive/passover unfavourable conditions when it does not have a host to complete the life cycle.
8. Justify the name of virus i.e., "Human Immunodeficiency Virus" by establishing T-helper cells as the basis of immune system.
9. Reason out the specificity of HIV on its host cells.
10. What are the symptoms of AIDS.
11. Explain opportunistic diseases that may attack an AIDS victim.
12. What are the common control measures against the transmission of HIV.
13. Describe the structure of prions and name any two diseases caused by them.
14. Describe the structure of viroids and name the diseases caused by them.
15. What do you mean by AIDS, HIV, ART, CLCuD and TMV?
16. Distinguish between:
    (a) bacteriophage and HIV virus
    (b) lytic and lysogenic cycle of bacteriophage (c) prions and viriods

Extensive Questions

17. Give the classification of viruses based upon capsid and genomes.
18. Describe the general structure of a virus.
19. Describe the structure of bacteriophage with diagram.
20. Describe the structure of human immunodeficiency virus with diagram.
21. Describe the Lytic and Lysogenic life cycles of a virus.
22. Describe the usage of bacteriophage in genetic engineering.
23. Explain the life cycle of HIV.
24. Describe the treatments available for AIDS.
25. Describe the causative agent, symptoms, transmission, treatment and prevention of the following diseases:
    (a) Hepatitis (b) Herpes (c) Polio (d) Cotton leaf curl disease

6

PROKARYOTES

After completing this lesson, you will be able to

- Outline the 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 archeal features that distinguish them from bacteria.
- Explain that most Archaea inhabit extreme environments.
- Justify the occurrence of bacteria in the widest range of habitats.
- 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.
- 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 unfavorable 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.
- 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 preventative measures.
- Describe important bacterial diseases in plants in terms of spots, blights, soft rots, wilts, and galls; emphasizing their symptoms, causative bacteria, and preventative 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.

All cells can be grouped into two broad categories: prokaryotic cells and eukaryotic cells. All prokaryotes have a simple structure than eukaryotes. This chapter is an introduction to prokaryotes. The prokaryotes have an intense effect on human health, economy and environment. The prokaryotes are being extensively used these days in research and technology and this chapter lays emphasis on this important aspect of prokaryotes.

6.1 TAXONOMY OF PROKARYOTES

The Dutch scientist **Antonie van Leeuwenhoek** first discovered bacteria in 1674, using a single-lens microscope of his own design. He called them "animalcules". **Ehrenberg** introduced the name bacterium in 1882.

The taxonomic position of prokaryotes has been continuously changed since their discovery. There are two separate system of classification are followed in which the prokaryotes are accommodated in different ways.

6.1.1 Taxonomic Position of Prokaryotes as "Kingdom Monera"

In traditional two kingdom system of classification all microorganisms including prokaryotes were placed in plant kingdom. In 1861, **John Hog** proposed kingdom **Protista** to accommodate microorganism so prokaryotes were also placed in this kingdom. In 1866, **Ernst Haeckel** made a separate group, the Monera for prokaryotes within the same kingdom Protista.

In 1938, **Herbert Copland** elevated the status of Monera to kingdom level, so first time; prokaryotes were recognized as a separate kingdom **"Monera".** In 1969, American biologist **Robert H. Whittaker** proposed five-kingdom system that incorporated the basic prokaryotic-eukaryotic distinction which has been modified by **Lynn Margulis** and **Karlene V. Schwartz** in 1988. They also assigned a separate kingdom "Monera" for all the prokaryotes.

6.1.2 Taxonomic Position of Prokaryotes as "Domain Bacteria" and "Domain Archaea"

The term "bacteria" was traditionally applied to all microscopic, single-celled prokaryotes. However, molecular systematics studies, showed prokaryotic life to consist of two separate **domains**, (group of kingdoms, i.e., a taxonomic category above the kingdom level) called **Bacteria** and **Archaea** that 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 Phylogenetic position of prokaryotes

The evolutionary relatedness among various groups of organisms is called **phylogeny**. A major step forward in the study of phylogeny of bacteria was the recognition in 1977 that archaea has a separate line of evolutionary descent from bacteria. This new phylogenetic taxonomy was based on the discovery that the genes encoding ribosomal RNA are ancient and distributed over all lineages of life with little or no gene transfer. Therefore rRNA are commonly recommended as **molecular clocks** for reconstructing phylogenies, and divided prokaryotes into two evolutionary domains as part of the three-domain system, eubacteria, archaea and eukaryotes.

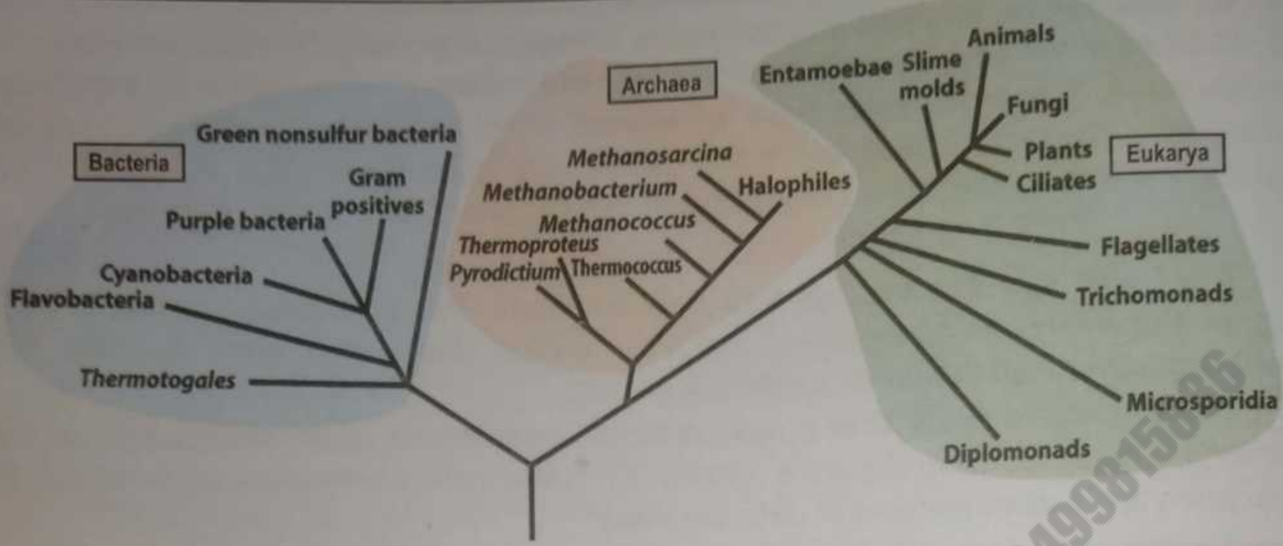


Fig. 6.1: Phylogenetic position of prokaryotes

6.2 ARCHAEA

The microorganisms Archaea were previously called archaeobacteria. Archaea shares certain traits with bacteria and other traits with eukaryotes. However, archaea also have unique characteristics and are different enough from bacteria to be incorporated into their own domain, archaea.

> Classical photosynthesis using chlorophyll has not been found in any archaea, suggesting that chemoautotrophy predated photo- autotrophy during evolution. Cyanobacteria are believed to be responsible for first introducing oxygen into the primitive atmosphere.

6.2.1 Unifying Features of Archaea

The unifying features of archaea are:

Composition of cell wall

The cell walls of archaea do not contain peptidoglycan. In some archaea the cell wall is largely composed of polysaccharides and in others, the wall is pure protein. In a few there is no cell wall.

Composition of cell membrane

The plasma membranes of archaea contain unusual lipids that allow them to function at high temperatures. Lipids of archaea contain glycerol linked to branched chain hydrocarbons in contrast to lipids of bacteria that contain glycerol linked to fatty acids.

Methanogenesis

Methanogenesis the ability to form methane is a type of metabolism that is performed only by some archaea.

Mode of nutrition

Archeae use three sources of energy to prepare food i.e. by using sunlight, by using inorganic compounds and by using organic compounds.

Ribosomal RNA sequence

The most fundamental difference between archaea and eubacteria is in their nucleic acid, e.g., rRNA. For instance, near nucleotide number 910 (out of 1500) in one type of rRNA researchers have found the following difference.

Eubactera: AAACUCAAA **Archaea:** AAACUUAAA

Table 6.1: Differences between bacteria and archaea

Main Features	Bacteria	Archaea
rRNA sequences	Many unique to Eubacteria	Many match eukaryotic ones
RNA polymerase	Relatively small and simple	Complex similar to eukaryotic
Introns (noncoding parts of genes)	Absent	Present in some genes
Antibiotic sensitivity (to streptomycin, chloramphenicol)	Inhibited	Not inhibited
Peptidoglycan in cell wall	Present	Absent
Membrane lipids	Carbon chains unbranched	Carbon chains branched

6.2.2 Most Archaea Inhabit Extreme Environments

The first prokaryotes that were classified in domain Archaea are species that live in extreme environments. Archaea includes (a) Methanogens, (b) Halophiles, (c) Thermoacidophiles.

Methanogens

The methanogens are methane gas producer and are found in anaerobic environments in swamps, marshes and in the intestinal tracts of human and other animals. This methane, is also called biogas.

Halophiles

The halophiles grow where nothing else can live, such as on fish and meat that have been heavily salted to keep most bacteria away. The halophiles require high salt concentrations for growth.

Thermoacidophiles

The thermoacidophiles are isolated from extremely hot, acidic environments such as hot springs, geysers, submarine thermal vent and around volcanoes.

6.3 BACTERIAL ECOLOGY AND DIVERSITY

Bacteria are found almost everywhere in environment and show great diversity.

6.3.1 Occurrence of bacteria

Bacteria occur in the widest range of habitats. Bacteria are found almost everywhere in air, water, soil, food and in the bodies of plants and animals including human beings. In fact, many bacteria species are extremophiles, which are adapted variously to extreme temperature, pressure, pH, salinity and other abiotic factors.

6.3.2 Major groups of bacteria

Historically, bacteria have been subdivided taxonomically into groups based on their cell wall types (Gram–positive or Gram-negative), presence of endospore, metabolism, growth and nutritional characteristics, physiological characteristics and other criteria.

6.3.3 CYANOBACTERIA - The Most Prominent Photosynthetic Bacteria

Cyanobacteria (Gk. *kyanoa*, blue and *bacterion*, rod) are the most prominent photosynthetic bacteria which are found in any damp place. Majority of them are free living while some are found as epiphytic or symbiotic forms. Cyanobacteria have Gram-negative type of cell wall. The body may be unicellular and solitary or in the form of filaments which may form colonies. In filamentous forms the cells are arranged in linear row, the trichome which is embedded in mucilage sheath e.g., *Anabaena*, *Nostoc* etc.

Photosynthesis takes place in the extensive system of membrane (thylakoid membranes), which is located in the outer zone of the cytoplasm inner to the cell membrane. In addition to chlorophyll-a, cyanobacteria also use phycobilins as accessory pigment. **Phycocyanin**, a blue pigment is their predominant phycobilins. Like algae and plants they use carbon dioxide as a source of carbon, water as hydrogen donor, both photosystems (non-cyclic photophosphorylation) to harvest light energy and release oxygen during photosynthesis. They are believed to be responsible for first introducing oxygen into the primitive atmosphere.

About one third of cyanobacteria are able to fix atmospheric nitrogen. In most cases nitrogen fixation occurs in **heterocycts**, which are without nuclei, thick walled cell found at certain intervals in the **trichome**. In Pakistan cyanobacteria, e.g., *Nostoc* and *Anabaena* are purposely cultivated to increase the soil fertility, because of nitrogen fixation by these organisms.

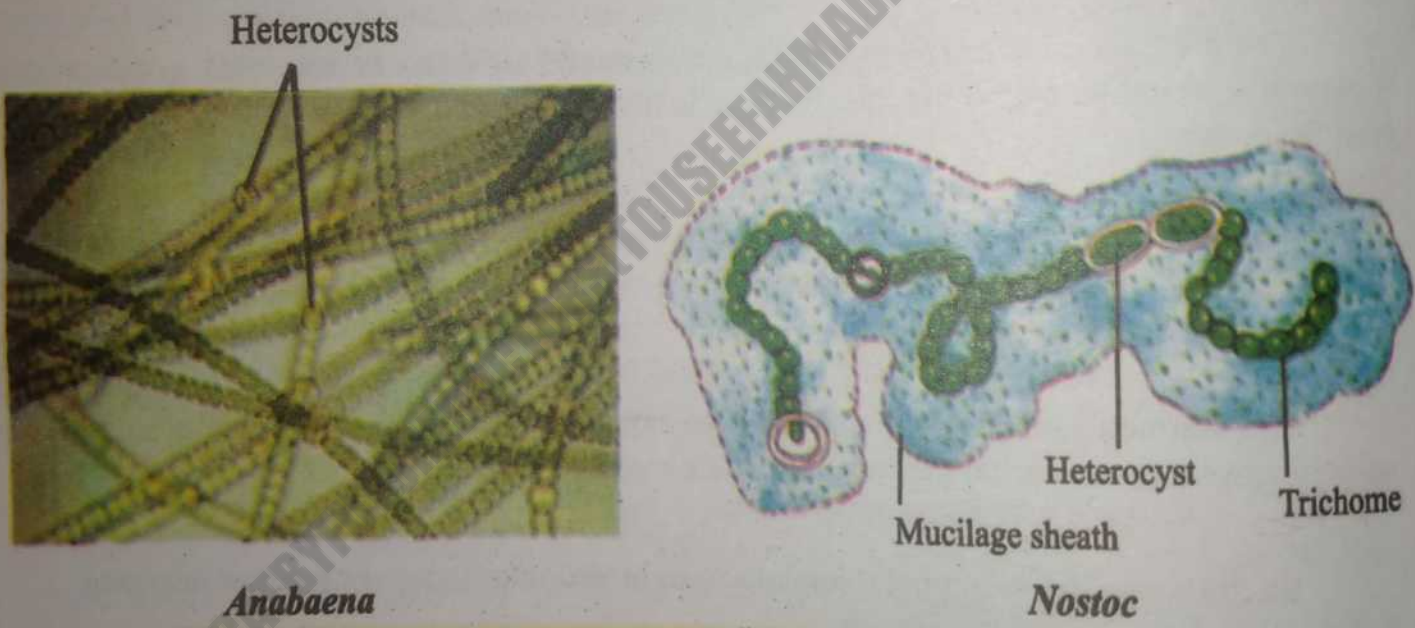


Fig. 6.2: Examples of cyanobacteria

6.4 SIZE, SHAPE AND STRUCTURE OF BACTERIA

A typical bacterium consists of cell wall, cell membrane, cytoplasm, genetic material, and specialized structures outside the cell wall. The structure of bacteria as model of prokaryotic cell has already been discussed in section 1.4 of chapter-1. Here, you are going to learn detailed structure and chemical composition of bacterial cell wall, outer coverings and some other features.

6.4.1 Diversity in Size of Bacteria

The smallest known bacteria belong to the group of *Mycoplasmas*, which infect animals. They are spherical bacteria and have approximate diameter of 0.1 to 0.2 μm. *Escherichia coli*, have rod shape and are about 7 μm long and 1.8 μm in diameter. Some *Spirochaets* reach 500 μm in length. One of the largest bacteria belong to *Epulopiscium*. It is visible to naked eye (600 μm long, 80 μm thick).

6.4.2 Diversity in Shapes of Bacteria

Bacteria have three main shapes: spherical, rod shaped and spiral. However it has recently been shown that certain bacteria are capable of dramatically changing shape, for example *Helicobacter pylori* exists as both a helix-shaped form and a spherical form. Such bacteria are called **pleomorphic**.

Cocci

Cocci are spherical bacteria. Cocci generally appear in groups which can be distinguished on the basis of plane of cell division and number of cells. As a result of single (vertical) plane of cell division, bacteria appear in pairs, called **diplococci** or in chain of many cells, called **streptococci**. As a result of two plane of cell divisions (first vertical then again vertical but at right angle to the first), bacteria appear in a square of four cells, called **tetrad**. As a result of three plane of cell divisions (first vertical then again vertical but at right angle to the first and then horizontal), bacteria appear in a cubical arrangement of eight cells, called **sarcinae**. If plane of cell division becomes irregular and many bacteria are produced which arrange like bunches of grapes, called **staphylococci**. The examples of cocci are: *Streptococcus pneumoniae*.

Bacilli

Bacilli are straight or rod shaped organisms. They always divide in vertical plane so they are found either in pairs, called **diplobacilli** or in chains of many cells, called **streptobacilli**. Some rod shape bacteria have spherical ends like cocci. Such bacteria are called **coccobacilli**. The examples of rod shaped bacteria are *Escherichia coli*.

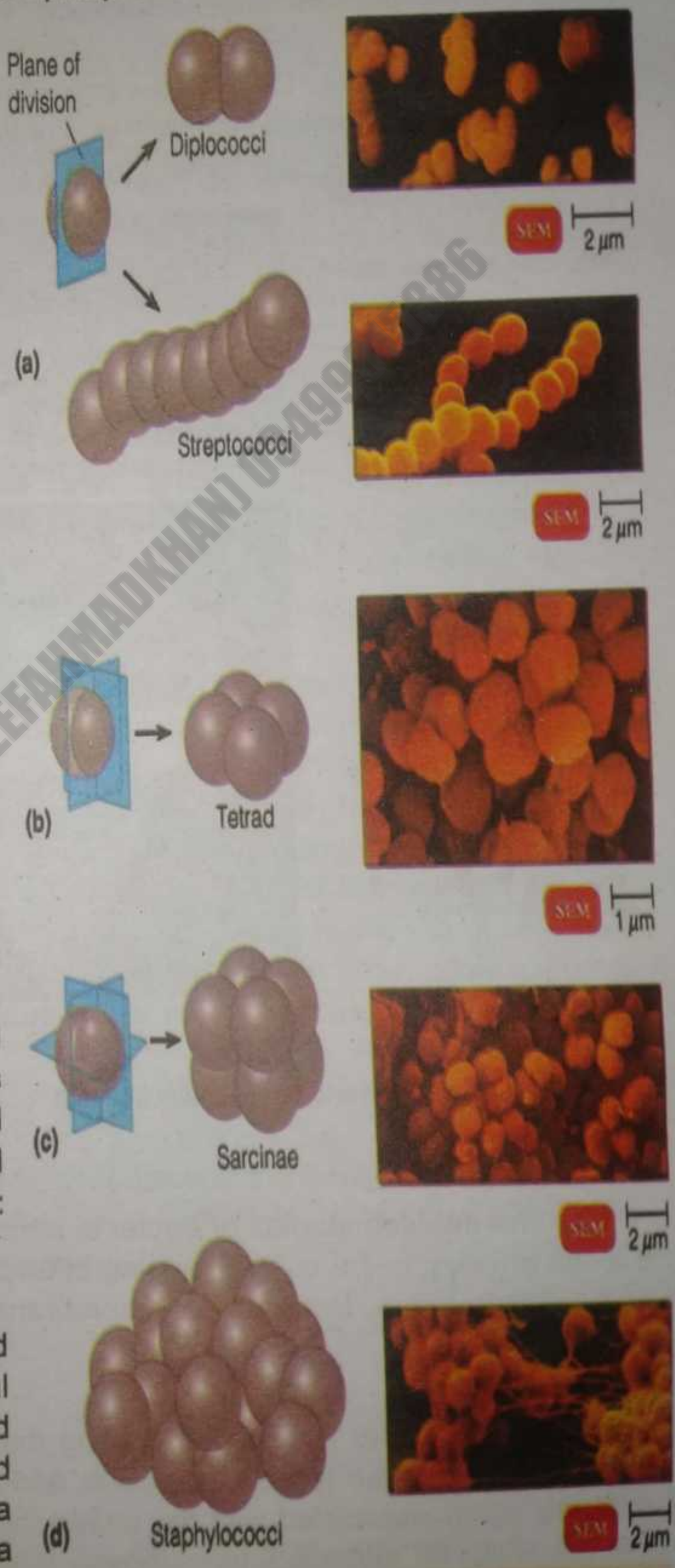


Fig. 6.3: Shapes and arrangement of cocci

Spirilli

Spirilli are spiral shaped bacteria. They usually occur singly, seldom form colonies. Thin and flexible spiral shaped bacteria are called **Spirochetes**. e.g., *Treponema pallidum*. Relatively, thick and rigid spiral shaped bacteria are called **spirillum** e.g., *Spirillum minus*, whereas, curved or comma shaped bacteria which are intermediate to spiral and rod shape, are called **vibrio** e.g., *Vibrio cholarae*.

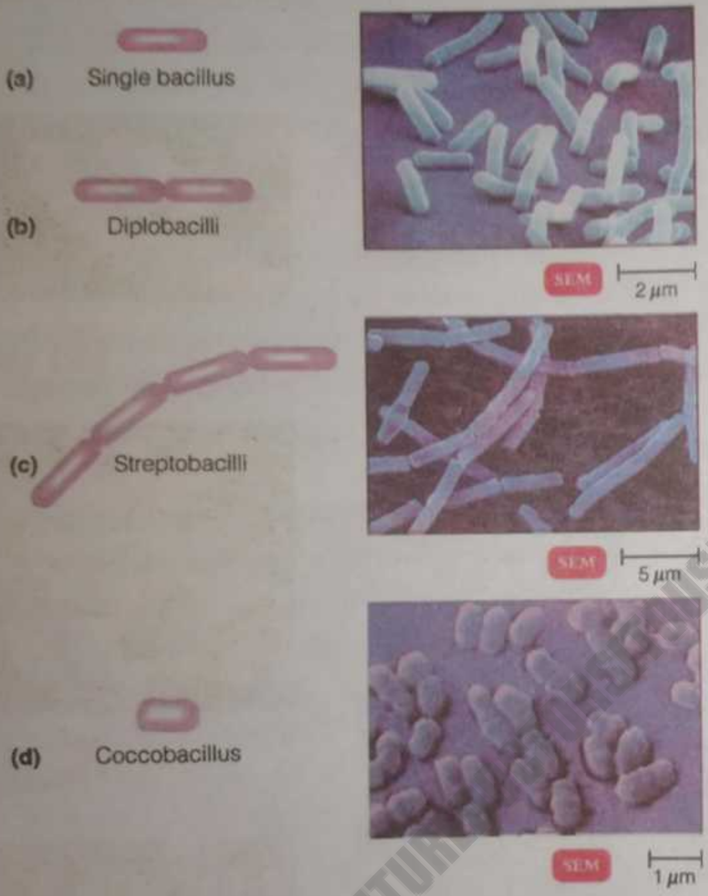


Fig. 6.4: Shapes and arrangement of bacilli

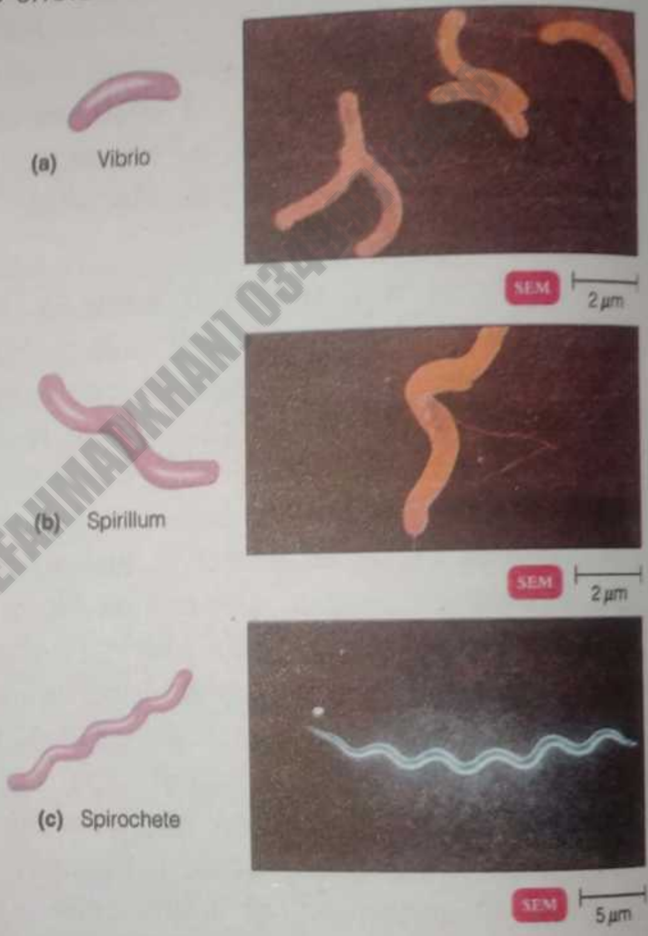


Fig. 6.5: Shapes and arrangement of spirilli

6.4.3 Structure and Composition of Bacterial Cell Envelop

The detailed studies of bacterial structure by the electron microscope revealed that the cell envelop is the outer wrapping of bacterial cell which consist of glycocalyx, cell wall and cell membrane. However, cell membrane sometime considered as the part of bacterial protoplasm.

Glycocalyx

The glycocalyx is an outer coating that covers the outside of bacterial cell wall. The glycocalyx exist in two forms i.e., capsule and slime. The **capsule** is a condensed layer that is relatively tightly associated with the underlying cell wall and gives sticky or gummy nature to the cell, whereas, **slime** is a more loosely attached layer that gives slimy or slippery nature to the cell and can be removed from the cell more easily. Generally, the glycocalyx is made of polysaccharide. However, in some cases, protein can also be present.

There are two prominent functions of the glycocalyx. In the form of **slime** it prevents the phagocytosis of bacteria by the cells of immune system called **macrophages**. A bacterium with a glycocalyx becomes more pathogenic. The second function of a bacterial glycocalyx is to promote the **adhesion** of the bacteria to living and inert surfaces and the subsequent formation of adherent, glycocalyx-enclosed populations that are called **biofilms**. Biofilm bacteria can become very hard to kill, partly due to the presence of the glycocalyx material.

Gram staining (Extra Reading Material)

Gram staining is a method of differentiating bacterial species into two large groups (Gram-positive and Gram-negative). The name comes from the Danish bacteriologist Hans Christian Gram, who developed the technique.

Gram staining differentiates bacteria by the chemical and physical properties of their cell walls. In a Gram stain test, Gram-positive bacteria retain the crystal violet iodine or CVI complex (primary dye), while safranin or fuchsine, a counterstain (secondary dye) is then added which gives all Gram-negative bacteria a red or pink colouring.

The term peptidoglycan is derived from the peptide and sugars (glycan) that make up the molecule. Synonyms for peptidoglycan are **murein** and mucopeptide.

Bacterial cell wall

Cell wall is the part of bacterial envelop. It is situated outer to the cell membrane. It is composed of an inner layer of **peptidoglycan** and an outer **lipoprotein membrane** (found only in Gram negative bacteria). The peptidoglycan provides structural support and maintains the characteristic shape of the cell.

The peptidoglycan layer is much thicker in Gram-positive than in Gram-negative bacteria. Some Gram-positive bacteria also have fibre of **teichoic acid** that protrudes outside the peptidoglycan, whereas Gram-negative bacteria do not have it. In contrast, the Gram-negative have a complex outer layer consisting of lipopolysaccharide and lipoprotein. The Gram-negative cell wall also contains a protein, the **porins** in outer membrane which act like pores for particular molecules. Lying between the peptidoglycan layer of cell wall and the cell membrane in Gram-negative bacteria is the, **periplasmic space** which is the site of enzymes that degrade antibiotics. **Pilus** is present only in Gram negative bacteria. They allow bacterial cell to adhere to tissue and can help the bacterial cell resist attack from immune system cells in the human body.

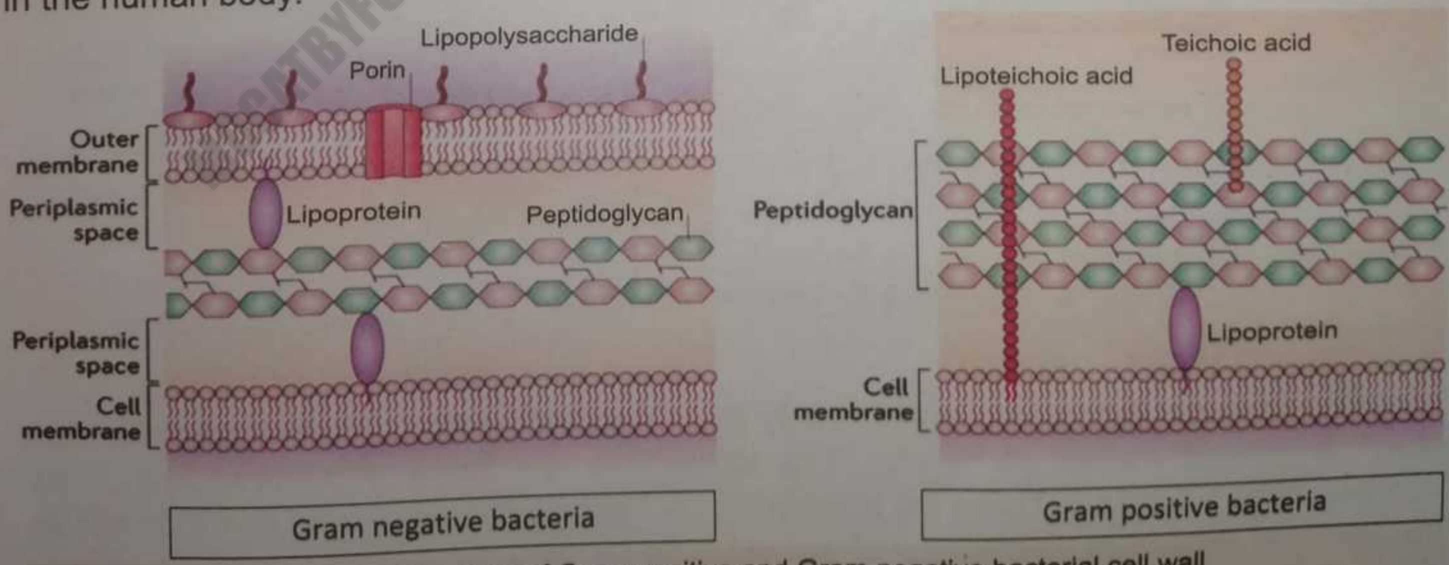


Fig. 6.6: Structure of Gram positive and Gram negative bacterial cell wall

Table 6.2: Difference between Gram positive and Gram negative cell wall

	Character	Gram positive	Gram negative
1	Number of layers	One	Two
2	Thickness	Thick (20-80 nm)	Thin (8-10 nm)
3	Outer membrane	Absent	Present
4	Periplasmic space	Present in some	Present in all
5	Chemical composition	Peptidoglycan, Teichoic acid and lipotechoic acid	Lipopolysaccharide, lipoporteins and peptodoglycan
6	Porins proteins	Absent	Present
7	Lipid	Less	More
8	Peptidoglycan	More	Less
9	Permeability of molecules	More penetrable	Less penetrable
10	Resistance to molecules	less	More

6.4.4 Bacterial cell membrane

The **cell** or **plasma membrane** lies beneath the cell wall which lacks cholesterols in lipid bilayer unlike eukaryotic plasma membrane. At certain points this membrane invaginates into the cytoplasm to form infolding, these are known as **mesosomes**. In addition to the control of transport of materials across the cell, bacterial plasma membrane also involves in cellular respiration, photosynthesis and DNA replication.

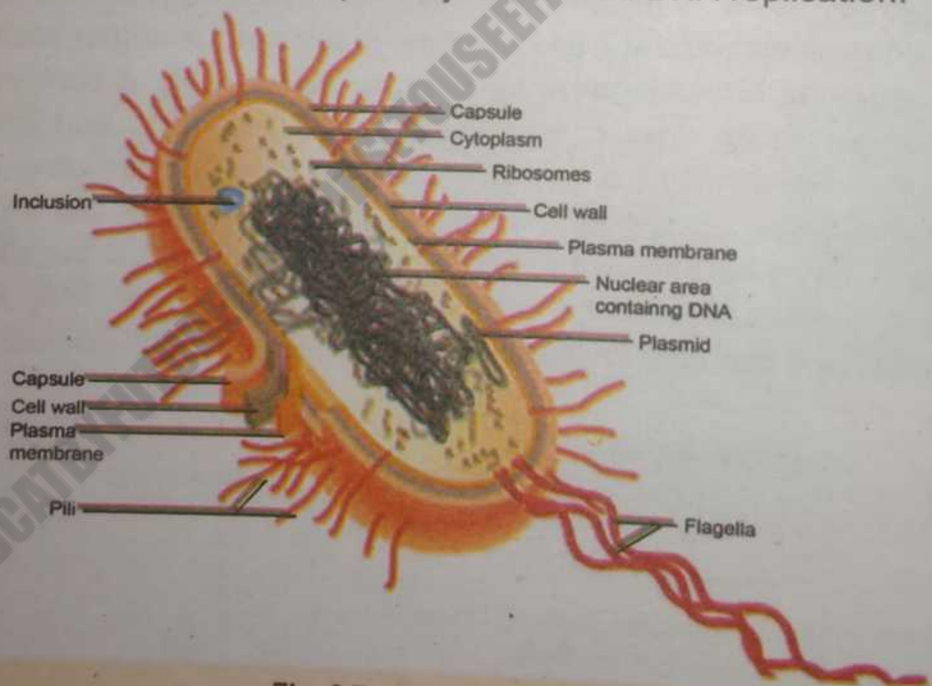


Fig. 6.7: Bacterial cell structure

6.4.5 Bacterial Cytoplasm

The **bacterial cytoplasm** is also a jelly like dense mass which lacks cytoskeleton and cellular organelles except ribosomes. The **ribosomes** are large in number and freely dispersed in the cytoplasm. These are smaller than eukaryotic ribosomes and characterized as 70S. Bacterial ribosomes also consist of two subunits i.e., smaller subunit (30S) and a larger subunit (50S). Ribosomes are the sites of protein synthesis. Small granules of stored food and waste materials are also present in bacterial cytoplasm. Stored food includes glycogen, proteins, fats etc. whereas; wastes may consist of alcohol, lactic acid, acetic acid etc.

6.4.6 Bacterial genome

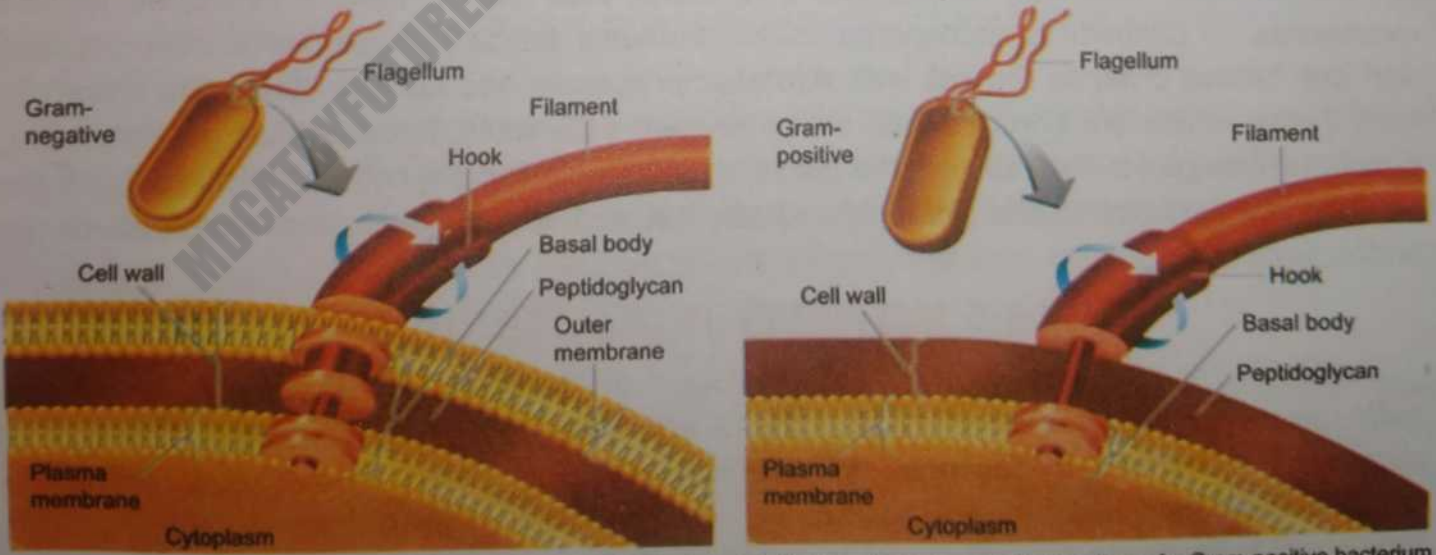
The **nucleoid** is the nuclear region of bacteria which is not separated from the cytoplasm by nuclear membrane. It is seen in the electron microscope as an area lighter than the cytoplasmic contents. It consists of a large circular double stranded DNA molecule which is also known as bacterial chromosome. Due to this single chromosome bacteria are considered as **haploid** organisms. A short duration of diploid state comes in their life cycle just before cell division when they replicate their DNA. Bacterial DNA differs from eukaryotic DNA as it is circular molecule. The nuclear DNA controls growth and metabolic activities of bacteria. In addition to the nuclear DNA some bacteria also contain one or more extra nuclear small circular double stranded DNA molecules, the **plasmids**. They often contain genes for antibiotics or drug resistance and heavy metals resistance.

6.4.7 Bacterial appendages

The structures that project from the surface of bacterial cell are called bacterial appendages that include flagella and pili or fimbriae. **Flagella** are long thread like structures which are used for locomotion. Bacterial flagella are composed of flagellin protein and lack microtubules. In this way they differ from eukaryotic flagella. **Pili** or **fimbriae** are tubular extensions of cell membrane and project through the cell wall. They are composed of pilin protein and can only be seen by electron microscope and are found only on certain species of Gram negative bacteria. Pili are used to transfer genetic material during conjugation. The other function of pili is attachment on the surface of tissues of an infected person.

6.4.8 Structure of Bacterial Flagellum

Bacterial flagellum is non-contractile, and lacks microtubules unlike eukaryotic flagellum. It is about 20 ηm diameter and up to 20 μm in length. It consists of three parts: a basal body, a hook and a filament. The **basal body** originates from cytoplasm just beneath the



(a) Parts and attachment of a flagellum of a Gram-negative bacterium (b) Parts and attachment of a flagellum of a Gram-positive bacterium

Fig. 6.8: Structure of flagellum of bacteria

cell membrane. It consists of two pairs of discs (Gram positive bacteria have only one pair) which are connected by a central rod. The basal body anchors the flagellum in cell envelop. The **hook** is curved structure which connects the basal body to the filament. It is projected from the cell surface. The **filament** is a hollow structure which originates from the hook. The filament is composed of the globular protein **flagellin**. The mechanism of movement of bacteria flagella is quite different from eukaryotic flagella (already discussed in chapter 1). Its basal body produces rotatory motion. The 360° rotation of paired discs of basal body enable the flagellum to rotate which in turn causes the cell to spin and move forward.

6.4.9 Bacterial Spores and Cysts

During late stage of growth, when essential nutrients are depleted in the environment and other conditions such as temperature, pH of the medium and availability of water become unfavourable certain bacteria form resistant and metabolically dormant bodies. Depending on the type of bacteria, these bodies are divided into endospores, exospores, and cysts. Especially endospores are characterized by a complex structure and resistance to high temperatures. That is why this dormant form is capable of surviving for periods more than thousand years. The spore develops within the vegetative cell inside the cell wall, so it has been named **endospore**. The original cell forms a copy of its chromosome and surrounds it with a tough wall, forming the endospore. Water is removed from the endospore. The metabolism inside it stops. The rest of the original cell then disintegrates. The endospores germinate when their environmental conditions become favourable.

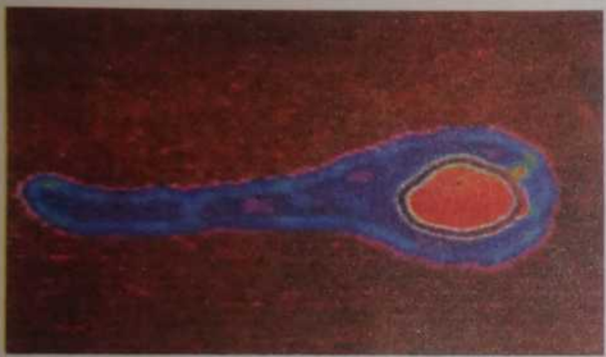


Fig. 6.9: Endospore

On the other hand the *Actinomycetes*, which are a large group of spore-forming, Gram-positive bacteria that grow by forming long tubules called **filaments**. Under nutrient poor conditions these filaments differentiate into round thick walled resting structures termed **exospores**. In contrast to endospores, these structures are part of the reproductive process and are formed outer to the cell wall. *Azotobacter* species and several others are known to form **cysts**, which are dormant cells with thickened cells walls. Encystment (cyst formation) occurs by changes in the cell wall; the cytoplasm contracts and the cell wall thicken. Cysts are resistant to desiccation and some chemicals, but cannot withstand high temperatures as endospores can.

6.5 MOTILITY IN BACTERIA

Motility or movement is an important aspect of bacterial life in that the organism can swim toward optimal concentrations of nutrients and away from toxic substances. This type of purposeful movement in response to chemical stimuli is called **chemotaxis**. Sometime bacteria show movement toward optimal light concentration or away from strong light. Such movement in response to light stimuli is called **phototaxis**. Motility in bacteria is achieved by any of several mechanisms, such as flagellar movement, spirochaetal movement and gliding motility.

6.5.1 Flagellar movement

Most bacilli and spirilli are motile by means of flagella; cocci are usually non-motile. The presence of flagella, as well as their number and distribution on the cell, are important characteristics for purposes of identification and classification of bacteria. When one or more flagella ari se only from one or both ends of a rod or spiral-shaped cell, the arrangement is termed **polar**. For example: if a bacterium possesses single flagellum at one end, called **monopolar monotrichous**; if the bacterium possesses single flagellum at both ends, is called **bipolar monotrichous** or **amphitrichous**. Similarly, if a bacterium possesses a pair of flagella at one end, called **monopolar bitrichous**; if the bacterium possesses a pair of flagella at both ends, is called **bipolar bitrichous** or **amphibitrichous**. But, if a tuft (more than two) of flagella is present at one end of a bacterium, called **lophotrichous**, and if a tuft of flagella is present at both ends of a bacterium, called **amphilophotrichous**. When, flagella arise randomly over the entire surface of the cell, the arrangement is termed **peritrichous**.

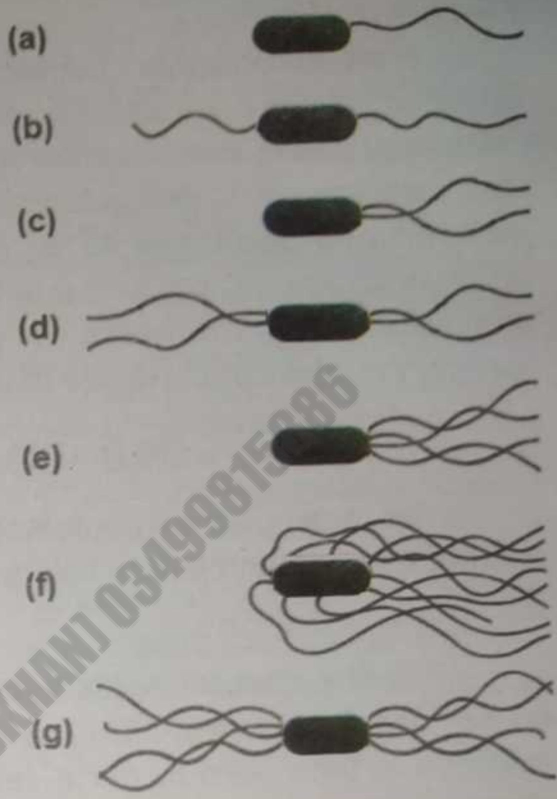


Fig. 6.10: Arrangements of bacterial flagella (a) Monopolar monotrichous, (b) Bipolar monotrichous, (c) Monopolar bitrichous, (d) Bipolar bitrichous, (e) Lophotrichous, (f) Peritrichous, (g) Amphilophotrichous.

6.5.2 Spirochaetal movement

A somewhat modified version of the bacterial flagellum is called axial filament. It is present in Spirochaete. The axial filament runs lengthwise between the bacterial inner membrane and outer membrane of the cell wall in periplasmic space. Spitochetes can perform flexing, swimming creeping or spinning type of movements with the help of axial filament.

6.5.3 Gliding motility

Like spirochaetal movement, the gliding motility is also represented by some genera of the cyanobacteria and myxobacteria. These organisms can move slowly over solid surfaces. They do not have filamentous structures either internally like axial filament of spirochetes or externally flagella of bacilli but they secrete a slimy substance like garden snails during locomotion.

6.6 MODES OF NUTRITION IN BACTERIA

Bacteria can be classified on the basis of method of obtaining energy and carbon. They may be either heterotrophic, which make their organic compounds from other organic sources, or autotrophic, which make their organic compounds from inorganic sources i.e., carbon dioxide.

6.6.1 Autotrophic Bacteria

There are two major groups of autotrophs: photoautotrophs and chemoautotrophs.

Photoautotrophs

Photoautotrophic bacteria are generally called photosynthetic bacteria. With exception to the cyanobacteria all the other photosynthetic bacteria contain unique type of chlorophyll called **bacteriochlorophyll**. The chlorophyll is incorporated in the membrane of their mesosomes. Unlike green plants, algae, and cyanobacteria, they do not use water as their reducing agent, and so do not produce oxygen. Instead they use hydrogen sulphide, which is oxidized to produce granules of elemental sulphur. This in turn may be oxidized to form sulphuric acid. However, like green plants, the photosynthetic bacteria use the energy of sunlight to make carbohydrates from CO_2

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

The examples of photosynthetic bacteria are green sulphur bacteria, green non-sulphur bacteria and purple sulphur bacteria.

Chemoautotrophs

The **chemoautotrophic bacteria** make carbohydrates from inorganic substance. They do not use light energy. They oxidize inorganic substance. The energy produced by this oxidation is then used to make carbohydrates. Sulphur bacteria oxidize sulphur to produce energy.

The energy thus produced is used by bacteria to make carbohydrate $(CH_2O)_n$. The examples of chemoautotrophic bacteria are nitrifying bacteria, sulphur bacteria.

$$2H_2S + O_2 \longrightarrow 2S + H_2O + \text{Energy}$$

$$2H_2S + CO_2 \xrightarrow{\text{Energy}} (CH_2O)_n + H_2O + 2S$$

6.6.2 Heterotrophic Bacteria

Heterotrophic bacteria cannot synthesize their organic compounds from simple inorganic compounds, so they depend on the organic compounds present in the environment. There are two types of heterotrophic bacteria: saprotrophs and parasites.

> **Science Titbits**
>
> Cellular respiration is the breakdown of complex compounds into simpler for the release of energy which may be aerobic or anaerobic, accordingly bacteria are known as aerobic bacteria, e.g., *Pseudomonas* and anaerobic bacteria e.g., *Spirochete*. Some are facultative bacteria e.g., *E.coli* which grow either in the presence or absence of oxygen. The bacteria which require a low concentration of oxygen for growth are known as microaerophilic, e.g., *Campylobacter*.

Saprotrophs

Saprotrophic bacteria contain extensive enzyme system that breakdown the complex substances of humus (decaying dead organic matter) to simpler compounds. The bacteria then absorb the simpler compounds, for example many soil bacteria, e.g., *Pseudomonas*, *Azobacter*.

Parasites

Parasitic bacteria obtain their food from the host. Parasitic bacteria include pathogenic (disease causing) bacteria, e.g., *Streptococcus pneumoniae*.

6.7 GROWTH AND REPRODUCTION IN BACTERIA

Microbes that are provided with nutrients and the required environmental factors become metabolically active and grow.

6.7.1 Phases of Bacterial Growth

Bacterial growth takes place on two levels. On one level, a cell builds up protoplasm and increases its size; on the other level, the number of cells in the population increases. Bacterial growth occurs in four major phases which can be represented by bacterial growth curve.

Science Titbits

Recently, some microbiologists have divided the growth curve into six phases by the letters A to F as follows

(a) Lag phase- Growth rate is zero.
(b) Acceleration phase- Increasing growth rate.
(c) Exponential phase — Constant growth rate.
(d) Retardation phase- Growth rate is decreasing.
(e) Maximum stationary phase- Growth rate is zero.
(f) Decline phase- Growth rate is negative (death).

Lag phase

In this phase there is increase in cell size but not multiplication. Time is required for adaptation (synthesis of new enzymes) to new environment. During this phase vigorous metabolic activity occurs but cells do not divide. Enzymes and intermediates are formed and accumulate until they are present in concentration that permits growth to start.

Log or Exponential phase

In log or exponential phase, the number of cells increases exponentially with respect to time, i.e., the number of cells doubles with each doubling time. The average time required for the population, or the biomass, to double is known as the **generation time** or **doubling time**. The cells multiply at the maximum rate in this exponential phase, i.e., there is linear relationship between time and logarithm of the number of cells. This continues until one of two things happens: either one or more nutrients in the medium become exhausted, or toxic metabolic products, accumulate and inhibit growth. Oxygen becomes limited for aerobic organisms.

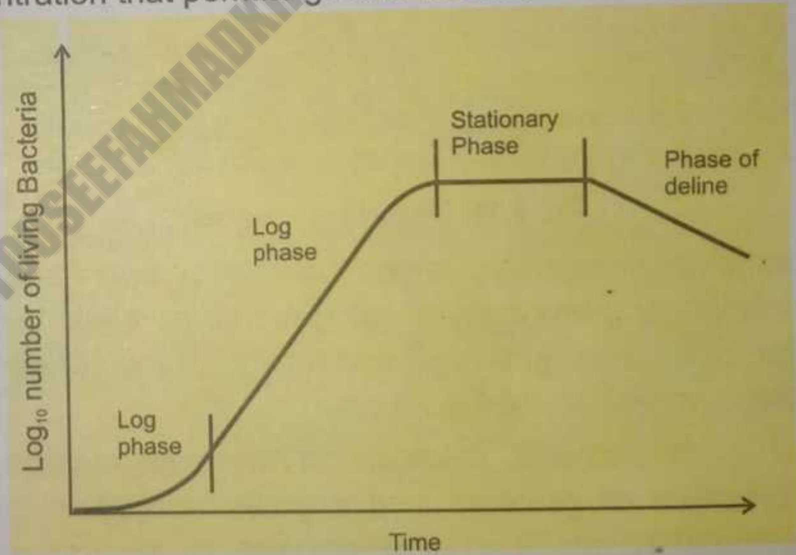


Fig. 6.11: Typical growth curve of bacterial population

Stationary phase

In this phase, due to exhaustion of nutrients or accumulation of toxic products death of bacteria starts and the growth cease completely. The count remains stationary due to balance between multiplication and death rate.

Death or Decline phase

In this phase there is progressive death of cells. The rate of cell division is gradually decreased and eventually cells stop multiplying. However, some bacteria may survive by forming resistant spores or cysts during this phase.

6.7.2 Reproduction in Bacteria

Bacteria generally reproduce by asexual method. In true sense sexual reproduction is absent in bacteria but various methods of genetic recombination are misleadingly called sexual reproduction.

Asexual reproduction

Most common method of asexual reproduction in bacteria is binary fission. However, some bacteria reproduce by budding.

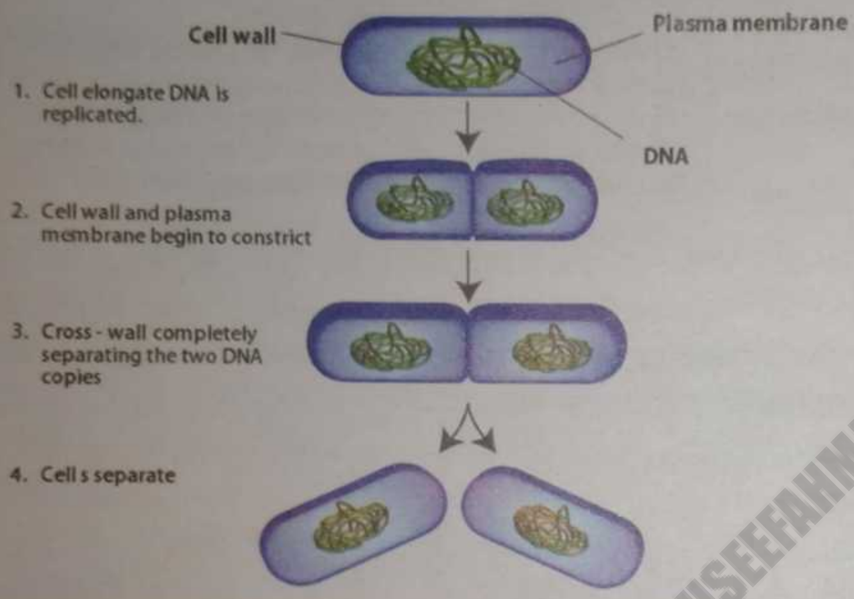


Fig. 6.12: Binary fission in bacteria

Binary fission is the commonest type of reproduction under favourable conditions in which cell divides or splits into two similar daughter cells. During the process, the bacterial DNA gets attached to the cell membrane and undergoes replication. As the cell enlarges the daughter DNA gets separated. A cross wall is formed between the separating daughter DNA. It divides the cell into two daughter cells. The daughter cells soon grow to maturity within 20 minutes and divide again.

Budding: In case of budding, a small protuberance, called **bud**, develops at one end of the cell. Genome replication follows, and one copy of the genome gets into the bud. Then the bud enlarges, eventually becomes a daughter cell and finally gets separated from the parents cell.

Sexual reproduction

In bacteria, there is no true sexual reproduction because there is no meiosis, formation of gametes and zygote. Instead, it involves transfer of a portion of genetic material (DNA) from a donor cell to a recipient cell. This process is called **genetic recombination** or **parasexuality**. It occurs in three ways: conjugation, transduction and transformation.

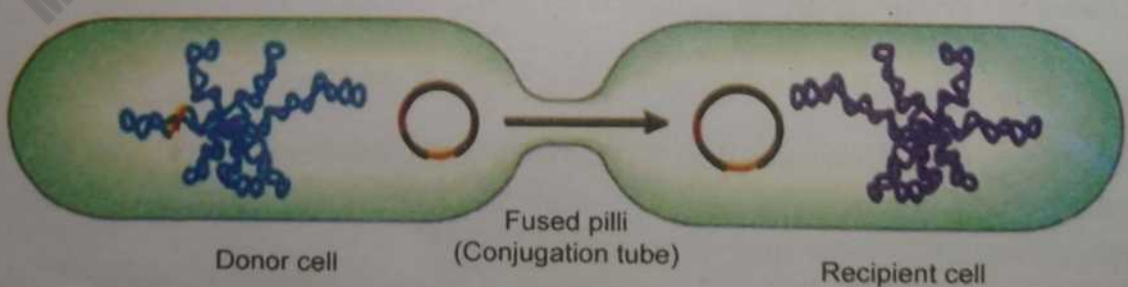


Fig. 6.13: Genetic recombination in bacteria (conjugation)

Conjugation takes place only between bacteria of the same or closely related species. Two bacteria of different mating types come together. Sex pilus forms a conjugating bridge, which temporarily joins the two cells together. The bacterium that will give the DNA is called **donor** and the bacterium that will receive the DNA is called the **recipient**. Often a **plasmid** rather than the main bacterial DNA is transferred.

The transfer of genetic material from one bacterium to another bacterium through the third party, the bacteriophage virus, is called **transduction**. Actually it occurs when a

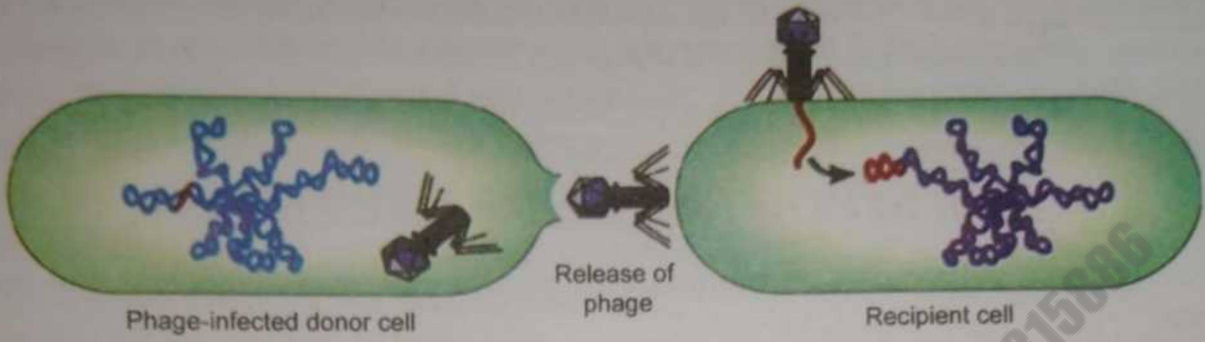


Fig. 6.14: Genetic recombination in bacteria (transduction)

bacteriophage is replicated in a bacterial cell, at the time of assembly of its components a portion of host bacterium may be enclosed into the viral capsid. When such viruses cause infection to other bacterial cells the DNA fragment of the previous host bacterium is thus transferred to the new host bacterium.

When bacteria die or when they are reproducing very rapidly, they release fragments of their DNA into their immediate environment. Such DNA fragments may be up taken by other bacteria by means of diffusion in that environment. This process of absorption of DNA into a cell from its immediate environment is called **transformation**. As a result the cell is transformed into a new type of cell. These cells are called **transformed cells**.

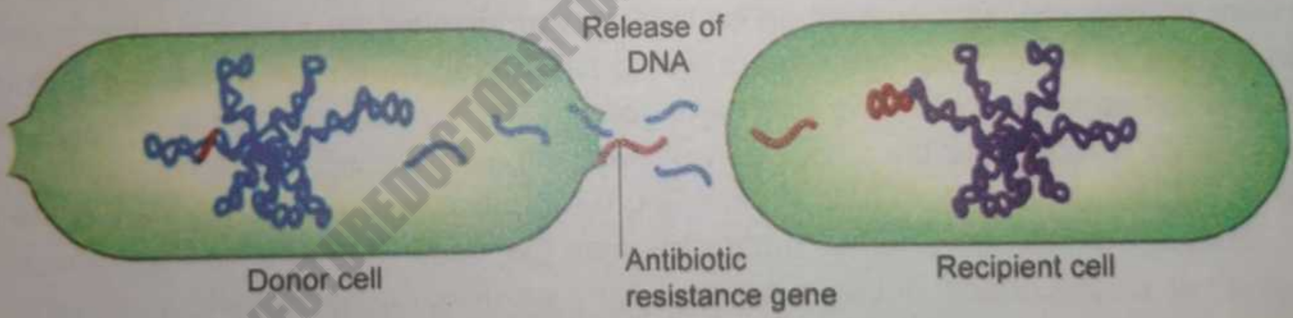


Fig. 6.15: Genetic recombination in bacteria (transformation)

Activity

Teacher would guide the students to draw a graph to present the time taken in each phase of bacterial growth and the number of bacteria.

Phases of growth (*Escherichia coli*)		
Phase	**Time taken in phases of growth**	**Number of Bacteria**
Lag Phase	10 minutes	1
Log Phase	210 minutes	1024
Stationary Phase	210 to 310 minutes	2304
Death Phase	310 to 510 minutes	0

6.7.3 Genetic Variability in Bacteria

Bacteria, as asexual organisms, inherit identical copies of their parent's genes (i.e., they are clonal). However, all bacteria can evolve by selection on changes to their genetic material (DNA) caused by different methods of genetic recombination or mutations. Mutation rates vary widely among different species of bacteria and even among different clones of a single species of bacteria. Genetic changes in bacterial genomes come from random mutation due to different factors during replication.

6.8 IMPORTANCE OF BACTERIA

Bacteria are very important members of biodiversity from ecological and economic view point.

6.8.1 Ecological Importance of Bacteria

Ecological Importance refers to the role of bacteria in environment, such as decomposition of dead/complex organic matter, humus formation to increase the fertility of soil, bioremediation etc.

Role of bacteria in decomposition of dead/complex organic matter

Bacteria serve as **recyclers of nature** as they are involved in decomposition of dead/complex organic matter in the environment. If the dead bodies are not decomposed, the organic nutrients present in their bodies would not be released in the environment. The organic carbon present in dead bodies might diminish all the carbon dioxide from the atmosphere if there were no decomposers present on earth. Can you imagine the situation if there were no carbon dioxide in the atmosphere? There would have been no photosynthesis in the plants and as a result no food would have been produced by plants. Bacteria play a very crucial role in environment through the decomposition of dead organic matter. Bacteria use them as a source of nutrients, and in turn help in recycling the organic compounds trapped in the dead matter. Through this process, other organisms also get benefited, who can use the simpler forms of organic compounds/ nutrients released from the dead matter by various bacteria.

Role of bacteria to increase soil fertility by humus formation and nitrogen fixation

The partially decaying organic matter of dead organisms is called **humus**. It contains nutrients and increases soil fertility for the growth of plants. It also increases the water retaining capacity of the soil. Bacteria and fungi are the only organisms that decompose dead animals and plants and thus, take part in humus formation.

Nitrogen is the most important element for plants for their growth and metabolic activities. Soil is the only source of nitrogen for plants as they cannot inhale nitrogen directly from the atmosphere. Nitrogen from the atmosphere can be available to the plants through the process of **nitrogen fixation**. This process takes place with the help of nitrogen fixing bacteria like *Rhizobium* and *Cyanobacteria* in the soil. These species of bacteria convert the atmospheric nitrogen into nitrates and nitrites as a part of their metabolism, and make it available to the plants. Some plants (leguminous plants) have a mutualistic association with the bacteria (root nodulus bacteria) living into their tissues for this purpose.

Role of bacteria in removal or degradation of environmental pollutants

Removal or degradation of environmental pollutants by using living organisms is called **bioremediation**. It involves the use of many bacteria that either naturally love to eat contaminants or have been genetically altered to give them the taste for toxins. Scientists are designing microbes to clean sites of contaminants such as oil, radioactive waste and mercury.

6.8.2 Economic Importance of Bacteria

The economic importance of bacteria refers to the role of bacteria in research and technology, plant diseases and in human diseases.

Role of bacteria in research and technology

When we think of bacteria, we usually think about the illness it can cause and our need to get rid of it. However, bacteria play a lot of positive roles in our lives which are unknown to many of us. Bacteria play an important role in many technological fields, mainly in biological research, mining, medicine, production of food products, plastics synthesis and sewage treatment. The overall commercial worth of bacteria in these operations is immense.

Bacteria have been used and being continuously used in the study of genetics and genetic engineering. Bacteria were used as model organism in number of famous experiments such as the discovery of DNA as heredity material, discovery of semi conservative replication of DNA and etc. Many components of bacterial cell are also being used as tools in genetic engineering experiments.

The miners can extract metal from low grade ores in an eco-friendly way by using certain bacteria.

Bacteria are useful to mankind is in the production of complex organic molecules that are of use in small amounts as part of the normal process of living, these include antibiotics, vitamins, amino acids and enzymes. In addition to these compounds, the dairy products such as yogurt, cheese, butter etc. are also produced with the help of bacteria.

Now a days biodegradable plastic is being made by using bacteria.

Owing to their characteristics of degrading harmful chemicals and pollutants, bacteria naturally, help in treatment of waste water.

Role of bacteria in causation of diseases and spoilage of food

Beside lot of benefits some bacteria are harmful for us. Parasitic bacteria attack plants and cause various diseases. Many human diseases are caused by bacteria. Bacteria cause decay of wood, leather, fabrics etc. Bacteria spoil the food materials by decomposition.

6.8.3 Bacterial diseases in man

Bacteria cause many diseases in man such as cholera, typhoid, pulmonary tuberculosis and pneumonia.

Cholera

Symptoms: Watery diarrhea and vomiting. **Cause:** It is caused by *Vibrio cholerae*. **Treatment:** It consists of prompt, adequate replacement of water and electrolytes, either orally or intravenously. **Prevention:** Drink and use safe water, ensure proper hygiene. Vaccine is also available.

Typhoid

Symptoms: High fever, tender abdomen and enlarged spleen occur. **Cause:** It is caused by *Salmonella typhi*. **Treatment:** Antibiotics should be used. **Prevention:** It is prevented mainly by public health and personal hygiene measures. Vaccines are available for the prevention of typhoid.

Pulmonary tuberculosis

Symptoms: The symptoms include mild fever lasts for 7-14 days and mild dry cough. Later on night sweats, weight loss, anorexia, and weakness, dry hacking cough with blood stained sputum. **Cause:** The causative agent is *Mycobacterium tuberculosis*. **Treatment:** Multiple-drug therapy is used during the long 6 to 9 month duration of treatment or DOTS (directly observed treatment short course) of only two months duration. **Prevention:** BCG Vaccine (Bacillus Calmette-Guerin) can be used.

Pneumonia

Symptoms: Pneumonia often begins with sudden chill, cough and pleuritic pain. Sputum is red brown "rusty" colour. **Cause:** The causative agent is *Streptococcus pneumoniae*.

Treatment: Antibiotics are used.

6.8.4 Bacterial diseases in plants

The important bacterial plant diseases are leaf spots, blights, soft rots, wilts and galls.

Leaf spot

Symptoms: Brown to white spots on leaves. **Cause:** It is caused by *Xanthomonas campestris* on tomato and pepper. **Prevention:** Prevention of contact between the pathogen and the host, use of disease free seeds.

> **Science, Technology and Society Connections**
>
> - **List some biotechnologies utilizing bacteria.**
>
> *Escherichia coli* has been used to produce protein products of recombinant DNA technology, such as insulin, human growth hormone, etc. Genetic engineers often use a plasmid vector to introduce new genes into plant cells. The plasmid they use is from soil bacterium *Agrobacterioum tumefaciens*. *Saccharomyces ceresvisiae* (yeast) has been used to produce hepatitis B vaccine, alpha and gamma interferons.

Blight

Symptoms: The symptom is termed blight in maize, rice and oat etc. **Cause:** *Xanthosomonas oryzae* causes blight disease in rice. **Prevention:** Disease free seeds and removal of diseased plant by physical method.

Soft Rot

Symptoms: Soft, wet, rotting on any part of the plant. **Cause:** *Corynebacterium* causes ear rot of wheat. **Prevention:** Removal of diseased plants by physical method.

Wilting

Loss of turgidity in the leaf blade increased with time and ultimately leads to wilting of leaf and drying. **Cause:** *Pseudomonas solanocaerum* causes wilt disease in potato. **Prevention:** Selection of disease free seeds and allowing proper spacing between the plants.

Galls

These are localised outgrowth mostly small but may be very large in some diseases. **Cause:** *Rhizobium leguminosarum* causes small galls called **root nodule** in legumes. **Prevention:** Crop rotation, removal of diseased plants etc.

Science, Technology and Society Connections

- **Narrate how bacterial diseases have affected human societies in the past.**

The plague, or "Black Death" which killed 100 million people during the mid-fourteenth century, is caused by highly infections bacteria, *Yersinia pestis*, spread by the fleas carried by infected rats. In 1994, an outbreak of plague occurred in India for the first time in 30 years. Tuberculosis, a bacterial disease has killed millions of peoples in the past and also thousands of people all over the world including Pakistan. *Streptococcus pneumoniae*, causes pneumonia has killed a large number of people in the past.

Science, Technology and Society Connections

- **Suggest how can we stop any epidemic to occur in future?**

Prevention is better than cure, so the measure to prevent any epidemic are: Massive programs of immunization for vaccine preventable diseases, e.g., tuberculosis, hepatitis B, polio etc., must be launched. Detection of cases at the earliest and to treat them properly is the goal. Complete quarantine of persons or domestic animals, which have been exposed to communicable diseases. Supply of safe drinking water. Control of vector disease, e.g., mosquitoes, house flies at larval stages and adult stage. To educate people for improving hygiene practices like washing of hands. If any communicable disease occurs it should be notified immediately, e.g., pneumonia, polio, etc.

6.9 THE BACTERIAL FLORA OF HUMANS

There are approximately ten times as many bacterial cells as human cells in the human body, with large numbers of bacteria on the skin and in the digestive tract. **Normal flora** is the term used to describe the various bacteria (and fungi) that are permanent residents of certain body parts, especially the skin, oropharynx, colon and vagina.

Table 6.3 Some of the member of normal location

Members of Normal Flora	Anatomic Location
Clostridium species	Colon
Escherichia coli and other coliforms	Colon, vagina, outer urethra
Lactobacillus species	Mouth, colon, vagina
Staphylococcus aureus	Nose, skin
Enterococcus faecalis	Colon
Viridans streptococci	Mouth, nasopharynx

6.9.1 Benefits of the bacterial flora to humans

Critical Thinking

Although many bacteria can cause dangerous diseases in general, bacteria make life on earth possible. Why?

The members of some normal flora play a role in the maintenance of health and the causation of disease in three significant ways: They can cause disease, especially in having an impaired immune system and weak, feeble individuals. Although these organisms are nonpathogens in their usual location, they can be pathogens in other parts of the body. They constitute a protective host defence mechanism. The nonpathogenic resident bacteria occupy attachment sites on the skin and mucosa that can interfere with colonization by pathogenic bacteria. The ability of members of the normal flora to limit the growth of pathogens is called **colonization resistance**. If the normal flora is suppressed, pathogens may grow and cause diseases.

They may serve a nutritional function. The intestinal bacteria produce several B vitamins and vitamin K. Poorly nourished people who are treated with oral antibiotics can suffer vitamin deficiencies as a result of the reduction in the normal flora.

6.10 CONTROL OF HARMFUL BACTRERIA

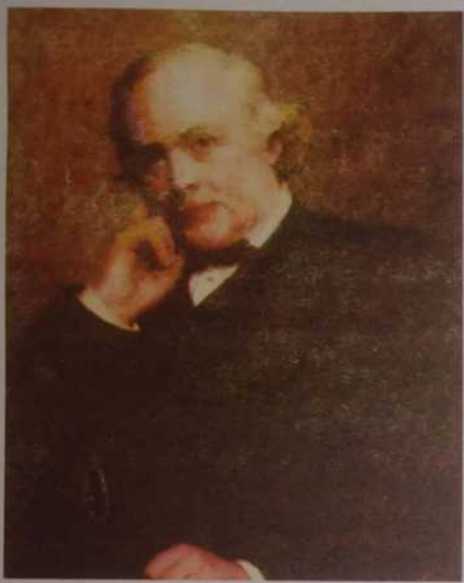


Fig. 6.16: Joseph Lister the first person to use antiseptic.

Bacteria can be controlled by chemical and physical methods.

6.10.1 Chemical methods to control bacteria

Antiseptics, disinfectants and chemotherapeutic agents are used as chemical methods for microbial control. The chemical substances used on living tissues that inhibit the growth of microorganisms are called **antiseptics**. Oxidizing and reducing agents are important chemical agents for **disinfection**, e.g., disinfectants that is halogens and phenols, hydrogen peroxide, potassium permanganate, alcohol and formaldehyde etc. These chemicals inhibit the growth of vegetative cells and are used on nonliving material.

Chemotherapeutic agents are chemicals and antibiotics that destroy the natural defence and stop the growth of bacteria and other microbes in the living tissue, e.g., sulphonamide, tetracycline, penicillin etc.

Fig. 6.17 Louis Pasteur

6.10.2 Physical methods to control bacteria

Sterilization process is the process in which physical agents like steam, dry heat, gas, filtration and radiation are used to control bacteria. Sterilization is destructive to all life forms. This process is used to sterilize surgical apparatus. It is also used to preserve food items on large-scale e.g., milk, meat etc. **High temperature** is usually used in microbiological labs for control of microbes.

Certain electromagnetic **radiations** below 300 nm are effective in killing of microorganisms. Gamma rays are in general used for sterilization process. Heat sensitive compounds like antibiotics, seras, etc., can be sterilized by means of membrane filters. **Pasteurization** is the process to kill microorganisms by heating at temperature enough to kill nonspore forming bacteria, e. g., milk is pasteurized by heating at 71 °C for 15 seconds and at 62 °C for 32 minutes.

Louis Pasteur introduced pasteurization. Food can be preserved for several days by keeping it at a temperature between 10 to 15°C e.g. milk, vegetables, cheese and meat. Food can be **frozen** at –10 °C to 18 °C for several weeks to several months, e.g., meat, vegetables. Food is dehydrated so that in **dry condition** bacteria may not grow, e.g., dried milk and dried meat. Adding preservatives inhibit the growth of bacteria. Acid is added to lower the pH. The contents of salt are increased so that water in the food is not enough for bacterial growth. Some chemicals like potassium metabisulphite are added. Pickles, candies, jam and breads are preserved by such methods.

Science, Technology and Society Connections

- Justify why it is important to disinfect articles of food and utensils before use?

Activity

1. Identification of bacteria from curd, mouth, or bacterial culture and observation of bacterial culture for different shapes and sizes
2. Staining bacteria using Grams staining technique
3. Preparation and observation of the temporary mount of root nodule bacteria
4. Study of *Nostoc*, *Ocillatoria* and *Anabaena* from fresh or preserved material

Exercise

MCQs

1. **Select the correct answer**

(i) Cyanobacteria
(A) are poisoned by oxygen (B) are not widely distributed
(C) have chlorophyll (D) have chloroplast

(ii) Cyanobacteria, unlike other types of bacteria that photosynthesize, do
(A) not give off oxygen (B) give off oxygen
(C) not have chlorophyll (D) not have a cell wall

(iii) Pili are made up of pilin, which is
(A) carbohydrates (B) lipids (C) protein (D) triglycerides

(iv) Most pathogenic bacteria cause disease by
(A) directly destroying individual cells of the host
(B) depriving the host of their nutrients
(C) producing toxins (D) depriving the host of oxygen

(v) Chemosynthetic bacteria
(A) are autotrophic (B) use the sun rays
(C) oxidize inorganic compounds to acquire energy
(D) both A and C are correct

(vi) A bacterium with flagella all around is
(A) monotrichous (B) lophotrichous
(C) amphitrichous (D) peritrichous

(vii) Conjugation is facilitated by
(A) capsule (B) pili (C) flagella (D) both pili and flagella

(viii) Bacterial membrane differ from eukaryotic membrane in
(A) lacking proteins (B) lacking lipids
(C) lacking polysaccharide (D) lacking cholesterol

(ix) Bacterial membrane also contains enzymes for
(A) respiration (B) photosynthesis
(C) protein synthesis (D) secretion

(x) Facultative anaerobes
(A) require a constant supply of oxygen
(B) are killed in an oxygenated environement
(C) do not always need oxygen (D) are photosynthetic

Short Questions

2. Write the differences between bacteria and archaea?
3. What are the photosynthetic pigments of bacteria?
4. How nitrogen fixation takes place in bacteria?
5. What is the chemical composition of cell wall of bacteria?
6. What are the morphological forms of bacteria?
7. What are the differences between cell wall of Gram positive and Gram negative bacteria?
8. How do bacteria survive under unfavourable condition?
9. Describe arrangements of bacterial flagella.
10. Draw and label structure of bacterial flagellum.
11. Give the functions of following in bacteria.
(a) ribosomes (b) cell membrane (c) nucleoid (d) plasmid
(e) mesosomes (f) slime capsule (g) flagella (h) cell wall (i) pili
12. Classify bacteria on the basis of methods of obtaining energy and carbon.
13. How chemosynthetic bacteria are autotrophic in nature?
14. What is binary fission? Explain with reference to bacteria.
15. Name any five diseases caused by bacteria in man.
16. Name any two bacteria that cause diseases in plants.
17. List five ways in which bacteria are beneficial to man?
18. What are the benefits of bacterial flora to human?
19. Which chemical methods are used to control microbes?
20. What are the physical methods to control microbes?
21. Explain genetic variability in bacteria.
22. Describe bacteria as recyclers of nature.

23. What is the role of bacteria in causation and spoilage of food?
24. List the important bacteria that make the normal bacterial flora residing in the oral cavity, respiratory and urinogenital tracts and large intestine of man.
25. Distinguish between:
    (a) lysosome and mesosome
    (b) Gram positive and Gram negative bacteria
    (c) lytic and lysogenic bacteria
    (d) pathogenic and non-pathogenic bacteria
    (e) autotrophy and heterotrophy in bacteria
    (f) photosynthetic and chemosynthetic bacteria
    (g) chemotaxis and phototaxis in bacteria
    (h) bacteria and mitochondria
    (i) prokaryotes and eukaryotes
    (j) cyanobacteria and bacteria
    (k) antiseptics and antibiotics.

Extensive Questions

26. Describe the taxonomic position of prokaryotes.
27. What are the unifying archaeal features that distinguish them from bacteria.
28. How are most Archaea inhabit extreme environments?
29. Why cyanobacteria are considered as the most prominent of the photosynthetic bacteria?
30. Give an account of glycocalyx. What are the functions of glycoalyx?
31. Describe the detailed structure and chemical composition of bacterial cell wall.
32. Explain the great diversity of shapes and sizes found in bacteria.
33. Describe the bacterial spores and cyst.
34. Explain motility in bacteria.
35. Describe the genomic organization of bacteria.
36. Describe autotrophic and heterotrophic nutrition in bacteria.
37. Explain the phases of growth of bacteria.
38. Describe asexual and sexual methods of reproduction in bacteria.
39. What is the importance of bacteria?
40. Explain the use of bacteria in research and technology.
41. Describe symptoms, causative bacteria, treatments and preventive measures of the following bacterial diseases in man:
    (a) Cholera (b) Typhoid (c) Pulmonary tuberculosis (d) Pneumonia
42. Describe the symptoms, causative bacteria, and preventive measures of the following bacterial diseases in plants:
    (a) Leaf spots (b) Soft rots (c) Wilting (d) Galls

7

PROTISTS AND FUNGI

After completing this lesson, you will be able to

- Explain protists as a diverse group of eukaryotes that has 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 for 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 the 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 mycorrhizae 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.

Reading

This chapter aims at the basic knowledge about kingdom protista and kingdom fungi. The members of these two kingdoms are eukaryotes and possess a position below the kingdom plantae and kingdom animalia in evolutionary lineage.

7.1 PROTISTS – THE EVOLUTIONARY RELATIONSHIP

Kingdom Protista consists of a vast assortment of primarily aquatic organisms whose diverse body forms, types of reproduction, modes of nutrition, and life styles make them difficult to characterize. The word **protist**, from the Greek, meaning "the very first," reflects the idea that protists were the first eukaryotes to evolve. The organisms of this kingdom resemble with other eukaryotes such as animals, plants and fungi but they cannot be placed in other eukaryotic kingdoms due to certain reasons. Therefore, the protists are defined as exclusion of other eukaryotes.

Many biologists divide the kingdom Protista into three groups i.e., animal like (the protozoa), plant like protists (the algae) and fungi like protists (slime molds and water molds).

7.1.1 Polyphyletic origin

The protist kingdom is a **polyphyletic group** of organisms; that is, protists do not share a single common ancestor. This hypothesis is based upon the variations exhibited by them in size, body structure, ways of obtaining nutrients, mode of life, habitat, methods of reproductions and means of locomotion.

7.1.2 Variations exhibited by protists

The protists show variations in size, methods of obtaining nutrients, mode of life, reproduction and locomotion.

Size: The **size** varies considerably within the protist kingdom, from microscopic protozoa to giant kelps, which are brown algae that can reach 75 metres in length.

Although most protists are **unicellular**, some have a **colonial organization** (a colony is a loose aggregation of cells), some are **coenocytic** (multinucleate but not multicellular), and some are **multicellular**. Unlike fungi, plants and animals, multicellular protists have relatively simple body forms without specialized tissues.

Methods of obtaining nutrients: These differ widely in kingdom protista. The autotrophic protists, e.g., the algae have chlorophyll and photosynthesize as plants do. Some of the heterotrophic protists, e.g., the water molds, obtain their food by absorption as fungi do. Other heterotrophs, i.e., the protozoa and slime molds resemble animals i.e., they ingest food derived from the bodies of other organisms.

Mode of life: It shows that many protists are free living while others form symbiotic association with different organisms. These associations range from **mutualism**, a more or less equal partnership in which both organisms benefit, to **parasitism** in which one organism lives on or in another and is metabolically dependent on it. Most protists are aquatic and live in oceans or freshwater. They make up a part of the **plankton**.

Reproduction: It is quite varied in the kingdom protists. All protists reproduce asexually and many also reproduce sexually with both meiosis and syngamy (the union of gametes). However most protists do not develop multicellular sex organs, nor do they form embryos.

Locomotion: Most protists are motile at some stage of their life cycle and have various means of **locomotion**. Movement may be accomplished by **amoeboid motion**, i.e., extending cell protrusions, by waving **cilia** or by lashing **flagella**. Many protists use a combination of two or more means of locomotion, e.g., both flagellar and amoeboid motion.

7.2 MAJOR GROUPS OF PROTISTS

We will discuss the **salient features** of major groups of protists. Protists include four major groups: Protozoa, Algae, Myxomycota and Oomycota.

7.2.1 PROTOZOA: The Animal Like Protists

The name protozoa comes from the Latin word meaning "first animals" (sing: *protozoon*). The term protozoa is used today to designate an informal group of unicellular protists that ingest food, lack cell wall and have centrioles. Body of the protozoan is a single mass of cytoplasm and consists of one cell containing all the structures of a typical cell. Protozoans have organelles called **vacuoles** to perform special function. Their food is digested inside **food vacuoles** when they are with lysosomes. Freshwater protozoans have **contractile vacuoles** for the elimination of water. **Reproduction** takes place by asexual and sexual method. The organs of **locomotion** are pseudopodia, e.g., *Amoeba*, cilia, e.g., *Paramecium*, flagella, e.g., *Trypanosoma*, the parasitic protozoans do not have any specific means of locomotion, e.g., *Plasmodium* (malarial parasite). **Regeneration** is common in protozoans. Protozoans form resistant **cyst** to overcome unfavourable conditions. The protozoans have been excluded from kingdom animalia due to their unicellular cell structure as rest of the animals are multicellular.

> ***Naegleria fowleri*, (Extra reading material)**
> *Naegleria fowleri*, an amoeba found in rivers, lakes, springs, drinking water networks and poorly chlorinated swimming pools. It causes primary amoebic meningoencephalitis. The "brain-eating" *Amoeba* has killed 10 persons in 2012, 8 in 2015 and 3 in 2016 in Karachi. Cases have also been reported from Islamabad and other parts of Pakistan.

Based upon means of locomotions, the protozoan are further classified into sarcodina, zooflagellata, ciliophora and sporozoa.

Sarcodina

These protozoans have cytoplasmic extentions i.e., pseudopodia as their locomotory structures. The sarcodines are mostly aquatic. Some of them are found in **freshwater** and have **no shell**, e.g., *Amoeba proteus* (free living) and *Entamoeba histolytica* (parasitic, causes amoebic dysentery in human). While other are found in **marine** water and have shell either made up of calcium carbonate (e.g., Foraminifera) or made up of silica (e.g., *Actinopods*).

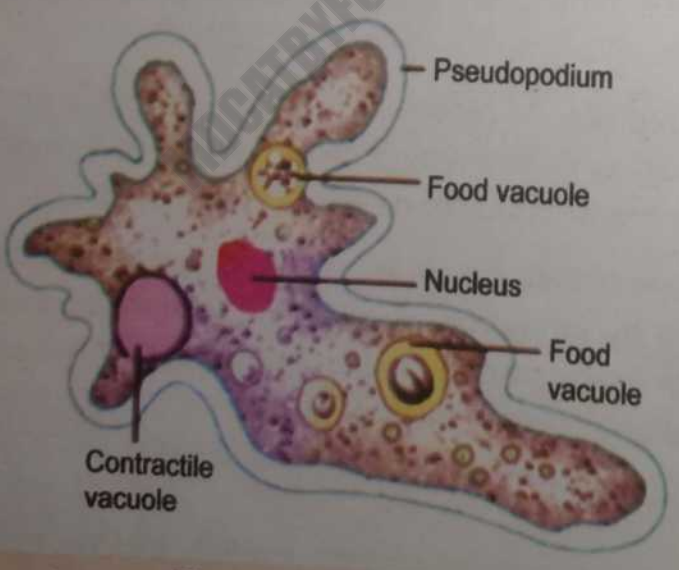
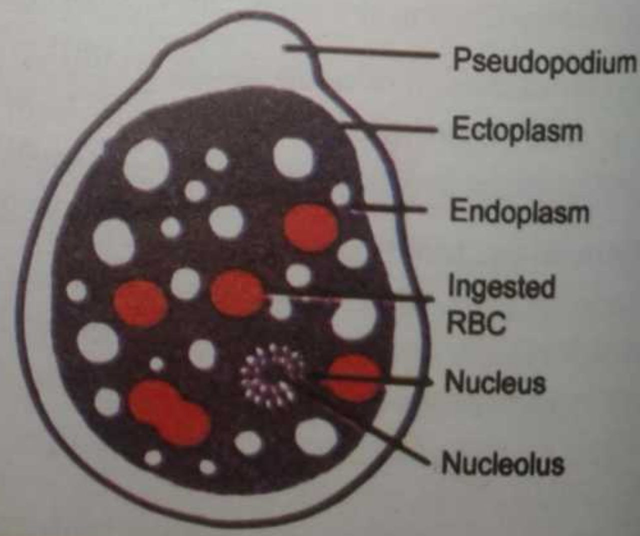


Fig: 7.1: *Amoeba proteus*



Entamoeba histolytica

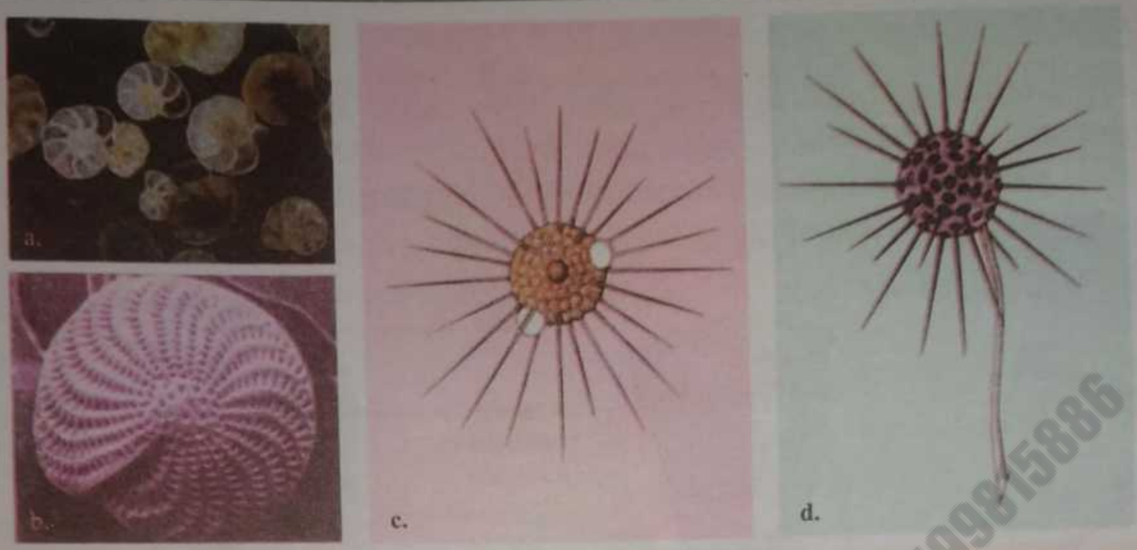


Fig: 7.2 (a, b) Foraminifera (c, d) Actinopods

Zooflagellates

Protozoans that move by means of flagella are called zooflagellates. *Trypanosoma* is a human parasitic zooflagellate causes sleeping sickness. Choanoflagellate is marine or freshwater zooflagellate. It is sessile and remains attached by a stalk. Flagellum is surrounded by a delicate collar which resembles the collar cell of sponges.

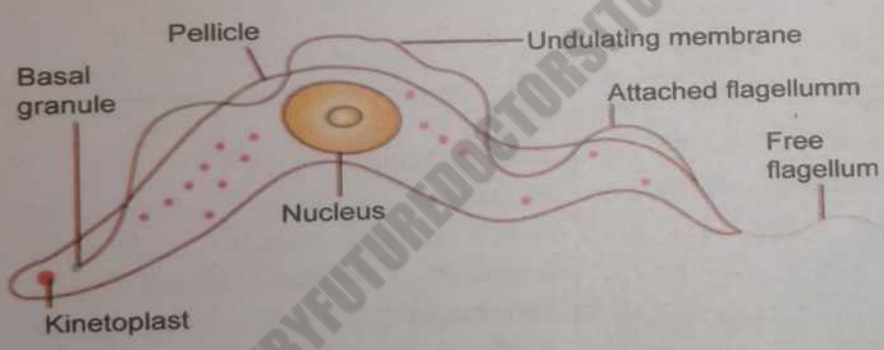
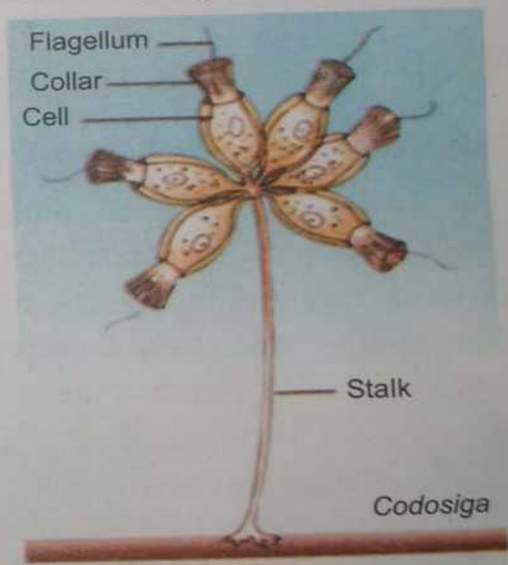


Fig. 7.3: (a) *Trypanosoma*



(b) Zooflagellates A colonial choanoflagellate

Science Titbits

Trichonymphas are complex specialized flagellates with many flagella. They live as symbionts in the gut of the termites. It contains a bacterium that enzymatically converts the cellulose of wood to soluble carbohydrates that are easily digested by the insect.

Trichonympha

Ciliates

These protozoans have hair like extensions called **cilia** and have additional outer flexible covering called **pellicle**. Ciliates differ from other protozoans in having two kinds of nuclei: one or more small diploid micronuclei that function in sexual process and a large, polyploid macronucleus that controls cell metabolism and growth. (e.g., *Paramecium*).

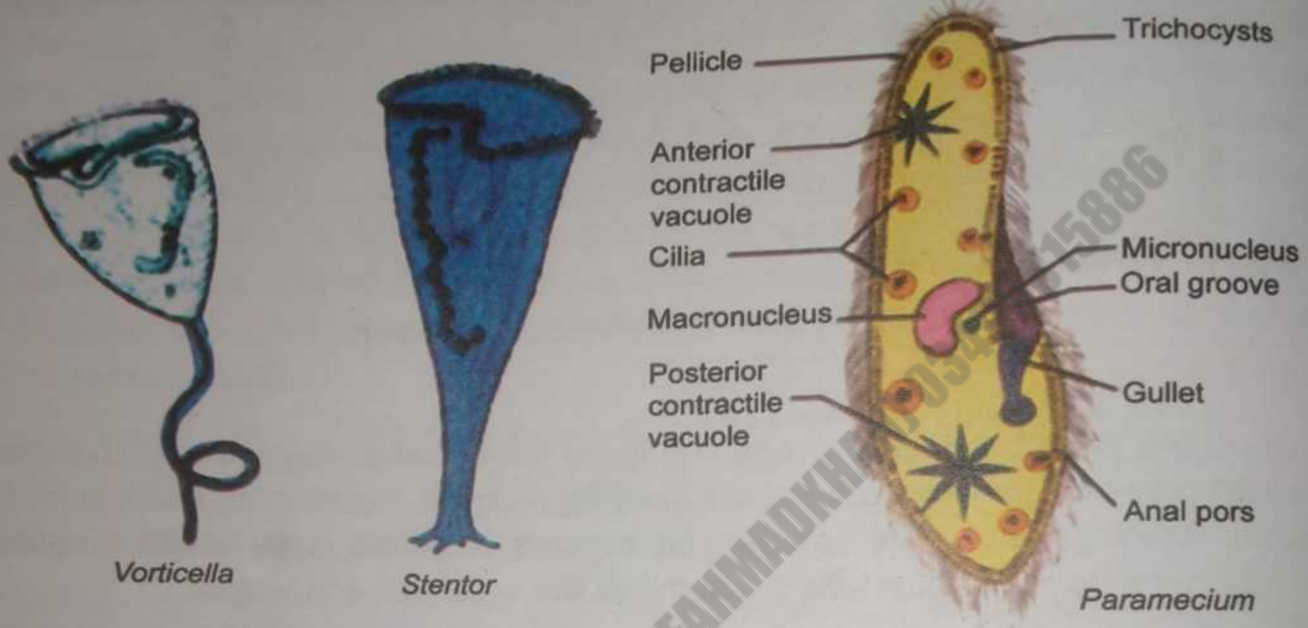


Fig: 7.4 Ciliates

Sporozoa/Apicomplexans

These are parasitic protozoans. They lack specific structures for locomotion but can move by flexing of body wall (undulating movement). At some stage of their lives, they develop a spore, a small infective agent transmitted to the next host. Many apicomplexans complete their lifecycle in two hosts. (e.g., *Plasmodium* or malarial parasite).

> **Science Titbits**
> All animals are believed to have evolved from a protistan ancestor, most likely a protozoan, because protozoans are heterotrophic, ingest food and are motile.

7.2.2 ALGAE: The Plant like Protists

Algae (singular: *alga*) are found in ocean, freshwater ponds, lakes, streams, hot springs, polar ice, moist soil, trees and rocks. Algae may be unicellular, filamentous or multicellular. In multicellular algae, e.g., sea weeds, the body is branched or leaf like flattened called **thallus**. The photosynthetic pigments found in algae are green chlorophylls (a, b, c, d and e), yellow and orange carotenoids (carotene and xanthophyll and red phycoerythrin (a kind of phycobilin). Chlorophyll "a" and carotenes are found in all groups of algae. Algal life cycle shows extreme variations. All algae except the red algae (Rhodophyta) have forms with flagellated motile cells in at least one stage of their life cycle. Algae differ from the plants in this respect that the sex organs in algae are unicellular, the zygote is not protected by the parent body and embryo is not formed. Therefore, they were excluded from kingdom plantae. Based upon pigment composition, algae are classified into many groups. Some of them are following.

Euglenoids

These are small unicellular freshwater organisms that do not have cell wall unlike other groups of algae similarly some of them are colorless and heterotrophs. Euglenoids have chlorophyll (a and b) and carotenoids. (e.g., *Euglena*).

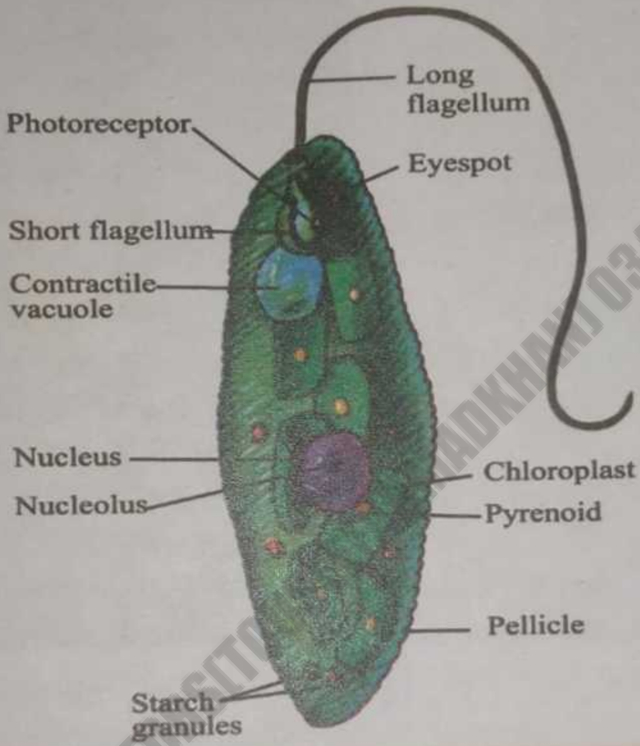


Fig: 7.5: *Euglena*

Dinoflagellates

Most dinoflagellates are unicellular. Their cells are often covered with shells of interlocking cellulose plates deposited with silicates. Dinoflagellates are known to have occasional population explosions or blooms. These blooms frequently colour the water orange, red or brown and are known as red ride. This is because of the release of a carcinogenic compound, called red toxin. Dinoflagellates have chlorophyll (a and c) and carotenes.

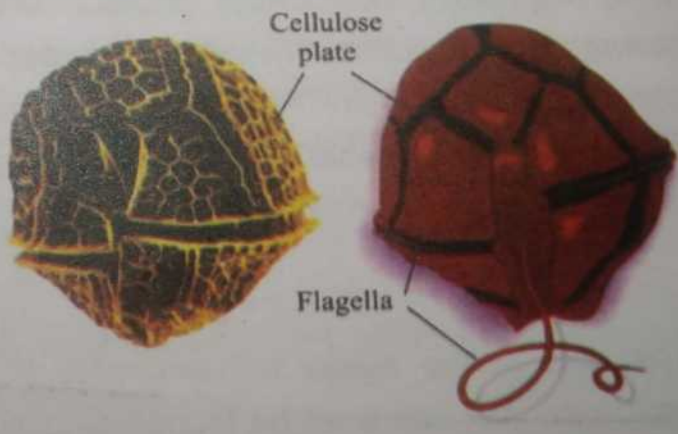


Fig. 7.6: Dinoflagellate

Diatoms

Diatoms are the most numerous unicellular algae in the oceans. They are also plentiful in freshwater. Diatoms are covered by transparent shells which are made up of silica and consist of two halves, with the larger halves acting as a "lid" for the smaller half. Diatoms have chlorophyll (a and c) and carotenes.

Brown Algae

These range from small forms with simple filaments to large multicellular forms up to 75 metre in length, live in cooler marine water. The large brown algae,called **kelps** are tough and leathry in appearance. They possess leaflike blades, stemlike stipes and rootlike anchoring holdfast. Brown algae also have chlorophyll (a and c) and carotenes.

Fig: 7.7: Diatoms

Fig: 7.8: Brown algae *Kelp*

Red Algae

They are mostly multicellular, present chiefly in warmer seawater growing in both shallow and deep waters. They can be up to a metre long attached to rocks or other substances by a basal holdfast. Red algae also have chlorophyll a and carotenes.

Fig: 7.9: Red algae

Green Algae

They live in the ocean but are more likely found in freshwater and can even be found on land. Green algae have pigments (Chlorophyll a, b and carotenoid), energy reserve products (starch) and cell wall composition (large quantity of cellulose) that are identical to those of plants. Because of these and other similarities of RNA sequence, it is generally accepted that plants and green algae have common ancesstors i.e., form monophyletic lineage (e.g., *Chlamydomonas*, *Spirogyra*, *Volvox*).

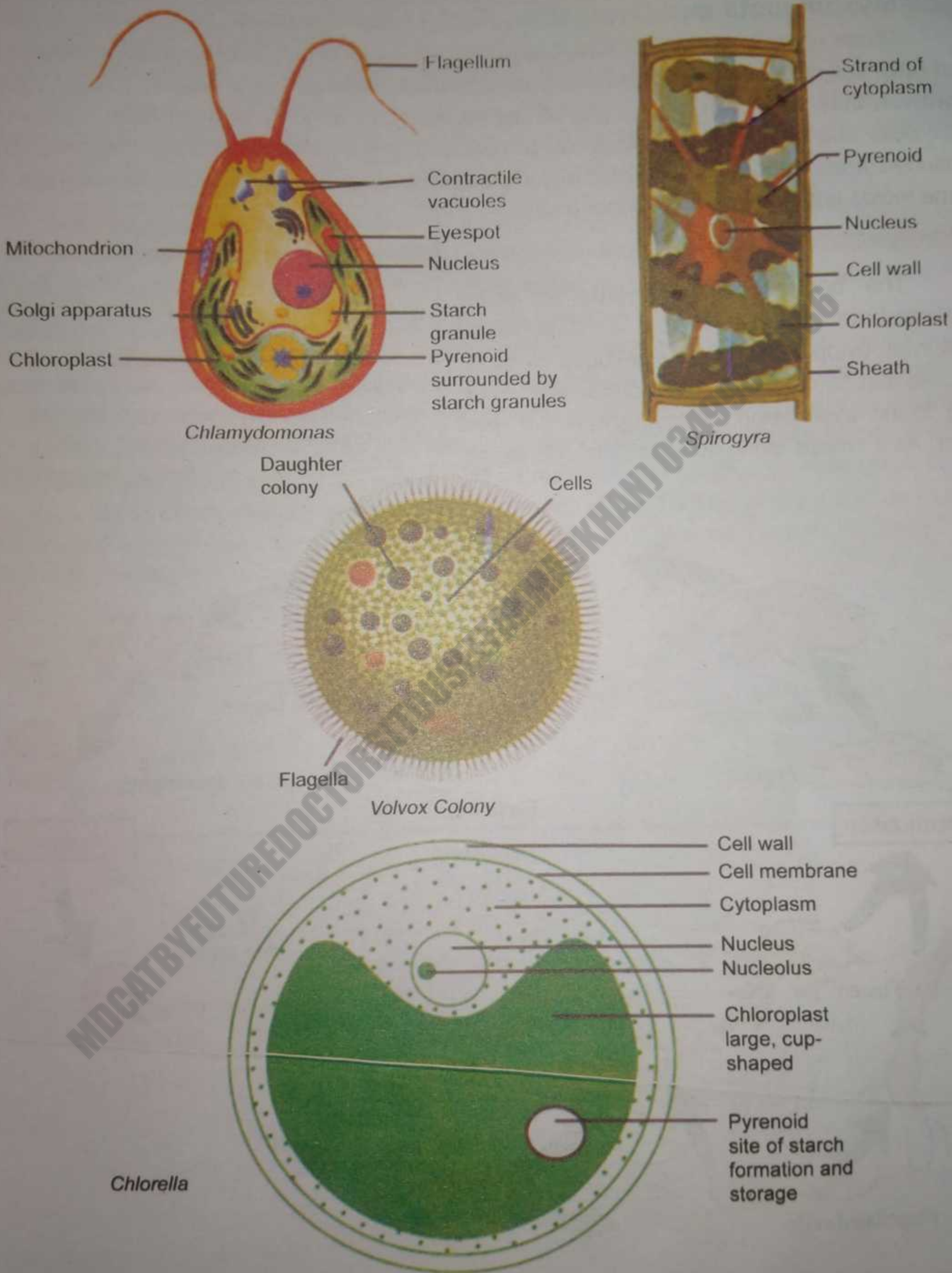


Fig: 7.10: Green algae

7.2.3 Myxomycota and Oomycota: Fungi Like Protists

These organisms are generally resemble with fungi in that they are non photosynthetic and have cell wall, some of them have bodies formed of thread like structures called hyphyae. However, they are not true fungi due to several reasons. Majority of them have centrioles in their cells and have cell wall made up of cellulose unlike fungi. Therefore, they have been excluded from kingdom fungi. Two major groups of fungi like protists are: Myxomycotes or slime molds and oomycotes or water molds.

Slime molds (Extra reading material)

Slime molds are organisms that are fungus like in one phase of their life cycle and amoeba like in another phase of their life cycle. Slime molds are similar in some respect to fungi i.e., body is filamentous, saprotroph, formation of zygote, and having nonmotile spores. Slime molds differ from fungi due to the presence of motility in the life cycle.

MYXOMYCOTA: Slime Molds

The body of **slime molds** is called **plasmodium**. It is a diploid multinucleated, flattened, cytoplasmic mass enveloped by slime sheath that can grow to 30 cm in diameter. They are found over damp, decaying logs and leaf litter. As it creeps along, it ingest bacteria, yeast,

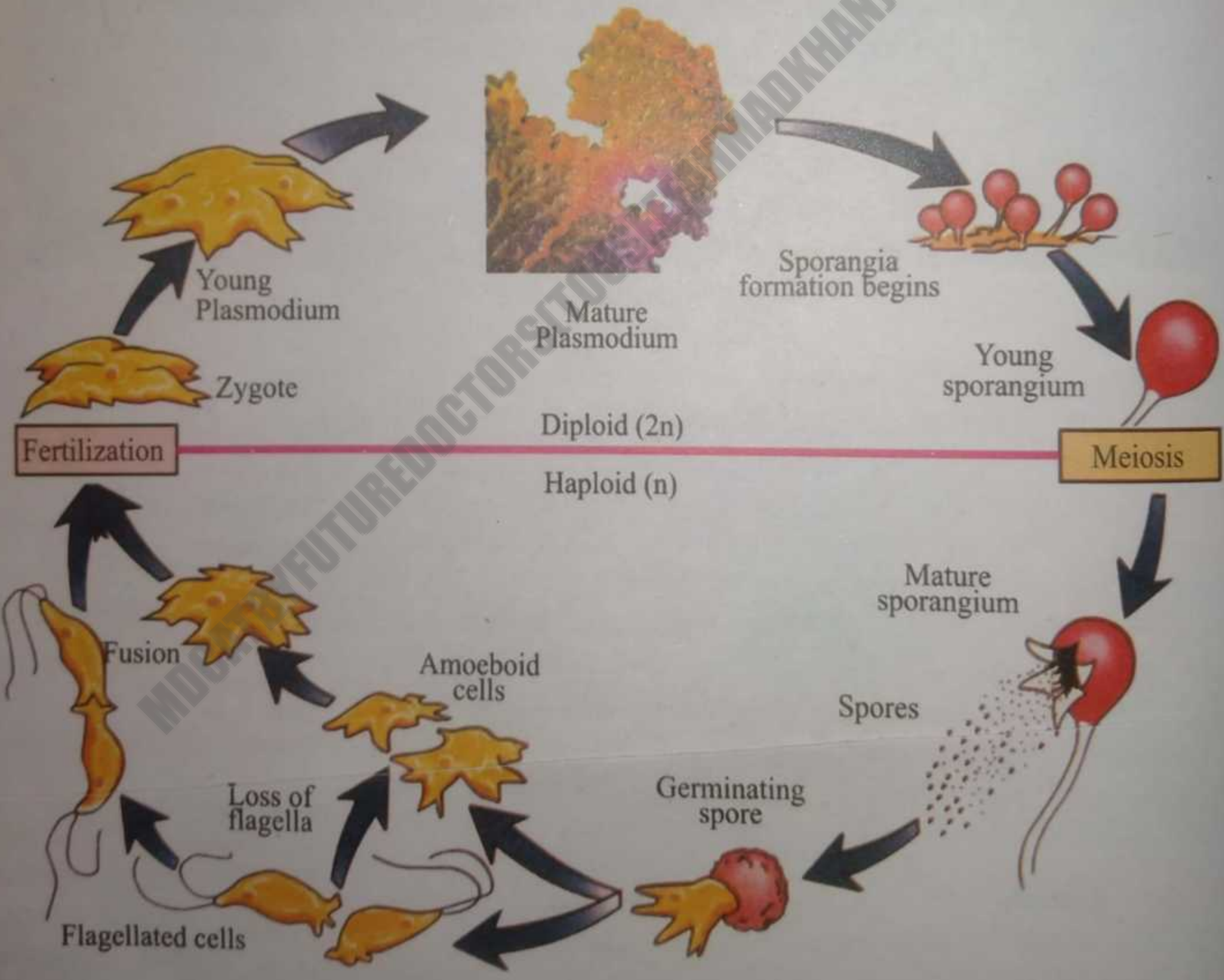


Fig: 7.11: Life cycle of plasmodial slime mold (*Physarum*) spores and decaying organic matter. Under unfavourable conditions, such as during drought the Plasmodium develops many sac like structures, called **sporangia** that produce **spores** by meiosis. On the return of favourable conditions, the spores germinate and release haploid flagellated cells or **amoeboid cells**. Eventually two of them fuse to form a diploid **zygote** that feeds and grows, producing a multinucleated plasmodium once again.

OOMYCOTA: The Water Molds

Oomycotes or water molds include white rusts and downy mildews. Most of the members of this group are parasites. Their body is called **mycelium**, composed of filamentous structures the **hyphae** as in fungi. The hyphae are **aseptate (coenocytic)**, i.e., without cross cell wall (septa). Most oomycotes live in freshwater or saltwater or in soil. Asexual reproduction takes place by **zoospores, which** are motile and have two flagella. Zoospores are produced in sac like structure, the zoosporangium. For sexual reproduction there are two types of **gametangia,** female **gametangium** is called **oogonium** and the male gametangium is called an **antheridium**. The flowing of the contents of an antheridium into an oogonium leads to the individual fusion of one or more pairs of male nuclei with eggs. This produces a special kind of thick walled zygotic cell called an **oospore**. This structure gives the phylum its name, i.e., phylum oomycota, e.g., *Phytophthora infestans*.

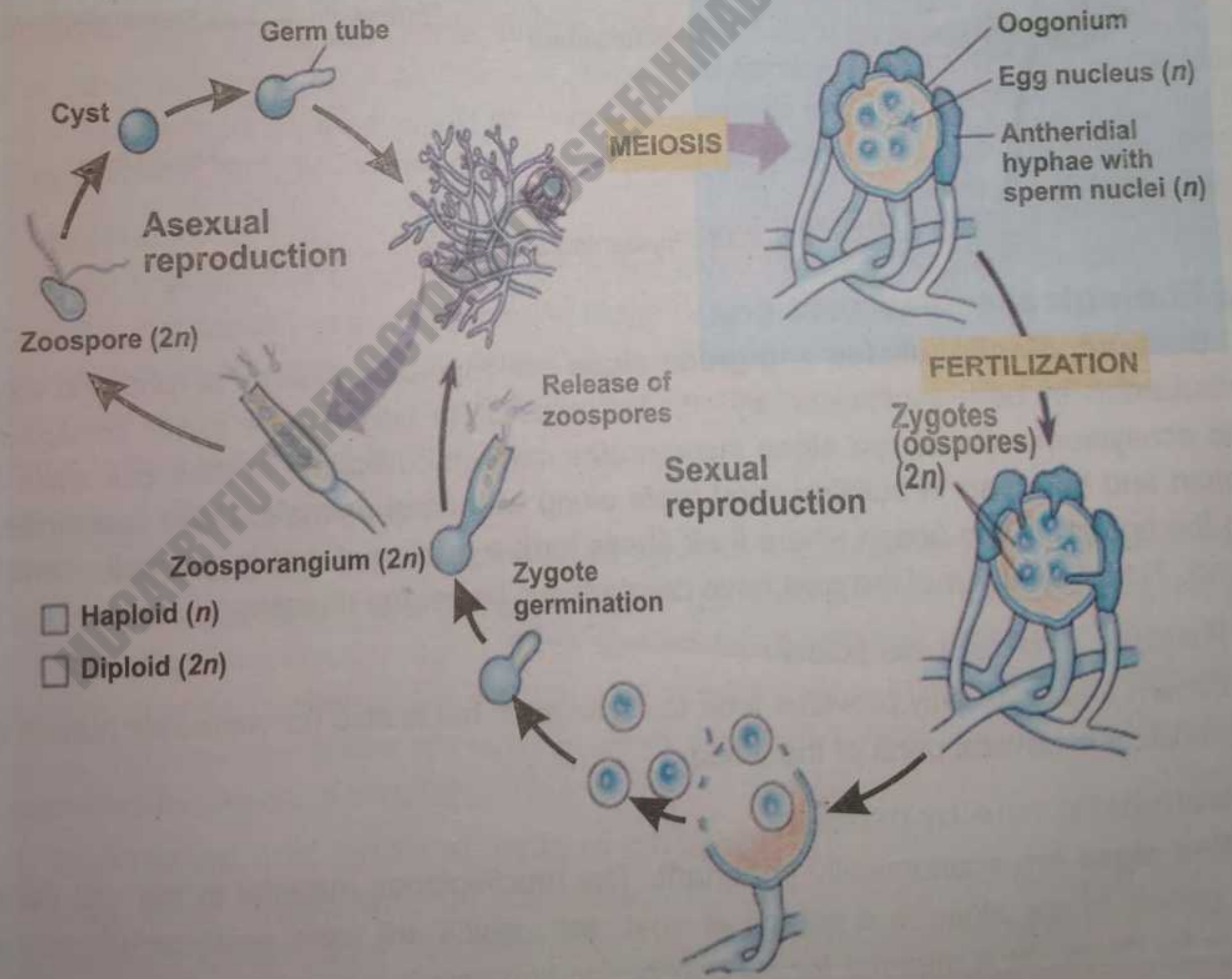


Fig: 7.12: Life cycle of oomycotes

7.3 IMPORTANCE OF PROTISTS TO HUMANS

7.3.1 Pathogenic role of protists

Many diseases in man are caused by protozoans such as, sleeping sickness, dysentery, malaria, which have already been discussed. *Phytophthora infestans* causes late blight disease in potatoes

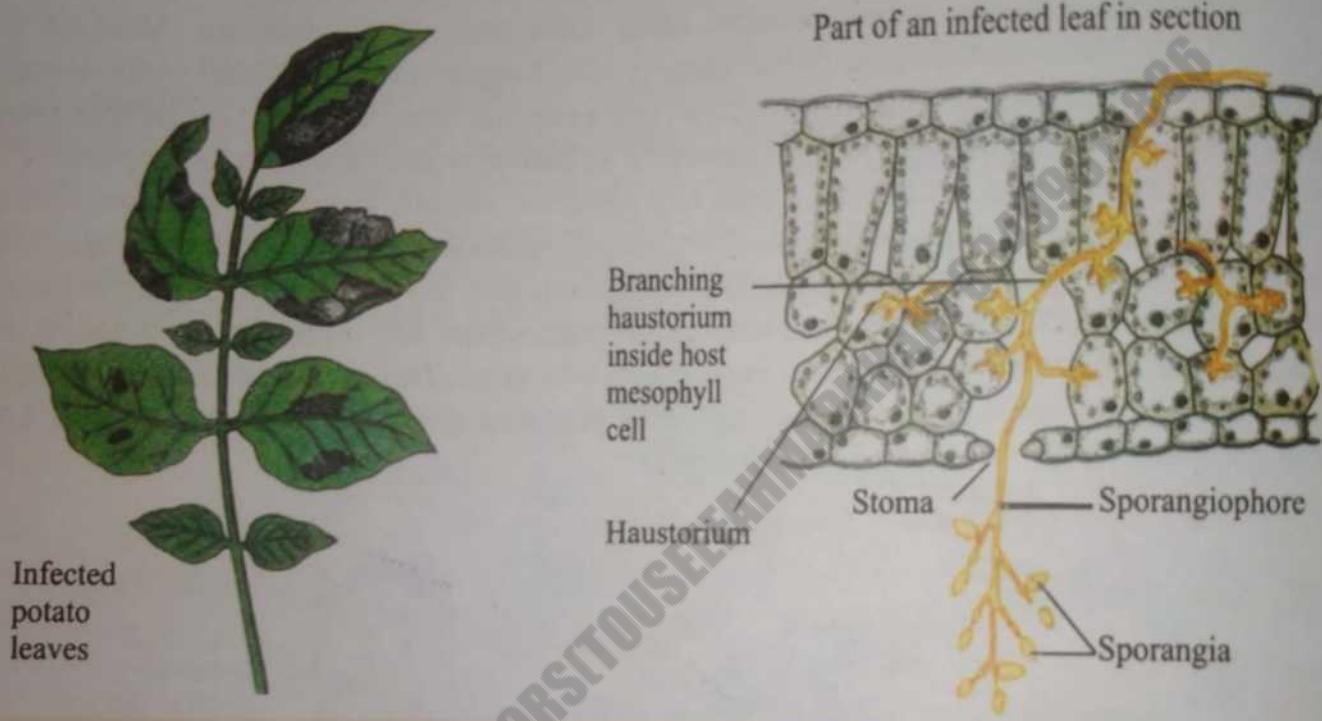


Fig. 7.13: *Phytophthora infestans*

7.3.2 Ecological role of protists

Diatoms, dinoflagellates and green algae are important sources of food and oxygen for heterotroph in both freshwater and marine ecosystem and act as major producers in aquatic ecosystems. Some red algae incorporates calcium carbonate in their cell walls from the ocean and take part in building coral reefs along with coral animals. Dead foraminiferans sink to the bottom of the ocean where their shells form a grey mud that is gradually transform into chalk. Foraminiferans of the past have created vast limestone deposits.

7.3.3 Role of protists as food

Brown algae not only provides food to organisms, but is also harvested for human food and for fertilizer in several parts of the world.

7.3.4 Industrial role of protists

Red algae are economically important. The mucilaginous material in the cell walls of certain genera of red algae is a source of agar, etc., which are used commercially to make capsules for drugs, as a material for making dental impression and a base for cosmetics. In laboratory agar is a culture medium for bacteria.

7.3.5 Role of protists in biological research

Chlorella has been used as an experimental organism in research in photosynthesis. A relatively new food source is single cell protein (SCP). The plasmodial slime mold *Physarum polycephalum* is a model organism that has been used to study many fundamental biological processes, such as growth and differentiation, cytoplasmic streaming, and the functions of cytoskeleton.

7.4 GENERAL CHARACTERISTICS OF FUNGI

The multicellular (except yeast), eukaryotic, absorptive heterotrophs which have cell wall made up of chitin and lack centrioles in their cells are classified as fungi. The study of fungi is called **mycology**. The person who studies fungi is called **mycologist**.

7.4.1 Taxanomic status of fungi (Fungi as separate kingdom)

Fungi are different from plants as: (1) Fungi have no chlorophyll (2) fungi never have flagella (3) fungi are saprotrophs. Fungi are different from animals as fungi: (i) have cell wall (ii) are absorptive heterotrophs (iii) are non-motile. So fungi can neither be placed in kingdom plantae nor in kingdom animalia. Similarly, fungi can not be classified in kingdom Protista as fungi are not direct decendendent of prokaryotes and they cannot be put into kingdom monera as fungi are eukaryotes. Fungi also show some unique characters not found in other kingdoms such as "nuclear mitosis". Because fungi are distinct from plants, animals and other eukaryotes in many ways, so they have been classified as separate kingdom.

Science Titbits

The ancestry of fungi which evolved about 570 million years ago, has not been determined. It has been suggested, that fungi evolved from red algae because both fungi and red algae lack flagella in all stages of their life cycle.

7.4.2 Habitat

Fungi grow best in moist habitats, but are found wherever organic matter is present. They survive dry conditions in some resting stage or by producing resistant spores. They can also tolerate a wide range of pH from 2-9, a wide temperature range and high osmotic pressure such as in concentrated salt/sugar solutions as in jelly, jam etc. These features also help them in their survival on land.

7.4.3 Fungal Cell structure

The fungal cells are eukaryotic in nature, have chitinous cell wall and lack centrioles and plastids. If carbohydrate is stored, it is usually as glycogen and not starch. Some cells have single nucleus (monokaryotic), some have two nuclei (dikaryotic) while other have multiple nuclei (multinucleate or coenocytic). Fungal cells show a unique mitotic division, called nuclear mitosis in which spindle fibers are formed within the nuclear envelope for the distribution of chromosomes between the daughter nuclei.

7.4.4 Size range and body structure of fungi

Fungi range in **size** from the unicellular, microscopic yeasts to the large, multicellular toadstool. Fungi do not have root stem or leaves. The body of most fungi is a multicellular structure known as **mycelium**. A mycelium is a network of filaments called **hyphae**. The hyphae may be non-septate or septate. Non-septate hyphae have no cross walls, are multinucleated or coenocytic, e.g., *Rhizopus*. Septate fungi have cross wall, e.g., *Penicillium*. The septate hyphae either consist of monokaryotic or dikaryotic cells. The mycelium that consists of monokaryotic hyphae is called primary mycelium and that consists of dikaryotic hyphae is called secondary mycelium. The cross walls of septate hyphae are perforated so that cytoplasm can move from one compartment to other. Yeasts are the only unicellular fungi and therefore, called non hyphal fungi. Some fungi also form large fruiting bodies (basidiocarp and ascocarp), which are actually the clusters of reproductive structures.

7.4.5 Locomotion in fungi

Fungi are non-motile, lack basal bodies and do not have flagella at any stage of their life cycle. They move towards a food source by growing towards it i.e., chemotropism.

7.4.6 Modes of nutrition in fungi

Fungi lack chlorophyll, so they are nonphotosynthetic. Thus, **mode of nutrition** is heterotrophic. Based upon ways of obtaining nutrient fungi may be saprotrophs, parasites, predator and symbionts (mutualists).

Saprotrophic fungi

Most fungi are saprotrophs, decomposers that obtain their food directly from dead organic matter. They secrete out digestive enzymes, which digest dead organic matter and the organic molecules thus produced are absorbed back into the fungus. Therefore, they are called absorptive heterotrophs. Saprobic fungi anchor to the substrate by modified hyphae, the rhizoids.

Parasitic Fungi

Some fungi are parasites, some are even predators, and still others are mutualists. Parasitic fungi absorb nutrients directly from the living host cytoplasm with the help of special hyphal tips called **haustoria**. They may be obligate or facultative. **Obligate parasites** can grow only on their living host and cannot be grown on available defined growth culture medium. Various mildews and most rust species are obligate parasites. **Facultative parasites** can grow parasitically on their host as well as by themselves on artificial growth media.

Predatory fungi

Some fungi are active predators. The oyster mushroom (*Pleurotus*) is omnivorous predatory fungus. It paralyses the nematodes, penetrate them, and absorb their nutritional contents, primarily to fulfill its nitrogen requirements. It fulfills its glucose requirements by breaking the wood. Some species trap soil nematodes by forming constricting ring, their hyphae invading and digesting the unlucky victim. Other predators have other adaptations, such as secretion of sticky substances.

Mutualistic fungi: Lichen and Mycorrhizae

Mutualism is the association in which both the partners are benefitted. The two key **mutualistic symbiotic association** formed by the fungi are lichens and mycorrhizae.

Lichens are an association between a fungus (mostly Ascomycotes and a few basidiomycotes), a cyanobacterium or green alga. The body of lichen has three layers. The upper layer is thin and tough which consists of fungal hyphae. The middle layer consists of fungal hyphae interwoven with photosynthetic cell. Bottom layer consists of loosely packed fungal hyphae. Specialized fungal hyphae which penetrate or envelope the photosynthetic cells, transfer nutrients directly to the rest of the fungus.

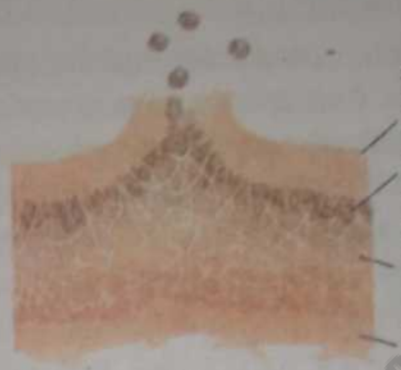


Fig: 7.14: A cross section of lichen

Mycorrhizae are mutualistic relationships between soil fungi and the roots of most plants. The hyphae help in the direct absorption of phosphorous, zinc, copper and other nutrients from the soil into the roots. Plants whose roots are invaded by mycorrhizae grow more successfully than do plants without mycorrhizae. There are two main types of mycorrhizae in which mycilia extend far out into the soil. **Endomycorrhizae** penetrate only into the outer cells of plant root forming coils, swellings and minute branches and also extend out into surrounding soil. **Ectomycorrhizae** form a covering that is exterior to the root, and they grow between cell walls. These are mostly formed with pines, firs etc.

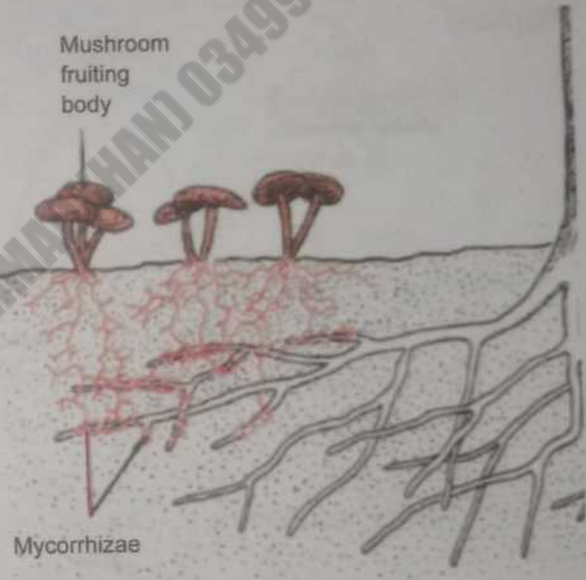


Fig: 7.15: Mycorrhizae

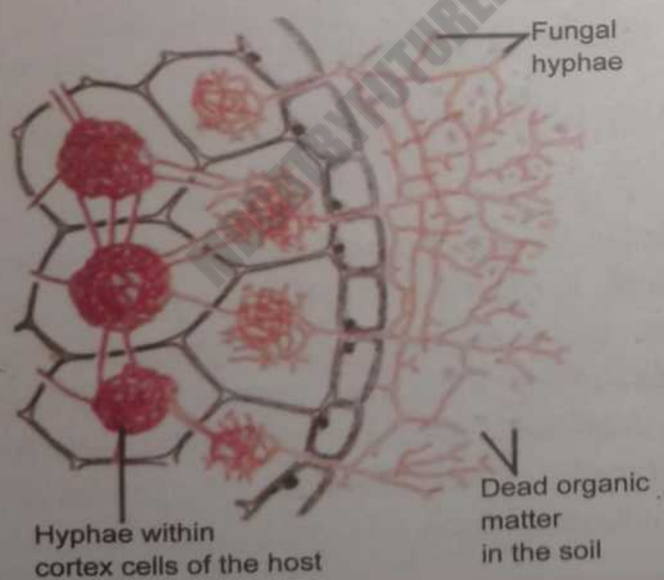


Fig: 7.16: Endomycorrhizae

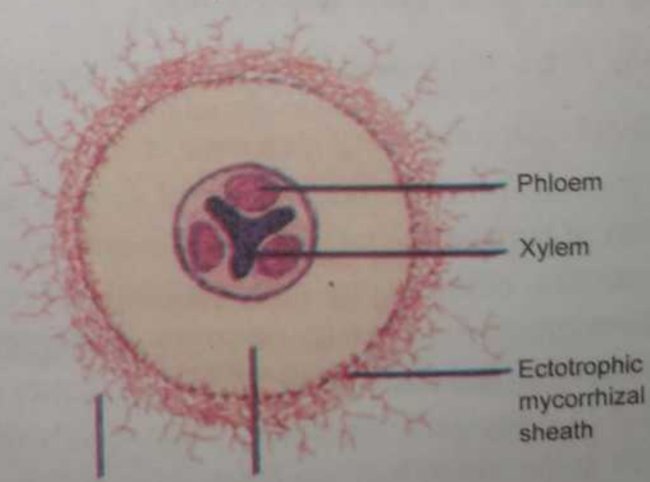


Fig: 7.17: Ectomycorrhizae

7.4.7 Reproduction in fungi

Most fungi can reproduce asexually and sexually (except imperfect fungi in which sexual reproduction has not been observed)

Asexual reproduction

Asexual reproduction takes place by sporangiospore, conidiospore, budding and fragmentation. **Sporangiospore** are produced in spherical sac like structures, the sporangia which are developed on the tips of special erectly growing hyphae, the sporangiophores e.g., *Rhizopus*. On the other hand, **conidiospores** are produced in the form of a cluster of chains on the tips of special erectly growing hyphae, the conidiophores e.g., *Penecillium*. **Budding** is only shown by yeast in which first, nucleus is divided into two daughter nuclei by nuclear mitosis then an out growth is formed which takes one of the daughter nuclei and subsequently separated from the parent cell. **Fragmentation** is the breakdown of mycelium into different fragments which again regenerate into new mycelium.

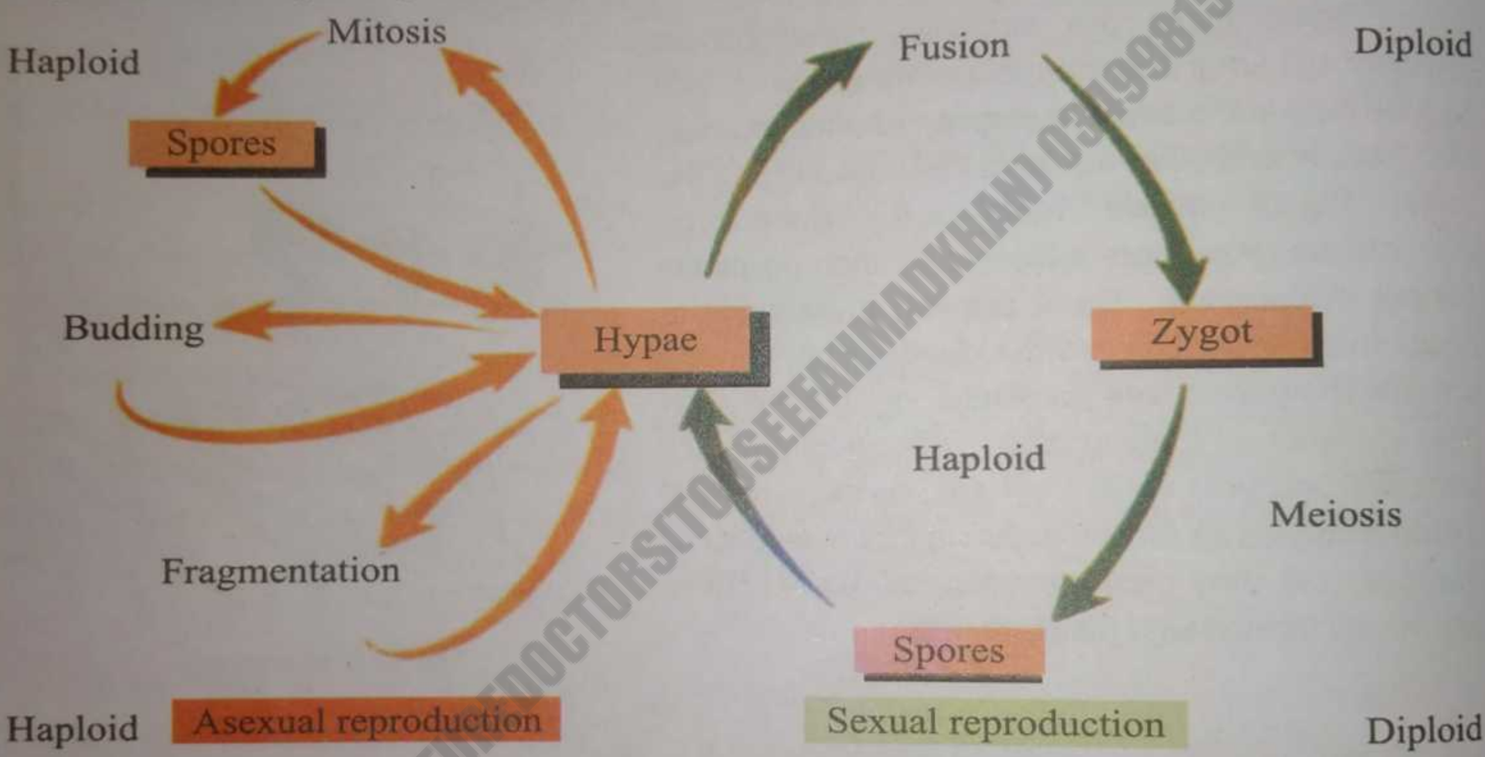


Fig: 7.18: A Generalized life cycle for fungi. Fungi alternate between sexual and asexual reproductive stages

Sexual reproduction

The detailed mechanism of sexual reproduction vary in different groups of fungi but fusion of haploid nuclei and meiosis are common to all. In sexual reproduction, hyphae of two genetically different but compatible mating types come together, their cytoplasm fuse (Plasmogamy) followed by nuclear fusion (karyogamy). In two of the three main groups of fungi (Basidiomycotes and Ascomycotes) fusion of nuclei does not takes place immediately after the fusion of cytoplasm; instead the genetically different nuclei of two individuals may coexist and divide in the same hyphae for most of the life of the fungus. Such a fungal hypha having two genetically different nuclei is called dikaryotic hypha.

7.5 DIVERSITY AMONG FUNGI

The kingdom fungi are diverse group of more than 100000 known species most of which are terrestrial.

Classification of kingdom fungi into four phyla/divisions is based primarily on the presence or absence of sexual reproduction, type of their sexual reproductive structures and methods of reproduction. These phyla are: Zygomycota, Ascomycota, Basidiomycota and Dueteromycota.

7.5.1 Zygomycota (Conjugating Fungi)

The phylum zygomycota is called conjugating fungi because during sexual reproduction their hyphae are fused just like the conjugation in bacteria. They are mainly

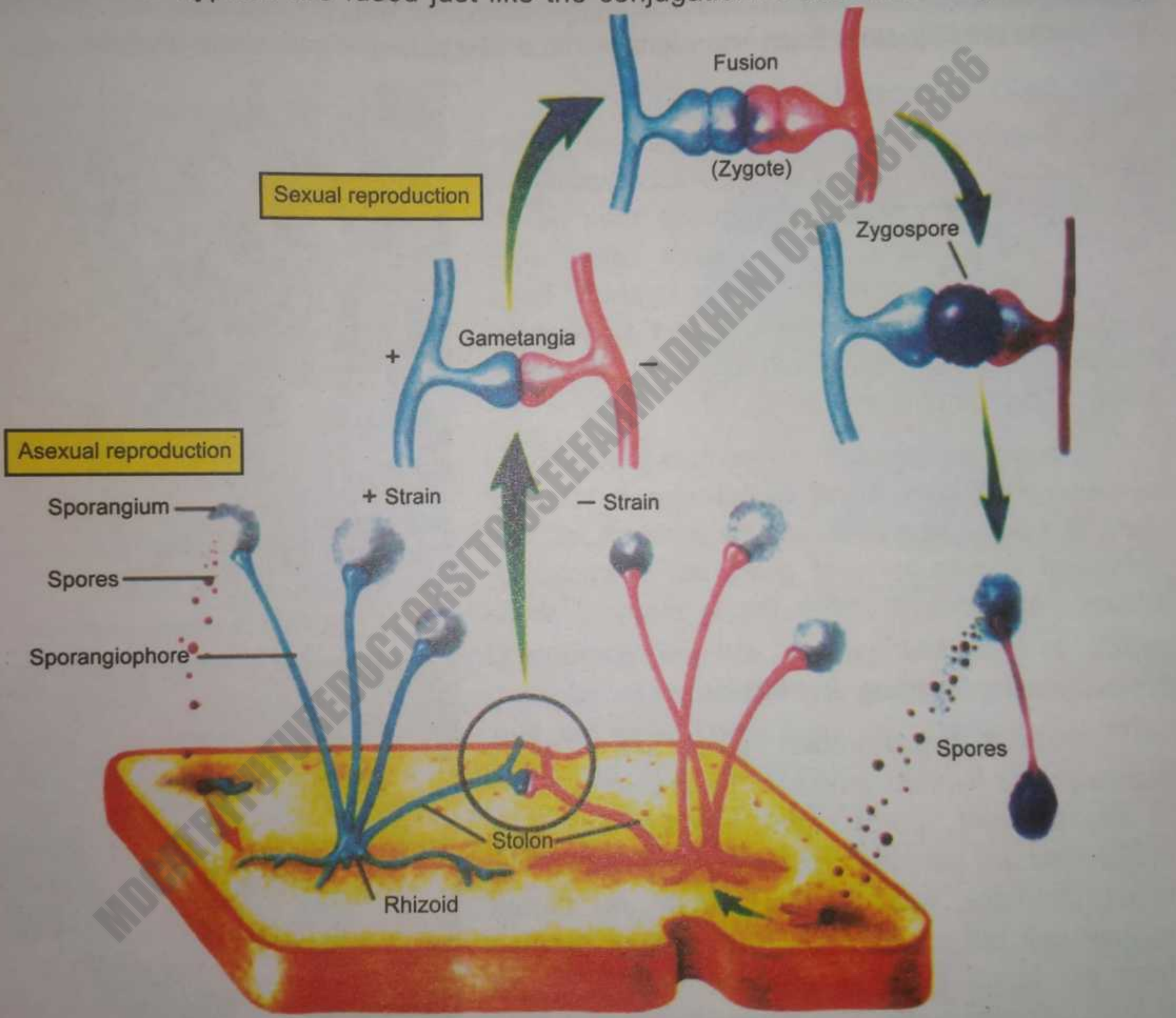


Fig: 7.19: Reproduction in *Rhizopus*

saprotrophs living on plant remains, on bakery goods, on vegetables and fruits. Some are parasites of small soil protists. Hyphae are nonseptate, mycelium well developed and branching. **Asexual reproduction** takes place by sporangiospores, e.g., *Rhizopus nigricans*.

Sexual reproduction takes place by **conjugation**. When hyphae (stolon) of opposite mating types meet, hormones are produced that cause the tips of the hyphae to come together and to form **gametangia**, structures that produce gametes. These structures become separated from rest of the mycelium by the formation of **septa**. Plus and minus nuclei then fuse to form a diploid nucleus, the **zygote**. There is no delay between plasmogamy and karyogamy and therefore, no dikaryotic phase.

The zygote develops into a **zygospore**. The division or phylum name refers to the **zygospore**. Zygospores **germinate** under favourable conditions and divide by **meiosis**. The wall of the zygospore splits and hypha grows upward. The tip of the hypha develops into a **sporangium**. The sporangium contains many nuclei. The wall of the sporangium ruptures and the spores are liberated. Each spore grows into a new plus or minus strain of mycelium.

7.5.2 Ascomycota (Sac Fungi)

Ascomycotes are the members of phylum ascomycota. It is a large group. Ascomycotes are also known as **sac fungi** because their sexual spores are produced in little sacs called **asci**. Their mycelium consist of septate hyphae. There is delay between plasmogamy and karyogamy, therefore, both monokaryotic and dikaryotic phases are found in the life cycle.

Fig: 7.20: Asci and Ascospore

Asexual reproduction involves production of spores called **conidia** or **conidiospores**. Conidia vary in shape, size and may be multicellular. The colour of conidia is what gives the characteristic brown, blue, pink or other tint to many of these molds. In unicellular **yeasts**, asexual reproduction takes place by **budding and fission**.


Fig: 7.21: Conidia

Sexual reproduction takes place when monokaryotic hyphae produced by the germination of two different spores, grow together and their cytoplasms are get fused (plasmogamy). Within this fused structure, haploid nuclei from the parent hyphae pair but do not fuse. New hyphae develop from the fused structure and the cells of these hyphae are **dikaryotic**. The dikaryotic hyphae grow to form a secondary mycelium which also develops a fruiting body known as **ascocarp**. It is a cluster of typical elongated sac like reproductive structures of this group, called **asci** in which ascospores are produced. Ascocarps can have different shapes. In cup fungi they are cup shaped, in molds they are flask shaped and in the **morels** they are stalked and crowned by bell shaped structure.

Within an ascus the two nuclei fuse and form a **diploid** nucleus, the **zygote**, which undergoes **meiosis** to form four haploid nuclei. This process is usually followed by one mitotic division of each of the four nuclei, resulting in eight haploid nuclei. Each haploid nucleus develops into an **ascospore**.

The ascospores, are then windblown if they land on a suitable location and germinate to form a new primary mycelium of monokaryotic hyphaeThe examples of sac fungi are Yeasts *(Saccharomyces)*, *Neurospora*, Morels, Truffles, *Penicillium*.

Fig. 7.22: Budding in Yeast

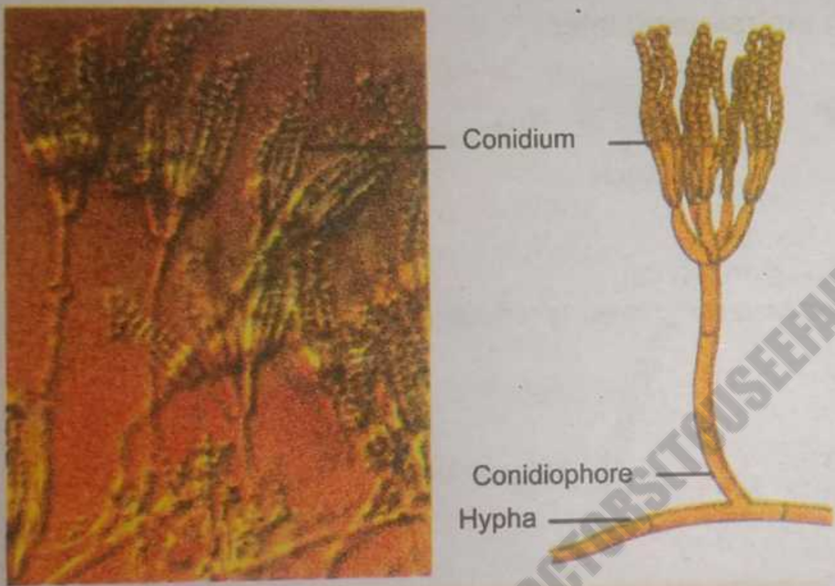


Fig. 7. 23(a) *Penicillium*

(b) *Penicillium* colony

7.5.3 Basidiomycota (Club-Fungi)

Basidiomycota includes edible and poisonous mushrooms, bracket fungi, puffballs and some notorious plant pathogens such as rust and smut. These fungi are commonly known as club fungi due to its characteristic club (rod) shaped reproductive structures, the basidia. These fungi also have primary and secondary septate mycelia of monokaryotic and dikaryotic hyphae respectively. There is also a delay between plasmogamy and karyogamy during sexual reproduction. Although club fungi occasionally do produce conidiospores asexually, they usually **reproduce** sexually.

7.5.4 Life cycle of a mushroom (Agaricus)

Life cycle start by the germination of characteristic haploid sexual spores of this fungus, called **basidiospores.** Each basidiospore has the potential to give rise to a new primary mycelium that consist of monokaryotic hyphae. The mycelium of Mushroom (*Agaricus*), consists of mass of white, branched, thread like hyphae that occur mostly below ground. A hyphae of a primary mycelium encounters another monokaryotic (n) hyphae of a different mating type and the two hyphae fuse. However the two haploid nuclei remain separated from

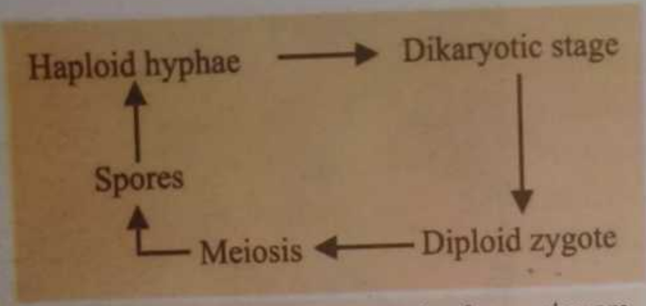


Fig: 7.24: Main steps of life cycle of a mushroom

each other. In this way a secondary mycelium with a **dikaryotic** (n + n) hyphae is produced, in which each cell contains two haploid nuclei. The n + n hyphae of the **secondary mycelium** grow and form compact mass, called **buttons**, along the mycelium. Each button grows into a **fruiting body** known as **mushroom**. A mushroom, which consists of a stalk and a cap, is called **basidiocarp**. The lower surface of the cap usually consists of many thin perpendicular plates called **gills** that radiate from the stalk to the edge of the cap. On the gills of the mushroom club shaped **basidia** are produced where haploid nuclei of the dikaryotic cells fuse to form diploid zygotes. Meiosis then takes place forming four haploid nuclei that move into finger like projections forming basidiospore, which are released later.

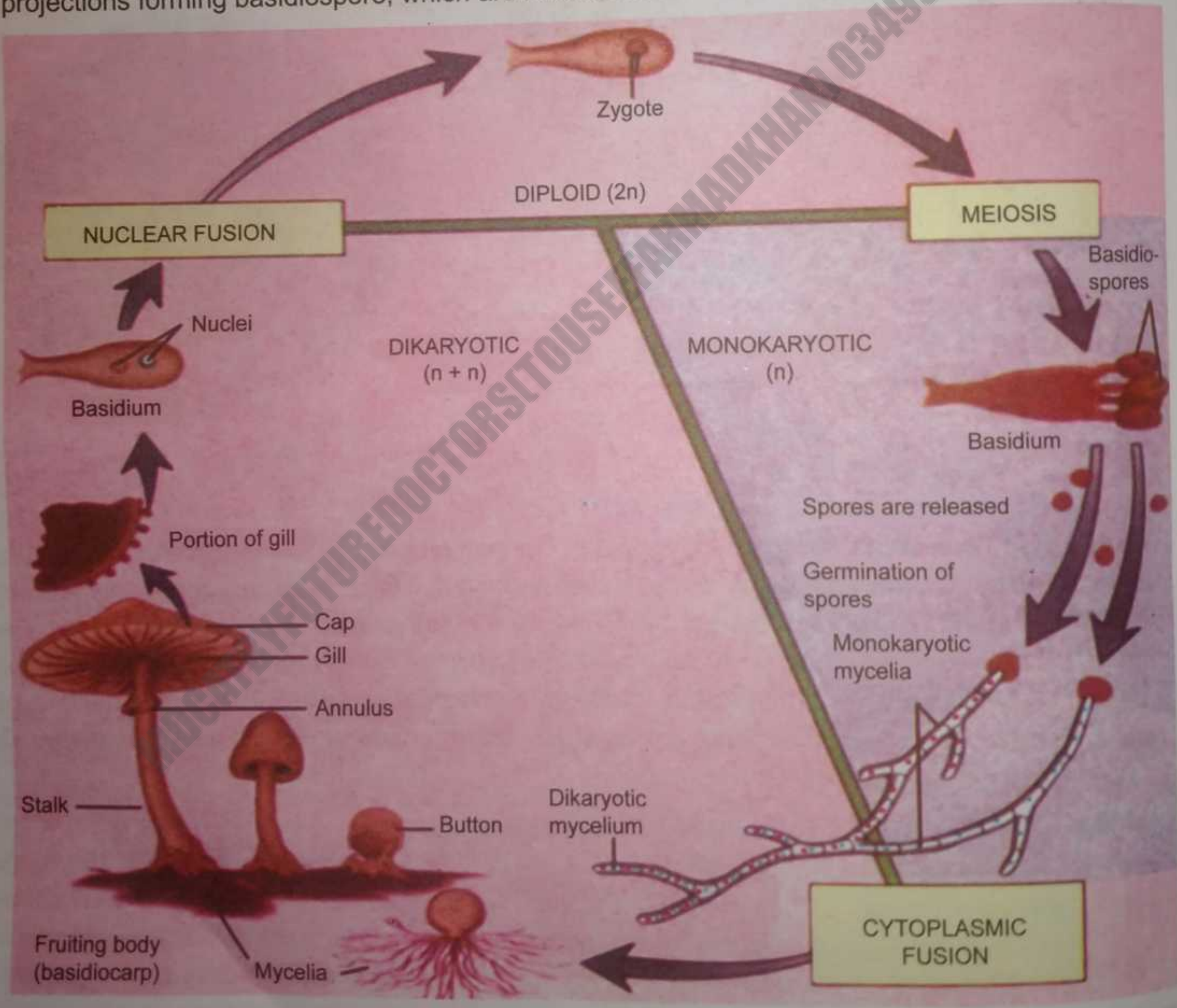


Fig: 7.25: Life cycle of a mushroom

7.6 IMPORTANCE OF FUNGI

Fungi are useful and also harmful to human beings. Fungi cause economic gains as well as losses. People eat fungi and grow them to make various chemicals. Fungi cause diseases in humans, other animals and plants. Here we will discuss use of fungi, antibiotics obtained from fungi, mutualism, edible fungi, ecological role of fungi and pathological role of fungi.

7.6.1 Ecological impacts of fungi

Fungi make important contributions to the ecological balance of our world. Like bacteria, most fungi are saprotrophs, decompose and absorb nutrients from organic wastes and dead organisms. In this way fungi help in maintaining the nutrient balance in nature. The organic waste is removed from the environment by the activity of saprotrophic fungi and bacteria.

The fungi and bacteria liberate huge amounts of CO_2 in the air by decomposing dead bodies of animals and plants. The green plants for the synthesis of organic food use this carbon dioxide. Thus fungi help in recycling of materials.

Humus is an important constituent of soil and essential for the proper growth of plants. It is formed from the organic waste material through the activities of fungi and bacteria.

Rusts (Extra reading material)

Rusts are called so because of numerous rusty and orange-yellow coloured disease spots on their host surface (mostly stem, leaves), later revealing brick/rust-red spores of the fungus. **Smuts** are called so because of their black, dusty spore masses that resemble soot or smut; these spore masses replace the grain kernels such as those of wheat, corn etc.

Science, Technology and Society Connections

- **Describe how helpful fungi have been for us as source of antibiotics and other useful chemicals.**

Often the first choice eukaryotic organisms for protein production is the yeast (*Saccharomyces cerevisiae*). Yeast cells can take up foreign DNA and integrate into their genomes. Yeasts also have **plasmids** that can be used as gene **vectors** and sometime yeasts are better than bacteria at synthesizing and secreting eukaryotic protein. Yeast is currently used to produce a number of proteins. In some cases the same product, for example interferons used in cancer research can be made in either yeast or bacteria. In other cases such as hepatitis B vaccine, yeast alone is used.

Some fungi such as lichen also contribute in bioindication of pollution, reduction of environmental pollution and ecological succession (development of an ecosytem)

7.6.2 Economic gains of Fungi

Fungi are used in food, baking, brewing and medicinal industry. Fungi are also being used in genetic research as model organisms.

Fungi as food

There are some 200 kinds of edible mushrooms e.g., *Agaricus*. Some edible mushrooms are cultivated commercially. Morels, and truffles, produce underground fruiting bodies are used as food e.g., (*Morchella sp.*). *Aspergilus sp* is used to produce soya sauce and soya paste from soya bean.

Fig: 7. 26: *Morchella sp.*

Use of fungi in baking

In making bread Amylase from fungi, which digest starch, can be added to increase the sugar contents. **Yeast** uses sugars as a source of energy in respiration. Both aerobic and anaerobic respiration result in production of carbon dioxide gas. When making bread, bubbles of the gas are trapped inside the warm dough causing it to rise.

Use of fungi in brewing

Wine production is called brewing. Different species of *Saccharomyces (yeast)* are used in brewing.

Use of fungi in genetic research

Yeasts are used in the biological research especially in genetic research. Researchers use *Saccharomyces* to study molecular genetics of eukaryotes, because its cells are easy to culture and manipulate. Pink mold *Neurospora* has also been used for genetic research. Yeast was the first eukaryotes to be used in genetic engineering. In 1983, a functional artificial chromosome was made in *Saccharomyces cerevisiae*. It was also the first eukaryotes whose genomic sequence was completely studied in 1996.

Poisonous fungi (Extra reading Material)

Edible and poisonous mushrooms can look very much alike and may even belong to the same genus. There is no simple way to tell them apart; they must be identified by an expert. Some of the most poisonous mushrooms belong to the genus **Amanita**. Toxic species of this genus have been appropriately called such names as "destroying angel" (*Amanita virosa*) and "death cap" (*Amanita phalloides*). Eating a single mushroom of either species can be fatal. Jack-o-lantern is a poisonous mushroom. Ingestion of certain species of mushrooms causes intoxication and hallucinations.

Amnita

Jack-o-lantern

Science, Technology and Society Connections

- Describe how helpful fungi have been for us as source of antibiotics and other useful chemicals.

Often the first choice eukaryotic organisms for protein production is the yeast (*Saccharomyces cerevisiae*). Yeast cells can take up foreign DNA and integrate into their genomes. Yeasts also have **plasmids** that can be used as gene **vectors** and sometime yeasts are better than bacteria at synthesizing and secreting eukaryotic protein. Yeast is currently used to produce a number of proteins. In some cases the same product, for example interferons used in cancer research can be made in either yeast or bacteria. In other cases such as hepatitis B vaccine, yeast alone is used.

Use of fungi in medicinal industry

The first antibiotic discovered was **penicillin**, made by the mold *Penicillium sp.* **Cyclosporins** are obtained from soil fungus is used in organ transplantation for preventing transplant rejection. **Griseofulvin** obtained from *Penicillium sp* is used to inhibit fungal growth.

7.6.3 Economic losses due to fungi

Fungi cause many important diseases in plants and also in animals including human beings.

Role of fungi in plant diseases

Fungi are responsible for many serious **plant diseases**, including epidemic diseases that spread rapidly and often result in complete crop failure. All plants are apparently susceptible to some fungal infection.

Some important plant diseases caused by **ascomycotes** are powdery mildews, chestnut blight, Dutch elm disease, apple scab, and brown rot, which attack cherries, peaches, plums, and apricots. Diseases caused by basidiomycotes include smuts and rusts that attack various plants for example the cereal crops of corn, wheat, oats etc.

Role of fungi in human diseases

Some fungi cause superficial infections in which only the skin, hair, or nails are infected. Ringworm and athlete's foot are examples of fungal infection of the skin. Candidiasis is a yeast infection of mucous membrane of the mouth or vagina caused by *Candida sp*.

Histoplasmosis is a serious infection of the lungs caused by inhaling spores of a soil fungus.

Ergotism is caused by purple ergot rye. It causes nervous spasm, convulsion, psychotic delusion and even gangrene.

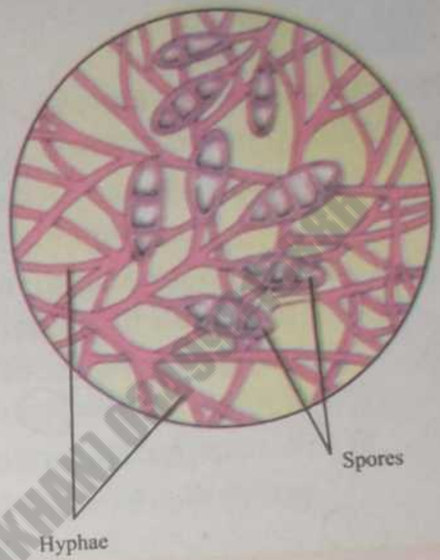


Fig: 7.27: Ringworm

Fig: 7.28: Athlete's foot

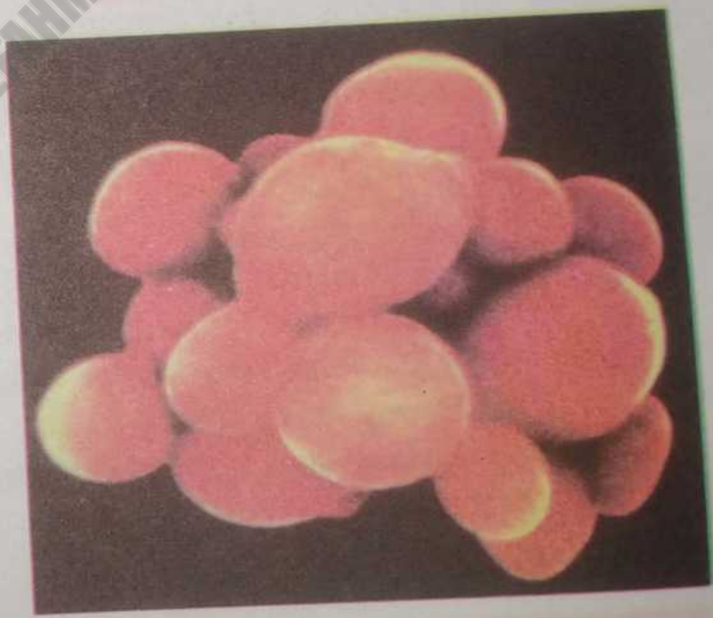


Fig: 7.29 Candida (Candidiasis)

Exercise

MCQs

1. **Select the correct answer**

(i) Which of the following is true of both fungi and some types of bacteria?
 (A) they both produce gametes
 (B) they both engulf microscopic animals
 (C) they both absorb materials across cell wall
 (D) they both fix nitrogen

(ii) The cell wall consists of two over lapping shells in
 (A) euglenoids (B) diatoms (C) dinoflagellates (D) brown algae

(iii) Which algal group is mismatched?
 (A) green algae --- closed relatives of land plants
 (B) dinoflagellates -- two part shell
 (C) brown algae – include the larges seaweed
 (D) diatoms – phytoplankton

(iv) The feeding stage of a slime mold is called
 (A) hyphae (B) plasmodium (C) rhizoids (D) mycelium

(v) Which is found in slime molds but not in fungi?
 (A) non-motile spores (B) amoeboid adult
 (C) zygote formation (D) photosynthesis

(vi) Fungi resemble animals because they are
 (A) saprotrophs (B) autotrophs (C) heterotrophs (D) heterosporous

(vii) Fungi cell walls contain chitin, which is also found in exoskeleton of
 (A) arthropods (B) molluscs (C) echinoderms (D) chordates

(viii) In the life cycle of an alternation of generations, multicellular haploid forms alternate with
 (A) multicellular diploid form (B) unicellular haploid form
 (C) unicellular diploid form (D) multicellular haploid form

(ix) Which of the following is associated with asexual reproduction in fungi
 (A) zygospores (B) ascospores (C) basidiospores (D) conidia

(x) Which protists form colourful and multinucleate masses?
 (A) euglenoid (B) cellular slime mold
 (C) water mold (D) plasmodial slime mold

Short Questions

What is meant by polyphyletic group?
How do ciliates differ from protozoans?

4. How do algae differ from plants?
5. What are the features that distinguish oomycotes from fungi?
6. What is zygospore and how it is formed?
7. How fungi resemble plants?
8. How fungi get their nutrition?
9. What are the methods of asexual reproduction in fungi?
10. Name few fungi from which antibiotics are obtained.
11. Give examples of edible fungi.
12. Write the differences between:
    (a) mutualism and parasitism
    (b) zooflagellates and ciliates
    (c) aseptate and septate hyphae
    (d) oogonium and antheridium
    (e) oospore and conidia
    (f) monokarotic and dikaryotic cell
    (g) fungi and plants
    (h) fungi and animals
    (i) zygomycota and basidiomycota
    (j) sporangium and ascocarp
    (k) ascus and basidium
    (l) endomycorrhizae and ectomycorrhizae

Extensive Questions

13. Explain protists as a diverse group of eukaryotes.
14. Explain the salient features of the protists Protozoa and give examples.
15. Explain the salient features of the protists Algae and give examples.
16. Explain the salient features of the protists Myxomycota and give examples.
17. Explain the salient features of the protists Oomycota and give examples.
18. How are protists important to humans?
19. What are the characteristics that distinguish fungi from other groups?
20. Give reasons why fungi are classified in a separate kingdom.
21. Explain the term club fungi. Draw and explain a diagram of the life cycle of a typical mushroom.
22. Write the importance of the unicellular fungi yeast.
23. Explain the mutualism established in mycorrhizae and lichen associations.
24. Write a brief note on edible fungi.
25. Describe the ecological impact of fungi.
26. Explain the pathogenic role of fungi.

8

DIVERSITY AMONG PLANTS

After completing this lesson, you will be able to

- Outline the evolutionary origin of plants.
- List the diagnostic features shared by all plants, with emphasis on alternation of generation.
- Describe the general characteristics of bryophytes.
- Outline the life cycle of 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.
- Identify the vegetative and reproductive structures of a *Pinus* and relate these with its life cycle.

Reading

The kingdom **plantae** or **plant kingdom** comprises hundreds of thousands of different species. They live in every type of habitat, from frozen Arctic tundra to tropical rain forests and deserts. Keeping in view the diversity and importance of plants, in this chapter we will study about land plants and how they evolved, emergence of seedless plants and evolution of seed plants. The presence of plants has enabled other form of living things to live on land.

8.1 THE EVOLUTIONARY ORIGIN OF PLANTS

In the beginning the plants were restricted only to aquatic conditions. The migration started towards land nearly 400 million years ago. Many important features of land plants also appear in a variety of protists, primarily green algae. For example, plants are multicellular, eukaryotic, photosynthetic, autotrophs, as are brown, red and certain green algae. Plants have cell wall made of cellulose. Likewise green algae, dinoflagellates and brown algae have also cellulose in their cell walls.

Chloroplasts with chlorophylls a and b are present in plants as well as in green algae, euglenoids and a few dinoflagellates. Biologists have identified the freshwater green algae (e.g., Chara, a pond organism) as the closest relatives of land plants. Both contain a higher percentage of cellulose in their cell wall, form phragmoplast during cell division, perform photo respiration and have similar flagellated sperms. Some sequences of nuclear and chloroplast genes are also matching.

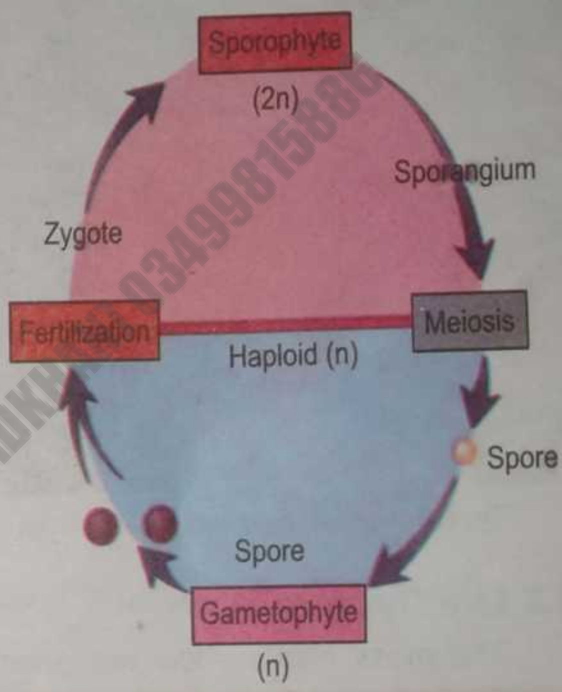


Fig: 8.1: Alternation of generation

8.1.1 Diagnostic Features of Plants

Plants are multicellular eukaryotes with well-developed tissue and have autotrophic nutrition. Plants are well protected from being dried up in air by their cuticle, formed from a waxy substance called **cutin**. The plant body has root, stems and leaves having vascular tissue xylem, phloem and **cellulose** rich **cell walls**. Plants show alternation of generation. It consists of the sporophyte the diploid generation that produces haploid spores by meiosis. Spores develop into a haploid generation. The gametophyte is the haploid generation, which produces gametes that unite to form a diploid zygote. The plants are oogamous (see glossary); the gametes are eggs and sperms.

8.2 NON-VASCULAR PLANTS

Plants are currently divided into two main groups: the nonvascular or bryophytes and the vascular plants or tracheophytes. The nonvascular plants lack vascular tissues. These plants do not have true roots, stems, and leaves. Therefore, the nonvascular plants are said to have root like, stem like, and leaf like structures.

8.2.1 General Characteristics of Bryophytes

The bryophyta is a group of plants comprising of liverworts, hornworts and mosses. Bryophytes are typically quite small and a few exceed 2 centimetres in length. They generally require a moist environment for active growth and reproduction, but some bryophytes tolerate dry areas.

The gametophytes of bryophytes are green and manufacture their own food. They are relatively large and prominent as compared to sporophytes. Some of their sporophytes are completely enclosed within gametophyte tissue, others that are not enclosed; turn brownish or straw coloured at maturity.

Fig: 8.2: Mosses covering several rocks

The main features of bryophytes are:

(1) They lack specialized vascular tissues.

(2) Multicellular sex organs produce embryo.

(3) Sporophytes are always smaller and obtain their food from the gametophyte.

(4) Their life cycles involve alternation of generation.

(5) Bryophytes are also called **amphibious plants** because they need water for development, existence and reproduction.

8.2.2 Life Cycle of Moss

The moss plants show two generations the sporophyte and the gametophyte, which regularly alternate with each other. It is known as **alternation of generation**. The life cycle is completed when the plant passes through these two generations.

The matured green shoot is the **gametophyte**. It produces gametes and reproduces by sexual method. The sex organ is at the apex of the shoot. The male sex organ is known as **antheridium** and the female sex organ as **archegonium**. The sex organs are intermixed with some multicellular hair like structures, known as **paraphyses**. The two sex organs may occur on the same plant i.e., **monoecious** or on two separate plants, i.e., **dioecious**. The **sporophyte** consists of a foot which is embedded in the tissue of the gametophyte and a **stalk** with a **sporangium**.

Spores are formed in the sporophyte by meiosis, thus the spores are haploid. The spore germinates into alga like structure called **protonema**, having bud and branches. The bud gives rise to gametophyte. In the antheridium the sperms are produced. In the **archegonium** the egg is produced. The flagellated sperms swim through the film of water to the egg. Fertilization is internal. The diploid zygote divides and forms the embryo. The embryo develops into a diploid sporophyte.

Science Titbits

The name moss is often commonly used for plants that are not truly mosses. For example reindeer moss is lichen that is a dominant form of vegetation in the Arctic tundra, Spanish moss is a flowering plant and club moss is relative to ferns.

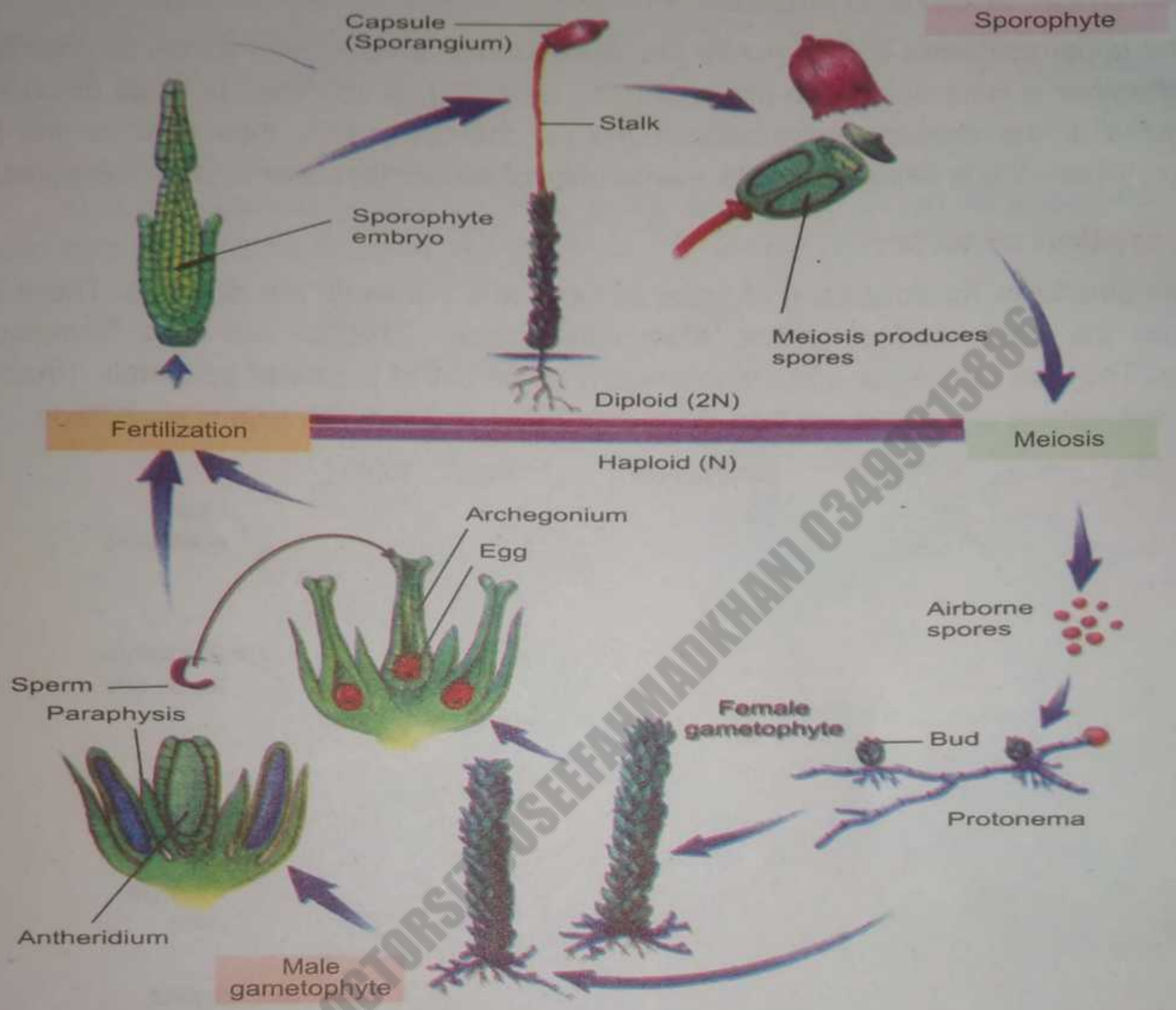


Fig: 8.3: Life cycle of moss (*Funaria*)

8.2.3 The Land Adaptations of Bryophytes

The land adaptive characteristics exhibited by nonvascular plants are:

(1) The Multicellular plant body and conservation of water

The plant body of liverworts called thallus is multicellular consists of hundreds of cells, e.g., *Marchantia* (*Mar-kan-shia*). Only the cells of the upper layer are exposed to the atmosphere. Some cells are photosynthetic and some are storage cells. Water cannot evaporate from these inner cells because the upper epidermis has covering of **cutin**, which is a wax like substance. It reduces the evaporation of water in some mosses and liverworts. The layer of cutin is called **cuticle**.

Fig: 8.4: *Marchantia* thallus

(2) Absorption of carbon dioxide

The upper epidermis in *Marchantia* has many **pores**, which open into the air chamber. The air chamber is surrounded with photosynthetic cells. CO_2 is absorbed by large amount of wet surfaces of the photosynthetic cells of the air chambers. CO_2 then diffuses into the cytoplasm. When CO_2 is being absorbed, evaporation of water may occur through the pores.

(3) Absorption of water

The structures for absorption of water in moss and liverworts are **rhizoids**. These are present on the lower surface of the *Marchantia* thallus. Rhizoids are long filamentous structures. They are unicellular and are extensions of the cell of the lower epidermis. Rhizoids increase the surface area for absorption of water from the soil and also help in anchorage.

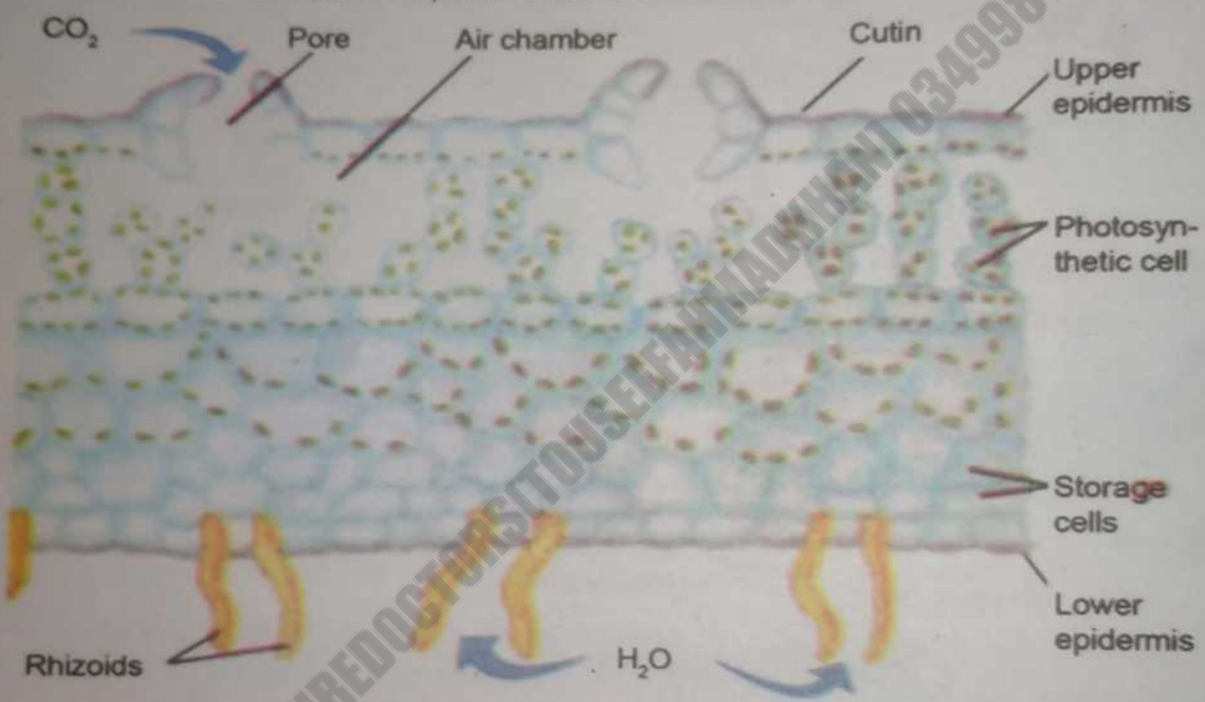


Fig: 8.5: Transverse section of *Marchantia* thallus

(4) Heterogamy

When two types of gametes are produced, it is called heterogamy. Sperms and ova are produced by the nonvascular plants, e.g., Moss, *Marchantia* etc. The **sperms** are flagellated and motile, require water for reaching egg. The **egg** is large and nonmotile. It contains large amount of food, which is used to nourish the early stages of the developing embryo after the fertilization of egg. Due to the water requirement for fertilization they cannot live away from water.

(5) Protection of reproductive cells

The moss, *Marchantia* etc. can be distinguished as male and female plants. The sex organs are multicellular and are covered by sterile hairs to prevent the drying of the sex organs. Most of the cells of the sex organs are sterile which form a protective coat around the egg and sperms. Protection of spore is performed by sporangium.

(6) Embryo Formation

Fertilization is inside the archegonium. The zygote divides to form the embryo and is retained inside the archegonium. The chances of survival of embryo are increased as it is protected by the wall of the archegonium. Embryo is present in all bryophytes and vascular plants.

(7) Alternation of Generations

The mosses and liverworts have a life cycle with al ternating gametophyte and sporophyte generations. It increases the chances of survival of the plants on land.

(a) Female thallus of *Marchantia* (b) Male thallus of *Marchantia*

Fig. 8.6: (a) Umbrella shaped structures that bear archegonia in *Marchantia* (b) Disk shaped structures that bear antheridia in *Marchantia*

8.2.4 Importance of Bryophytes

Mosses play an important role in their environment. They hold the soil in place and help prevent erosion. They provide food for animals, especially birds and small mammals. Commercially the most important mosses are the peat mosses. Their leaves hold water anc are beneficial as a soil conditioner. When added to sandy soils peat moss helps to hold anc retain moisture.

8.3 SEEDLESS VASCULAR PLANTS

Vascular plants include ferns and their allies, gymnosperms, and angiosperms. Vascular tissue consists of **xylem** and **phloem.** The vascular plants have true roots, stems, and leaves. Xylem, with its strong-walled cells, supports the body of the plant against the pull of gravity. The leaves are covered by a waxy **cuticle**. Leaves have small pores called **stomata**. The **sporophyte generation** is diploid and dominant in vascular plants. The vascular plants are widely distributed.

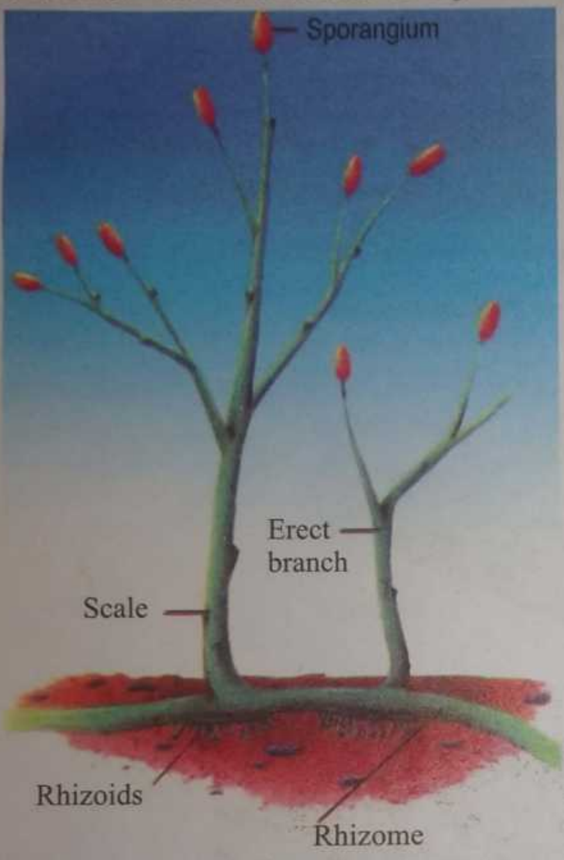


Fig: 8.7: *Rhynia*

The **seedless vascular plants** (ferns and their allies) disperse the species by producing windblown **spores**. When the spores germinate, a relatively **large gametophyte** is formed which is independent of the sporophyte for its nutrition. In these plants, **flagellated sperms** are released by antheridia and swim in a film of external water to the **archegonia**, where fertilization occurs.

Because the seedless vascular plants are not closely related, each type is placed in its own division. The seedless vascular plants include whisk ferns (division Psilotophyta), club mosses (division Lycopodophyta), horsetails (division Equisetophyta), and ferns (division Pteridophyta)

8.3.1 Psilopsida—Whisk ferns

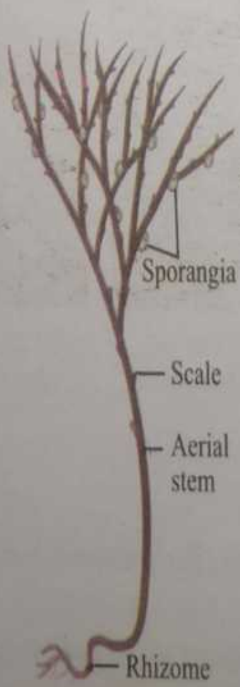


Fig: 8.8: Whisk fern, *Psilotum*

The group psilopsida includes the simplest known vascular plants known as **whisk ferns**, named for their resemblance to whiskbrooms. The whisk fern lack true roots but bear underground stems called rhizomes that bear **rhizoids**. Aerial stems have no leaves, they have only tiny scales fork repeatedly and carry on photosynthesis. **Sporangia** are present at the tips of the branches. Most members of this group are extinct. Example of extinct group are *Rhynia*. *Psilotum* is the most common living genus.

8.3.2 Evolution of Leaf

Leaves are present in higher vascular plants. They have evolved from the primitive vascular plants. There are two main types of leaves in vascular plants: (a) Single veined leaves. (b) Many veined leaves.

Single veined leaves are small and scale like. They have single vascular bundle and vein. Therefore they are called single or one veined leaves or microphyllous leaves e.g., club mosses (*Lycopodium*). **Many veined leaves** are large leaves having prominent blade. As many veins and vascular bundles are present, so they are called many veined leaves or megaphyllous leaves, e.g., Ginkgo etc.

There is no fossil record showing the evolution of **single veined leaves**. However two hypotheses have been proposed to explain their origin: (a) outgrowth hypothesis (b) reduction hypothesis

According to **out-growth hypothesis** single veined leaf originated as simple outgrowth from the naked branches of the primitive plant. The outgrowths had no vascular tissues. With the increase in size, vascular tissues were needed for the transportation of food, water etc. and support. Thus vascular supply was extended from main vascular bundle of stem giving rise to a single veined leaf.

Did you know?

In the **seed plants**, there is a separate **micro-gametophyte** (male) and **megagametophyte** (female). The microgametophyte and megagametophyte are dependent on the sporophyte, which is fully adapted to a dry environment. The mature microgametophyte is the **pollen grain**. The megagametophyte retains the megaspores in the megasporangium. This modified structure is called ovule. The fertilized egg in the ovule becomes **embryo**, which is retained within the body of the sporophyte, and fertilized ovule becomes a seed. Seed dispersal occurs by wind and water or by animals to a new location.

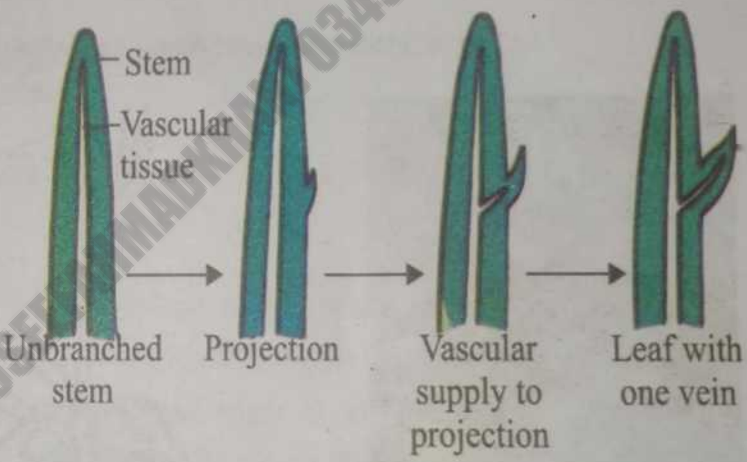


Fig: 8.9: Evolution of single veined leaf, outgrowth hypothesis

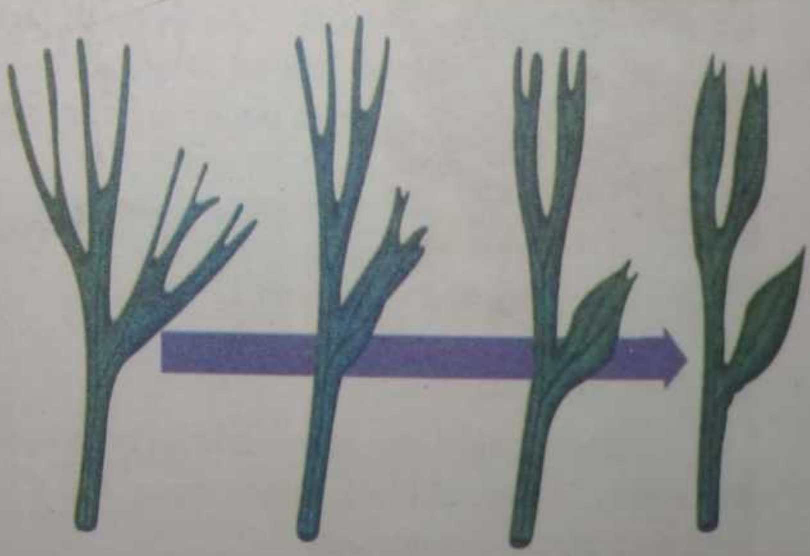


Fig: 8.10: Evolution of single veined leaf reduction hypothesis

The **reduction hypothesis** states that the early vascular plants had leafless branches. These branches were gradually reduced in size. Thus by simplification and reduction in size and flattening of the leafless branches the single veined leaves were evolved.

It is evident from fossil record that **many veined leaves** have evolved through modification of the forked branches found in early vascular plants e.g., *Rhynia*. According to this view the forked branches were changed to a single plane known as **planation**. The branches became flat. The spaces between the bundles and branches of vascular tissues became filled with photosynthetic tissues called **webbing**. The structure resembles superficially to the webbed foot of the duck and thus a many veined leaf evolved.

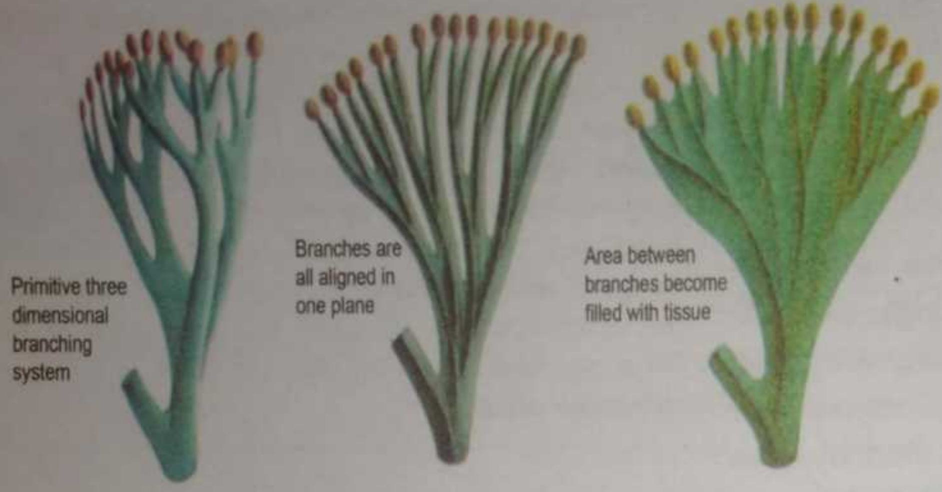


Fig: 8.11: Evolution of many veined leaf

8.3.3 Lycopsida – Club Mosses

The plant body consists of a branching **rhizome** which sends up aerial stems less than 30 cm tall. Tightly packed scale like leaves cover the stem and branches of the plants. The leaves are **microphylls**, having only one strand of vascular tissue. In club mosses the sporangia are born on terminal clusters of leaves called **strobili** which are club shaped. They are only living plants to have microphylls. The familiar members of this group belong to genera *Lycopodium* and *Selaginella*.

Fig: 8.12: Club moss, *Lycopodium*

8.3.4 Sphenopsida - Horsetails

Sphenopsida commonly known as horsetails, are found in waste and wet places all over the world. Sphenopsida includes more fossil plants than living one. Today there is only one surviving genus *Equisetum*.

A rhizome produces aerial stem. The stems are slender, green, hollow structure, and appear jointed as slender green side branches are present at the nodes. The small and scale like leaves also form whorls at the **nodes**, the nodes are separated by **internodes**. Many horsetails have strobilus at the tips of the stem.

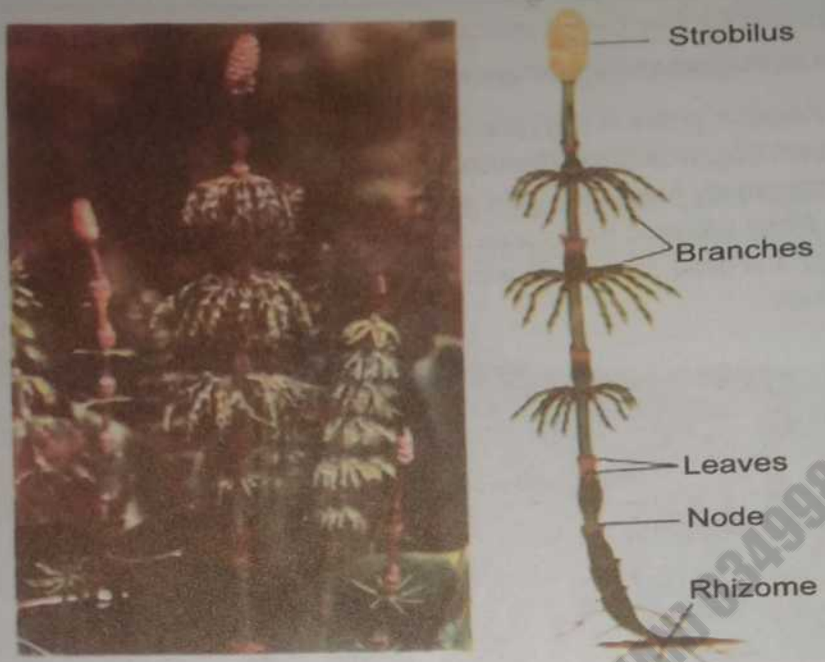


Fig: 8.13: Horsetail, *Equisetum*

8.3.5 Pteropsida - Ferns

Ferns belong to the group pteropsida, subgroup or class **filicinae**, which are most abundant group of seedless vascular plants in warm and moist tropical regions.

Ferns range in size from reduced aquatic forms less than a centimetre, to a tree fern that may have trunks more than 24 metres tall, with leaves up to 5 metres or more in length. Except few all the ferns are **homosporous**. Sporophyte generation is much larger, more conspicuous, and more complex than the gametophyte. Sporophyte is completely independent. Sporangia are foliar, i.e., attached to leaves or fronds. When the frond is young and immature, it is coiled. This pattern of development is called **circinate vernation**. It is an important feature of ferns.

Fig: 8.14: Ferns

Science, Technology and Society Connections

- **Describe the formation and importance of peat bogs.**

The moss *Sphagnum* grows in bogy places that are low lying, wet, spongy places forming dense and deep masses called peat bog. One of the distinctive features of this moss is a presence of large empty cells in the leaves, which apparently function to hold water. This feature makes peat moss particularly beneficial as a soil conditioner. When added to sandy soils, for example, peat moss helps to hold and retain moisture. In some areas as bogs, the dead *Sphagnum* accumulates and do not decay. This accumulated moss called **peat** can be used as fuel.

Peat bog

Peat mosses Sphagnum

8.3.6 Life Cycle of Fern (*Adiantum*)

Life cycle of *Adiantum* (Maidenhair fern) contains two generations i.e., sporophyte and gametophyte. Both of these generations are independent.

Sporophyte generation

Sporophyte of *Adiantum* produces vegetative leaves at start. At later stages, fertile leaves also start producing along with vegetative leaves. Fertile leaves produce sori (singular: *sorus*) on their underside. Sori are group of sporangia. These sori are covered with a flap of tissue called **false indusium**.

Sporangium

A mature sporangium is flattened, spherical or ellipsoidal. It consists of a stalk and upper swollen portion called **capsule**. Capsule is covered with single layered wall. Wall consists of two portions **annulus** and **stomium**. Annulus portion contains cells with thick cell walls.

Stomium consists of cell with thin cell walls. This is the site for bursting of sporangia. Inside sporangia, spores are produced by **meiosis** of spore mother cells. Many spores are produced inside sporangia. Spore wall contains two layers **exine** and **intine**.

When spores get mature, the wall of sporangia burst. Sporangium becomes dry, so the cells of annulus region contract which exerts pressure on stomium cells. Stomium is weak region of wall of sporangia, so sporangia get burst from this region.

Bursting of sporangia cause the dispersal of spores. After falling on suitable place, spore germinates. During germination, exine of spore bursts and intine elongates into a tube like structure. The apical portion of tube gives rise to new generation of *Adiantum* the gametophyte generation.

Gametophyte generation

The shape of gametophyte of *Adiantum* is heart like. It has a notch, where growing point resides. Gametophyte of *Adiantum* is many cells thick from centre and only one cell thick at margins. **Rhizoids** are produced from underside of gametophyte for anchorage and absorption of water and nutrients. Gametophyte contains chloroplasts, so carry out photosynthesis. Gametophyte is independent. Two kinds of organs **archegonia** and **antheridia** are produced on gametophyte.

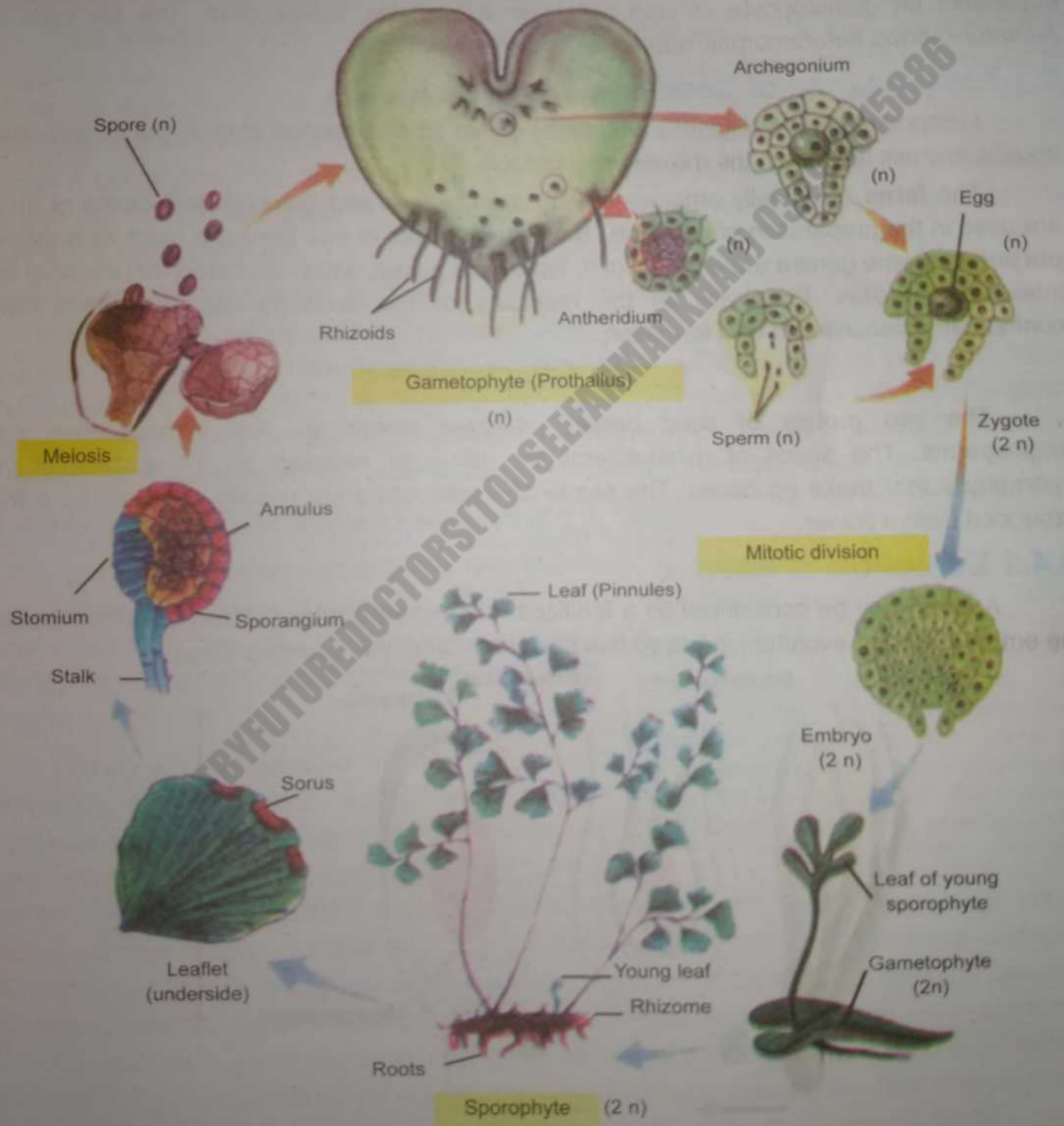


Fig 8.15: Life cycle of fern (*Adiantum*)

Archegonia is flask shaped structure with two portions i.e., **ventre** and **neck**. Ventre contains **egg** while neck contains **neck canal cells**. Antheridia are globose structures, in which many **antherozoids** are produced. Antherozoids when get mature has two flagella for movement in water.

Antherozoids after releasing from antheridia travel through water chemotactically towards archegonia. **Antherozoids** fertilize the egg inside archegonia. Resultant zygote develops into embryo. Embryo starts divisions to form sporophyte. Sporophyte remains dependent on gametophyte at start but soon it becomes independent. The life cycle of *Adiantum* shows heteromorphic alternation of generation.

8.3.7 Importance of Seedless Vascular Plants

Lycopodium and *Selaginella* are chiefly grown as **ornamental plants**. Ducks and other aquatic animals feed upon the rhizome of *lycopsida sp.*

The **ferns** are mostly ornamental plants of gardens and greenhouses. Some of them are used in the preparation of bouquets. Stems and leaves of tree ferns are used for **building purposes**. Some genera are edible. Some ferns yield a drug, which is utilized for removing the intestinal parasites. Practically all the members of the seedless vascular plants have contributed extensively to coal formation.

8.4 SEED PLANTS

The two groups of seed bearing vascular plants are the gymnosperms and angiosperms. The seeds of gymnosperm are produced exposed on the surface of the sporophylls that make up cones. The seeds of angiosperms are usually enclosed by a fruit produced from a flower.

8.4.1 Evolution of Seed

A seed may be considered as a fertilized **megasporanguim**. It has integument around the embryo. During evolution the seed has passed through the following stages.

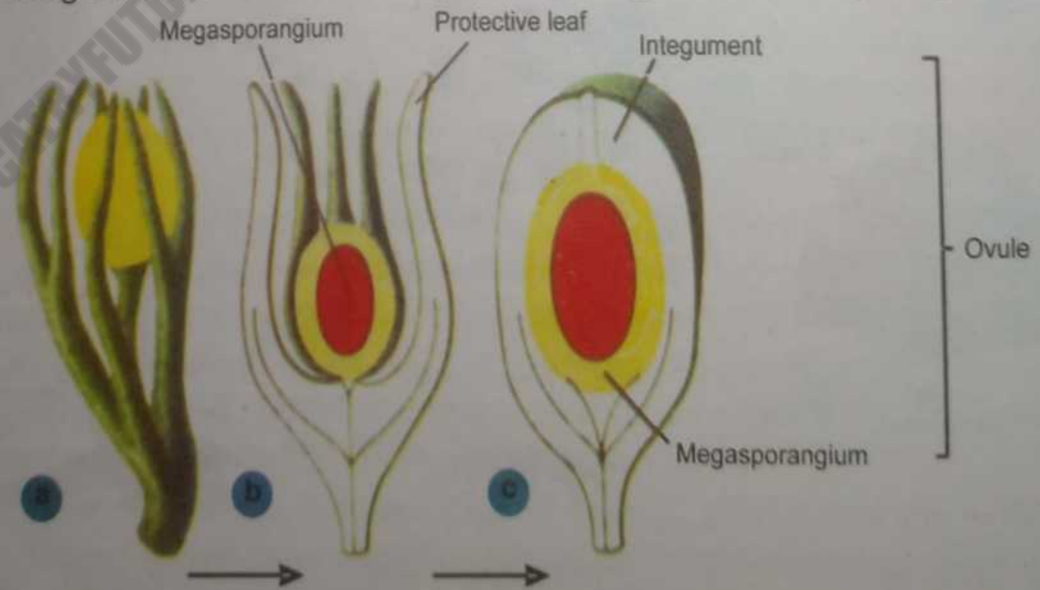


Fig 8.16: Evolution of seed

Development of Heterospory

All seed plants are heterosporous i.e., produce microspore and megaspore in microsporangia and megasporangia respectively. The megaspore grows into a female gametophyte and microspore grows into a male gametophyte. The megaspores of the seed plants are retained inside the sporangium, where the megaspore develops into a tiny female gametophyte.

Evolution of Pollen Tube

The evolution of pollen tube parallels the evolution of seeds. The egg produced inside an ovule is very well protected in the sporangium. It is so well protected that flagellated sperm would not have the slightest chance of ever reaching an egg. This obstacle has been overcome by the development of **pollen tubes**. Once the pollen grain reaches the cone or flower, it germinates. The germinated pollen grain is a tiny **male gametophyte**. It produces a long pollen tube, which grows to the ovule and then digests its way through the protecting layers to the enclosed egg.

Evolution of Integument around the Megasporangium and Seed

In carboniferous period fern like plants were present. The sporophyte of these plants had little protective branch like outgrowths, surrounding the megasporangium. During evolution the outgrowths fused together forming integument, enclosing the **megasporangium**. **Megaspore** is retained in the megasporangium. This modified structure is called an **ovule**. The fertilized ovule evolved into **seed** because of retention of developing embryo.

8.4.2 Gymnosperms (naked seed plants)

The plant body of gymnosperms may be tall, woody, perennial trees or shrubs. The plant body is a sporophyte, differentiated into stem, leaves and root. Stem is branched with the exception of *Cycas*, which is rarely branched.

There are two types of leaves. The foliage leaves and the scaler leaves. Foliage leaves may be simple or compound. The leaves are evergreen with thick cuticle. Venation is simple. The arrangement of leaves may be spiral or cyclic. Leaves exhibit xerophytic features like thick and tough cuticle, stomata sunken in pits, presence of wax on the surface. Xylem consists of tracheids and xylem parenchyma. Vessels and wood fibres are generally absent. Companion cells are absent in phloem. Cones are unisexual. Male and female sporophylls are arranged on straight axis. Gymnosperms are heterosporous, i.e., produce microspores and megaspores. There is alternation of generation, i.e., sporophytic and gametophytic generation. Polyembryony is of common occurrence, but finally a single em bryo matures.

Science Titbits

There are four groups of gymnosperms. Conifers, Cycads, Ginkgo and Gnetophytes. In gymnosperms, the seeds are not covered. Instead they are exposed on the surface of the sporophyll, leaves that bear sporangia. Reproductive organs are usually borne in the cones on which sporophylls are spirally arranged. Other than these features, the four groups of gymnosperms have little in common.

Uses of gymnosperms

Pine seeds like chilghoza are eaten as dry fruits. Ephedrine, a drug from *Ephedra* is used for the relief of asthma and other respiratory ailments. Conifers are a source of soft wood for construction, packing, plywood, board and for making paper. **Cycads** are grown as ornamental plants, a wild cycad, serves as a source of "sago". It is pure starch extracted in liquid state and then solidifies to form small granules. Resins, terpentine, tar and many oils are obtained from conifers.

Conifers: *Pinus* Cycas Ginkgo

Gnetophytes: (a) *Ephedra* (b) *Welwitschia*

Fig: 8.17: Gymnosperms

8.4.3 Angiosperms (enclosed seed plants)

Angiosperms are the flowering plants. Their seeds are enclosed by fruits. The leaves bearing ovules are folded and joined at the margins to form ovaries. The ovary after fertilization is changed into fruit. This is exceptionally a large and successful group of plants which is divided into Dicots and Monocots. They have common characters, like, vascular tissues, differentiated plant body, flowers, fruits, and seeds. The two groups may be differentiated as shown in table 8.1.

8.4.4 Life Cycle of a Flowering Plant

There is an alternation of generations in the flowering plants. The sporophyte, a diploid dominant generation alternates with haploid inconspicuous gametophytic generation.

The main plant body is diploid **sporophyte** which produces haploid spores. Flower is the reproductive structure which bears anthers and carpels as male and female reproductive parts respectively. The anther when fully developed contains 2 to 4 elongated sacs called **pollen sacs**. The pollen sacs contain pollen grains.

When the anther is developing, mitotic divisions produces **microspore mother cells**. Following meiosis in a diploid mother cell, four haploid microspores are produced. A **microspore** divides mitotically into a two celled, **pollen grain**. A tough wall develops around the pollen grain, which protects the contents of the pollen grain from drying out. Cells on the surface of the stigma secrete a sticky nutrient fluid containing sugar and other substances.

After pollination the pollen grains germinate on the stigma. Each pollen grain produces a slender, thin walled **pollen tube**. The pollen tube grows down, through the tissues of the stigma, style and ovary until it reaches the ovule.

As the pollen tube develops, the two nuclei of the pollen grain move into it. The two nuclei are called **generative nucleus** and the **pollen tube nucleus**. Generative nucleus divides again to form two somewhat elongated **sperms**. The tube nucleus is located near the tip of the pollen tube with two sperms following behind. The pollen tube, containing tube nucleus and the two sperms (male gametes), is the **male gametophyte**.

The **ovule** is an egg shaped structure attached by a stalk, to the inside of the ovary. Depending upon the species of the plant involved, an ovary may have one, two, several or even thousands of ovules. The ovule has an opening called **micropyle**. Megaspore mother cell of the ovule undergoes meiosis to produce four haploid cells. Only one of these cells survives. The surviving cell is called the **megaspore** which divides by mitosis three times to produce eight haploid nuclei. This structure is called **embryo sac.** Wall formation takes place and these nuclei are converted into cells. The cells of embryo sac are: antipodal cells, polar nuclei, synergids and egg. The embryo sac having these cells are called **female gametophyte**.

Antipodal cells are three in number and are present at the opposite end of the micropyle, and have no function and sooner or later get disorganized. **Synergids** are two in number at the micropyler end. These help in fertilization by guiding the pollen tube and as soon as their function is over these get disorganized. **Polar nuclei** are two in number, placed in the centre. By the time egg has been fertilized, the two polar nuclei have combined to form a single **fusion nucleus**.

Egg is one in number and is present between the two synergids. Soon after the tip of the pollen tube enters the embryo sac, the end of the tube ruptures and releases the two sperms into the embryo sac. The first sperm fuses with the egg to form a **zygote**.

The zygote develops into an embryonic plant within the ovule. The second sperm deposited in the embryo sac by the pollen tube moves to the centre and unites with the fusion nucleus. Union of one sperm with the egg and the second sperm with the fusion nucleus is called **double fertilization**. It only occurs in the flowering plants.

Formation of seeds and fruits

Zygote develops into an **embryonic plant** within the ovule. After fertilization fusion nucleus develops into an **endosperm**. It is **triploid**, i.e., consists of three sets of haploid

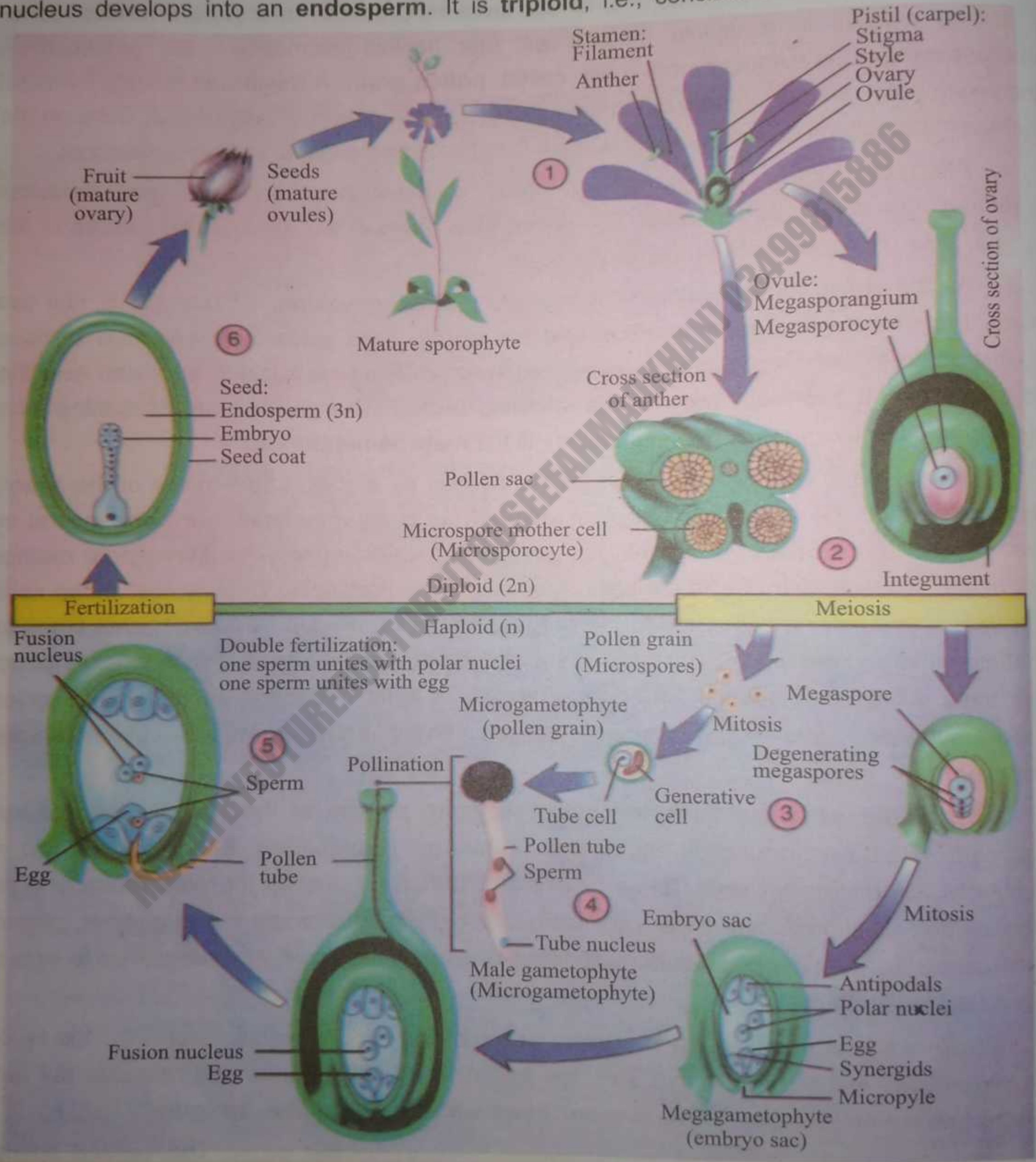


Fig 8.18: Life cycle of angiosperm

number of chromosomes, as two polar nuclei, and one sperm nucleus fuses to form it. Endosperm divides, enlarges and is used as store of food for the young embryo.

After double fertilization the formation of **embryo** and endosperm tissue takes place. As a result the ovule increases in size. The embryo consists of: (i) one or two cotyledons (ii) epicotyl (iii) hypocotyl. Both epicotyl and hypocotyl are the parts of the rod like axis attached to the cotyledons. In some plants cotyledons digest and absorb endosperm as the ovule is maturing into **seed**. The ovary wall enlarges and ripens to become the **fruit**.

Table 8.1: Differences between dicots and monocots

	Dicots	Monocots
LEAF	Broad, generally bifacial with reticulate venation	Long narrow, lanceolate, monoficial with parallel venation.
STEM	Vascular bundle in ring, vascular cambium is present which gives secondary growth.	Vascular bundles scattered vascular cambium usually absent so no secondary growth occurs.
ROOT	Primary root is a tap root which develops lateral root. 2-8 patches of xylem, vascular cambium present, secondary growth occurs.	Adventitious roots arise from the base of stem, and give rise to a fibrous root system. Always more than 8 patches of xylem. Vascular cambium absent so no secondary growth.
SEED	Embryo has two cotyledons.	It has one cotyledon.
FLOWER	Typically tetra or penta-merous calyx and corolla usually differ from each other. Flowers are usually insect pollinated.	Parts usually in three,i.e., trimerous. No distinction between calyx and corolla. Flowers are often air pollinated.
Example	Rose, pea, buttercup etc.	Lilies, orchids, grasses, wheat, rice.

Fig 8.19: Comparison: Monocots and Dicots

8.4.5 Angiosperms- Successful Land Plants

They have true roots, stems and leaves. The vascular tissue is well developed. **Xylem tissue** contains **xylem vessels** as well as **tracheids**. **Leaves** are generally broad, expanded blades and are very efficient in absorbing light for photosynthesis. Shedding of leaves during cold or dry spells is also an advantage for survival in harsh environment. **Angiosperms** are found in all types of habitats and some have even returned to water. The reproductive organs are the **flowers** which are modified for wind and insects pollination.

The life cycle demonstrates adaptations of angiosperms on land. Fertilization takes place through pollen tube independent of external water. Double fertilization increases reproductive success. Following fertilization the ovules located in ovaries develop into seed. An ovary wall is transformed into a fruit. Fruits provide protection for seeds and a mechanism for their wide dispersal.

8.4.6 Inflorescence

Flowers are borne either single or in clusters. A flower is said to be **solitary** when occurring singly, e.g., shoe flower.

Flowers borne in clusters along with the stem and associated whorls constitute **inflorescence**. Depending upon the arrangement of flowers, inflorescence is classified into

(a) Racemose (b) Cymose (c) Compound

Racemose Inflorescence

Here the main axis of inflorescence does not end in a flower but it continues to grow and give off flowers laterally. The basal flowers are older and upper are younger. e.g., *Brassica*.

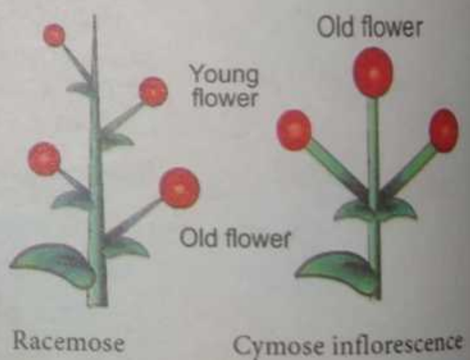


Fig: 8.20: Racemose and Cymose inflorescence

Cymose Inflorescence

Here the main axis terminates in a flower but the growth continues through the lateral buds. The flowers are arranged in basipetal succession, i.e., the basal flowers are younger and the upper flowers are older, e.g., *Dianthus* (pink).

Compound Inflorescence

In a compound inflorescence the main axis of the inflorescence branches repeatedly in racemose or cymose manner and the ultimate branches bear flowers in a racemose or cymose manner. Compound racemose, e.g., Amaltas (*Cassia fistula*), etc. Compound Spike, e.g., rice.

8.4.7 Significance of Angiosperms to Humans

Cereals constitute the staple food of man. Major cereals are wheat rice, maize, barley, oat, etc. **Pulses** are seeds of leguminous plants. These are rich in proteins. Common pulses are lentil, arhar, urd, pea, gram, green gram, soyabean, black gram. The main **vegetables** obtained from angiosperms include carrot, radish, cabbage, cauliflower, potato, tomato, okra (lady's fingers). The **fruits** are mango, apple, banana, guava, grapes, melon, mulberry, pears, etc. Nuts consumed as dry fruits are cashewnut, almonds, walnut, etc.

Edible oils used for cooking are obtained from groundnut, mustard, cotton seeds, coconut and sunflower. **Spices** include cinnamon, (dalchini), cloves, (laung), chillies, black pepper (kali mirch), caraway (zeera), coriander (dhania), fennel (saunf). Tea, Coffee and Cocoa are important **beverages** obtained from flowering plants. **Sugar** is obtained from sugarcane and beet roots. Many plants yield **fodder** for the cattle. Important fodder giving plants are barseem, senji, etc.

A large number of **drugs** are obtained from flowering plants. Some of the drugs are quinine, malathi, etc.

Important **timber** yielding plants are teak, sal, oak and sisso (sheeshum). Commercial cork is obtained from oak. Many plants provide us **fibres** for various uses. Textile fibres are obtained from cotton, rough fibres for making ropes and gunny bags are obtained from flax, hemp, etc. Jute fibres are used to make ropes, bags, carpets, and mats etc. The husk of fruits of coconut is used for making coir, brooms and duster etc. A large number of flowering plants are grown in gardens and houses as **ornamental plants**. Common among them are roses, petunias, etc.

Science, Technology and Society Connections

- Justify plants as a medical treasure.

Activity

1. Identification of the vegetative and reproductive structures of *Marchantia* and *Funaria* by examining the fresh or preserved material
2. Identification of the vegetative and reproductive structures of a local fern and a *Pinus* and relate them with the concerned life cycles
3. Study of different types of inflorescence of *Cassia, Brassica, Achyranthus, Morus,* Candytuft, *Helianthus* and *Avena sativa*
4. Describing the flowers of Rose, *Cassia fistula, Solanum nigrum* and *Avena sativa*

Exercise

MCQs

1. **Select the correct answer**

(i) Plants are thought to have descended from a common protistan ancestor ancient

(A) freshwater green algae (B) archaea

(C) cyanobacteria (D) brown alga

(ii) Gametophyte in bryophytes is
(A) haploid (B) diploid (C) triploid (D) pentaploid

(iii) Whisk ferns belong to the group
(A) pteropsida (B) lycopsida (C) psilopsida (D) annelida

(iv) Sago grains are obtained from
(A) cycas (B) pinus (C) moss (D) fern

(v) These are highly evolved of all the plants on the earth
(A) bryophytes (B) pteridophytes (C) gymnosperms (D) angiosperms

(vi) Moss plants develop from
(A) oospore (B) protonema (C) antherozoids (D) diploid spores

(vii) Fern plant is
(A) diploid sporophyte (B) diploid gametophyte
(C) haploid sporophyte (D) haploid gametohyte

(viii) Gymnosperms are characterised by
(A) multiflagellate sperms (B) naked seeds
(C) winged seeds (D) seeds inside fruits

(ix) Where a female gametophyte is present in an angiosperm?
(A) in the style of a flower (B) within an ovule
(C) in the stigma of a flower (D) packed into pollen sacs

(x) Gametophyte generation is dominant in
(A) pteridophytes (B) gymnosperms
(C) bryophytes (D) angiospersms

Short Questions

2. What are the features shared by algae and plants?
3. What are the features shared by the green algae 'Charophyceans' and plants?
4. What are the diagnostic features shared by all plants.
5. What is alternation of generation? Write its importance.
6. Why bryophytes are called 'amphibious plants'.
7. Write the main four features of bryophytes?
8. Name the land adaptation features of bryophytes.
9. What is the importance of bryophytes?
10. Write the features of seedless vascular plants.
11. Describe the development of heterospory.
12. What is the importance of seedless vascular plants.

13. Write the features of vascular plants.
14. Describe the evolution of pollen tube.
15. What is the importance of pollen tube?
16. What are the uses of gymnosperms?
17. What are angiosperms?
18. What is the advantage of the seed?
19. Describe the three types of inflorescence with examples.
20. Give one example of: Whisk ferns, club mosses, horsetails and ferns.
21. Write the differences between:
    (a) gametophyte and sporophyte
    (b) antheridium and archegonium
    (c) monoecious and dioecious
    (d) mosses and liverworts
    (e) roots and rhizoids
    (f) homosporous and heterosporous
    (g) angiosperms and gymnosperms
    (h) generative nucleus and pollen tube nucleus
    (i) antipodal cells and synergids
    (j) diploid and triploid
    (k) racemose inflorescence and cymose inflorescence

Extensive Questions

22. Describe the general characteristics of bryophytes.
23. Describe the life cycle of moss with diagram.
24. Give a brief account of: (a) Psilopsida (b) Lycopsida (c) Sphenopsida (d) Pteropsida with examples.
25. Describe evolution of leaf.
26. Describe the life cycle of fern (*Adiantum*)
27. Give an account of vascular plants as successful land plants.
28. Give an account of gymnosperms.
29. Describe the life cycle of a flowering plant and how it demonstrates an adaptation of angiosperms on land.
30. Discuss significance of angiosperms to humans.

9

DIVERSITY AMONG ANIMALS

After completing this lesson, you will be able to

- Describe the general characteristics of animals.
- Classify animals on the base of presence and absence of tissues.
- Differentiate the diploblastic and triploblastic levels of organization.
- Describe the types of symmetry found in animals.
- Differentiate pseduocoelomates, acoelomates and coelomates.
- Classify coelomates into protostomes and deuterostomes.
- Describe the general characteristics, importance and examples of sponges, cnidarians, platyhelminths, aschelminths (nematodes), mollusks, annelids, arthropods and echinoderms.
- 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.

The name animalia is derived from Latin word *anima* meaning breath or soul. All the animals of the world are included in the kingdom animalia. Now the question arises, what is an animal? How can we define an animal? In this chapter we will learn about the animal kingdom. We will go through the general characteristics of different groups of animals, criteria for animal classification and will have an introduction to animal diversity.

9.1 CHARACTERISTICS OF ANIMALS

Animals are found almost in all types of habitat. They may be free living motile, sessile or a parasite. They range in **size** from worms only seen with a microscope to blue whales. Animals are eukaryotic, multicellular, ingestive heterotrophs that lack cell walls.

9.2 CRITERIA FOR ANIMAL CLASSIFICATION

Animals can be classified according to (a) presence or absence of tissue (b) number of tissue layers (c) body symmetry (d) types of body cavity.

9.2.1 Classification based upon organization of tissues

Animals can be classified according to the **organization of tissues** into two subkingdoms: **Parazoa** and **Eumetazoa**. Parazoa includes the simplest multicellular animals that lack tissue organization but show division of labour. They are asymmetrical. It includes all the sponges.

In **Eumetazoa** – similar cells are grouped together into a highly coordinated unit called **tissue**. The tissues are assembled into larger functional unit called **organs**. Different organs operate together as **organ system.**

9.2.2 Classification based upon number of tissue layers

Animals can be classified according to **number of tissue layers** as diploblastic and triploblastic animals. The body of **diploblastic animals** consists of two germ layers of cells, the **ectoderm** and **endoderm**. Such animals have tissue level of organization. There is a jelly like **mesoglea**, between the two germ layers. There are no specialized organs. A neuron net is present. There is only one cavity called **gastrovascular cavity** with only one opening. The examples are animals of phylum cnidaria.

The body of the **triploblastic animals** consists of three germ layers ectoderm, mesoderm and endoderm. After embryonic development these layers in most triploblastic animals are not distinct as separate layers of cells, but are represented by the structures formed from them. The animals have specialized cells, organs and organ systems.

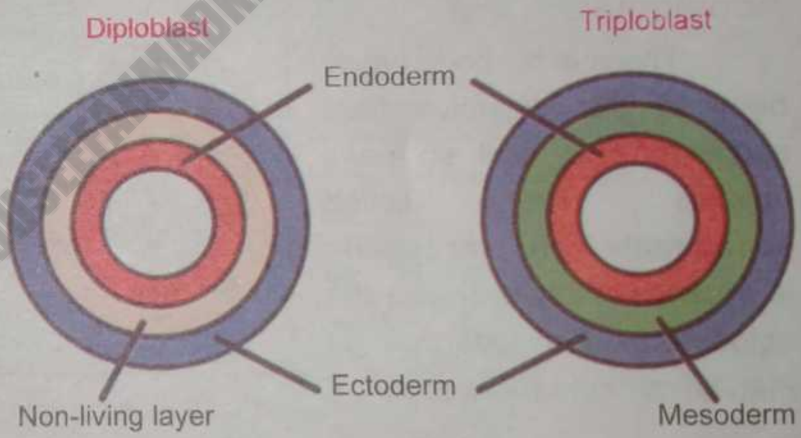


Fig. 9.1 Diploblastic and triploblastic level of organization

9.2.3 Classification based upon type of body symmetry

Animals can be classified according to **body symmetry**. The subkingdoms Eumetazoa are divided into: grade Radiata and grade Bilateria.

Grade Radiata

It includes all the animals with **radial symmetry** having a top and bottom and similar body parts are arranged as spokes or radiate from a central body axis, e.g., Jelly fish, sea anemone. Radial symmetry is considered an adaptation for a sessile life.

Grade Bilateria

In **bilateral symmetry**, a plane through the midline of the body divides it into roughly equivalent right and left halves that are mirror image. The front or anterior end of the animal generally has a head. The posterior or rear end of the animal may be equipped with a tail.

There are well defined dorsal and ventral surfaces. In Echinoderms the larval stages show bilateral symmetry and the adult secondarily develops radial symmetry. All the animals included in grade Bilateria are triploblastic. Bilateral symmetry is considered an adaptation to motility.

Fig: 9.2: Radial symmetry

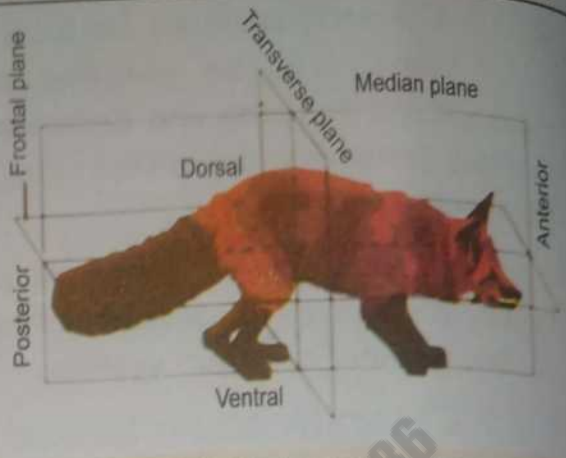


Fig: 9.3: Bilateral symmetry

9.2.4 Classification based upon type of body cavity

Animals can be grouped according to **type of body cavity or coelom**, a fluid filled space between the outer body wall and the digestive tube.

Acoelomate

There is no body cavity between the digestive tract and outer body wall, so these animals are called **acoelomate**. The mesoderm is packed solidly between the ectoderm and endoderm, e.g., Platyhelminthes (flatworm)

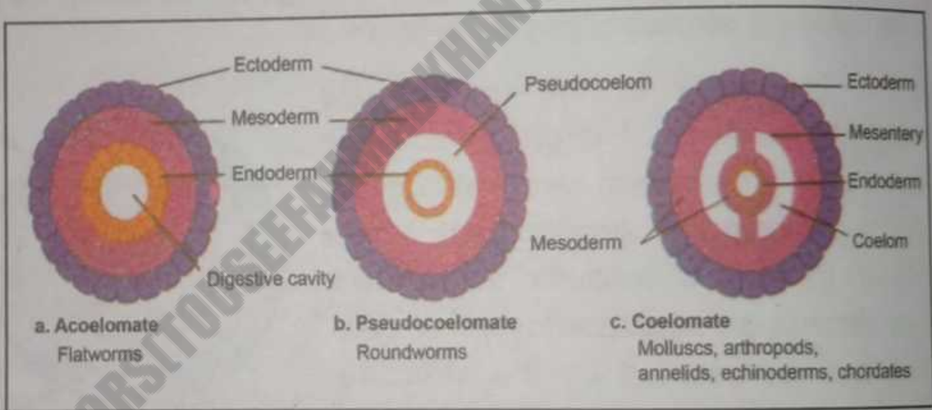


Fig: 9.4: Acoelomate, pseudocoelomate, and coelomate comparison

Pseudocoelomates

If the body cavity develops between the mesoderm and endoderm it is called pseudocoelom (false cavity). Animals with this type of body cavity are called **pseudocoelomates**, e.g., Aschelminthes (nematodes).

Coelomate

If the body cavity forms within the mesoderm and is completely lined by mesoderm the body cavity is a **true coelom**. It is filled with coelomic fluid. Animals with a true coelom are called **coelomate**. Animals from annelids to chordates are coelomate.

Coelomate can be divided into two groups: **protostomes** and **deuterostomes**. These groups reflect two main line of evolution based on their pattern of early development. Early during development, the embryo consists of a little ball of cells known as **blastula**. A group of cells move inward to form an opening called the **blastopore**. In most of the molluscs, annelids and arthropods, this opening develops into the mouth. These animals are **protostomes** (from Greek words meaning "first, the mouth").

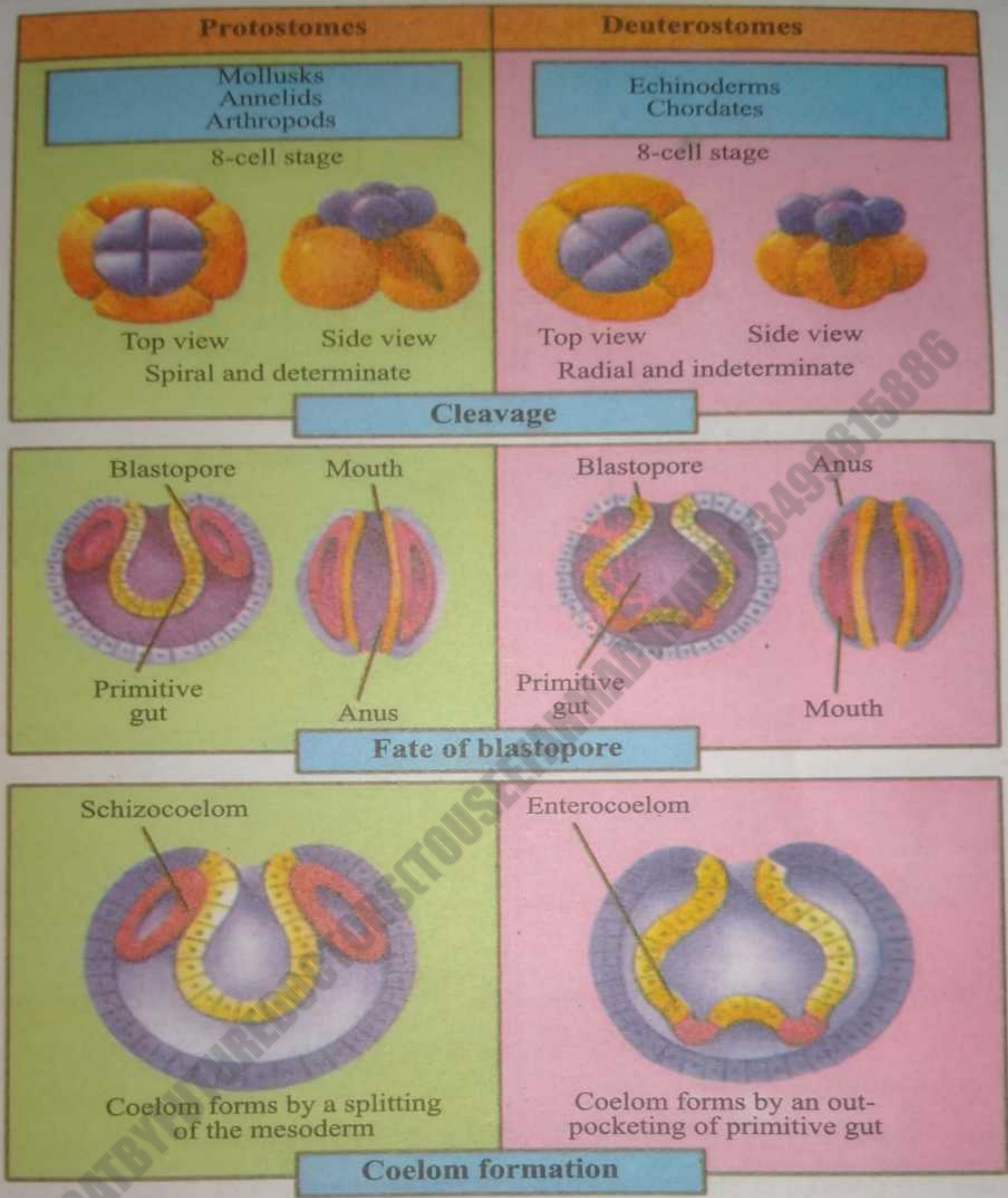


Fig: 9.5: Protostomes versus deuterostomes

In echinoderms (for example, sea stars and sea urchins) and chordates (the phylum that includes the vertebrates), the blastopore does not give rise to the mouth. Instead it generally develops into the anus. The opening that develops into the mouth forms later in development. These animals are the **deuterostomes** ("second, the mouth").

DID YOU KNOW?

Bioinformatics is an interdisciplinary field that develops methods and software tools for understanding biological data. As an interdisciplinary field of science, bioinformatics combines computer science, statistics, mathematics, and engineering to analyze and interpret biological data. Bioinformatics has been used for in silicon analyses of biological queries using mathematical and statistical techniques.

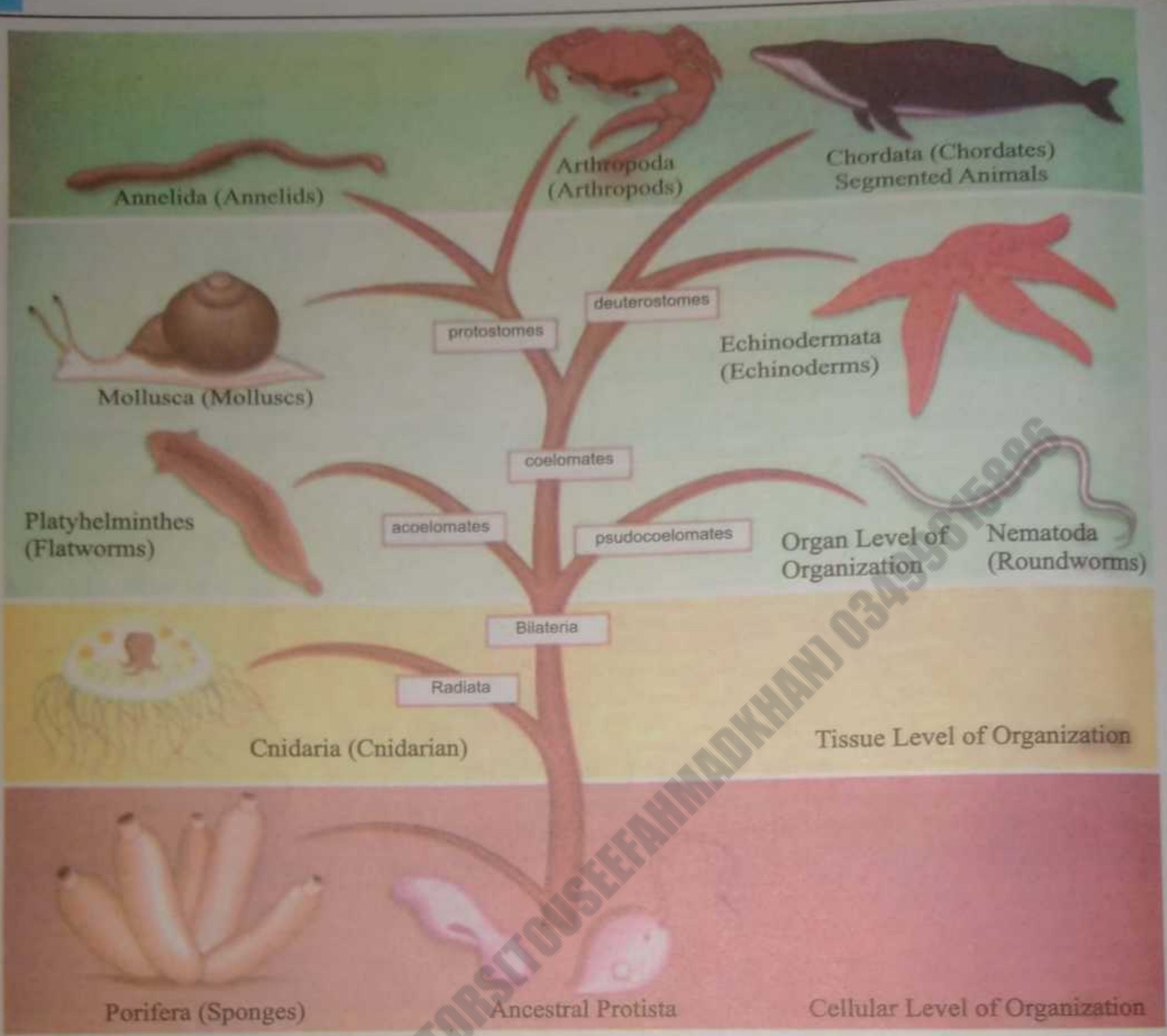


Fig: 9.6: Phylogenetic tree of the animal kingdom

9.3 DIVERSITY IN ANIMALS

Animals are diverse in structure. There is the vast differences in structural complexity of organisms ranging from the simplest sponges to humans.

9.3.1 Invertebrates

The animal species that lack a backbone are commonly known as **invertebrates**. Invertebrates account for 95% of known animal species. The invertebrates have been divided into eight major phyla: porifera, cnidaria, platyhelminthes, aschelminthes, mollusca, annelida, arthropoda, echinodermata.

1. PHYLUM PORIFERA (pore bearer)

General characteristics of phylum porifera: Sponges are sessile, attached to the rocks at the bottom of water. Larvae are motile. Sponges are all aquatic, mostly marine, some found in freshwater. They range in size from a few millimetre wide to more than a metre long.

Body is multicellular and not organized as tissue or organs. Body lacks symmetry. The sponges consist of outer dermal layer called **pinacoderm**, and inner layer **choanoderm** made of flagellated cells called **choanocytes**. The middle region is called **mesenchyme**. Body is perforated by many pores called **ostia**. There is a single cavity inside the body called **spongocoel**. Water enters through ostia travels through the canal and goes out by a large main opening called **osculum**. Sponges depend on food coming along with water currents. Various shapes of spicules form the skeleton. These are needle like and may be calcarious or siliceous. The bath sponge has spongin fibre.

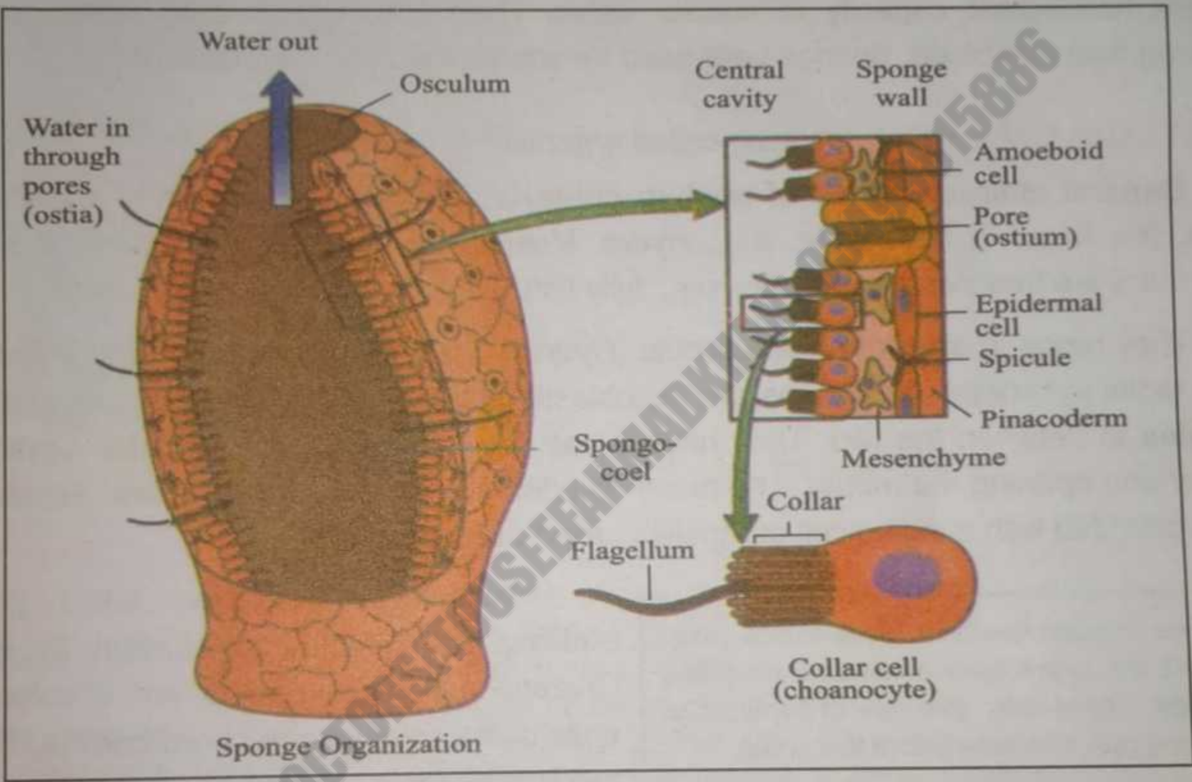


Fig: 9.7: Generalized sponge anatomy

Asexual reproduction takes place by budding or **gemmules**. Buds develop into new sponges. Sexual reproduction takes place by egg and sperm. Sexes may be separate or hermaphrodite. The embryo development includes free swimming ciliated larval stages.

Sponges have remarkable ability of **regeneration** from a small fragment. Sponges have evolved from the protists called choanoflagellates. The examples of Sponges are: *Spongilla Sycon*, etc.

Spongilla *Sycon*

Fig: 9.8: Examples of sponges

Evolutionary adaptations in sponges:
(1) Digestion: It is completely intracellular and occurs in food vacuoles within choanocytes. All the cells of the dermal and gastral layers are in contact with

water. **(2) Respiration:** There are no special organelles for respiration. **(3) Transportation:** It takes place through water current and diffusion. The water current system has greatly enlarged area for the feeding and gaseous exchange. **(4) Excretion:** It takes place through diffusion and outgoing water-current. **(5) Nervous system:** A sponge lacks nervous system. Sensory cells probably seem to coordinate the flow of water. Sponges seem to represent a dead end in evolution.

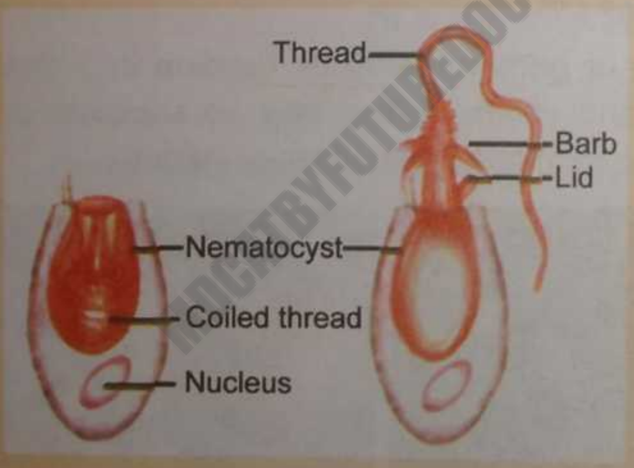
Importance of sponges: Skeleton of sponges are used for washing and bathing. Sponges have great capacity to absorb water. They are used in surgical operations for absorbing fluid and blood. Sponges are used for sound absorption in buildings.

2. PHYLUM CNIDARIA (stinging celled organisms)

General characteristics of phylum cnidaria: Cnidarians are entirely aquatic, mainly marine, few found in freshwater, e.g., *Hydra*. Most of the species are sessile, e.g., *Hydra*, while others are free living and motile e.g., Jelly fish. Some are colonial e.g., *Obelia*.

They range in size from microscopic (*Hydra*) to two metres in length (**jelly fish**). Body shows radial symmetry. Cnidarians are diploblastic animals having ectoderm, endoderm and **mesoglea** in between the two. They have a sac like internal **gastrovascular cavity**, which has only one opening the mouth. The mouth is often surrounded by **tentacles**. Tentacles and body is provided with stinging cell organelles called **nematocysts**.

The name Cnidaria has been given to this group of animals due to presence of special cells called cnidocytes. These cells give rise to nematocyst the stinging cells characteristic of this group.



Asexual reproduction takes place by budding and sexual reproduction by gametes. Cnidarians also occur in the form of colonies. The units of the colonies are called **zooids**. There are two main types of zooids. **Polyps** which are feeding zooids and **Medusae** are reproductive zooids, for sexual reproduction.

Evolutionary adaptations in cnidarians:

(1) Digestion: Gastrovascular cavity is often branched or divided with septa with a single opening. **(2) Transportation and excretion:** Takes place through diffusion (3) **Respiration and Excretion**: There is no respiratory and excretory system (4) **Nervous system**: Nervous system consists of nerve net and some sense organs.

Importance of cnidarians: Coral reefs protect shores from erosion by tidal waves. Corals are used in jewellery and others are used in aquaria, rock gardens etc. Some cnidarians have poisonous stings e.g., jelly fish and sea anemone.

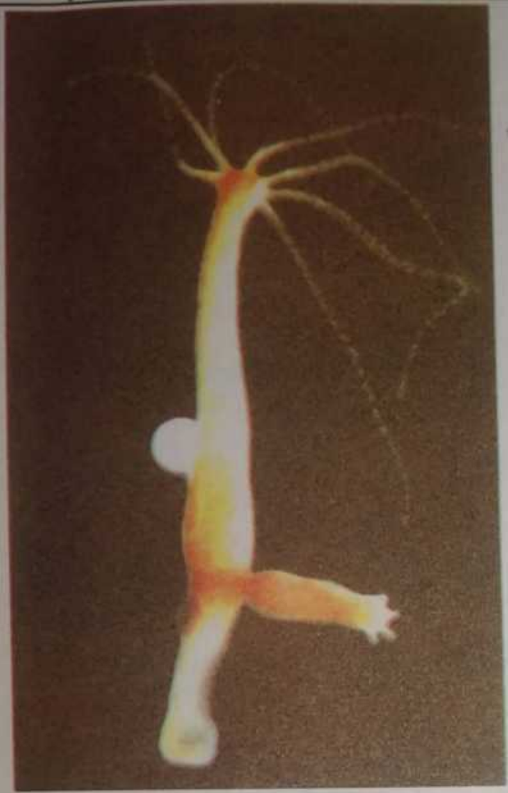


Fig: 9.9: *Hydra*

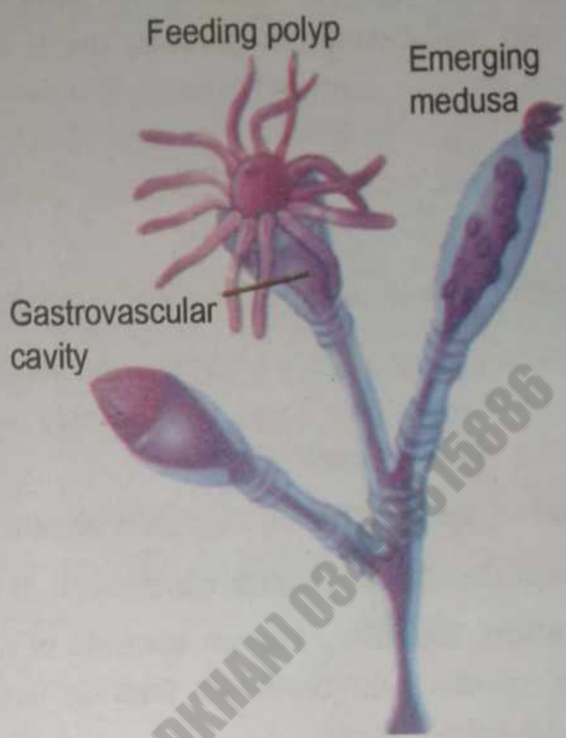


Fig: 9.10: *Obelia*

Coral Reefs (Extra reading material)

Corals are cnidarians. It is made of $CaCO_3$. The ectodermal cells of the corals take lime from the sea water and form their exoskeleton. These exoskeleton form coral reefs and even island. Coral reefs are found in the coastal water of Florida, West Indies, East coast of Africa, Australia and Island of Coral Sea.

Polymorphism (Extra reading material)

Coelenterate animals may show a number of zooids. They are of different forms. They take up different functions. This is called polymorphism. Polymorphism denotes division of labour among the zooids of the individual. A polymorphic colony contains many individuals called zooids. They are mainly two types: (1) Medusae (2) Polyps. Polyp is sedentary. It shows mouth and tentacles at the free end. The medusa is free swarming. It is represented by polyp form. It performs all functions. *Obelia* like animals Show two forms, polyp nutritive zooid and medusa reproductive zooid. This is called dimorphic organism. In a colony of Obelia three types of zooids are present: (1) Hydranth (a Polyp stage), (2) Blastostyle (asexually, reproducing zooid). (3) Medusae are present.

3. PHYLUM PLATYH ELMINTHES (flatworms)

General characteristics of phylum platyhelminthes: The flatworms are free living, e.g., *Planaria*, or parasite, e.g., Tapeworm. They are found in freshwater, marine, animal gut, liver. Body is soft and flattened dorsiventrally. Platyhelminthes are triploblastic and exhibits a bilateral symmetry. Coelom is absent, and the spaces are filled with mesenchyme tissue.

Eyespots are present in some flatworms. Free living forms are motile. They move by cilia present on the underside of the animals, e.g., *Planaria*. In parasitic forms movement is restricted. Reproduction takes places both by asexual and sexual means. Asexual reproduction is by fission. Most forms are monoecious.

The reproductive system is complex, usually with well-developed gonads, ducts and accessory organs. The fertilization is internal. The examples of flatworms are: *Dugesia* (planaria), *Fasciola* (liver fluke), *Taenia* (tapeworm).

Evolutionary adaptations in Platyhelminthes:

(1) Digestion: Digestive system is incomplete i.e., gastrovascular type, having only one opening to the exterior, the mouth.

(2) Respiration: Respiratory system is absent.

(3) Transport: Transport system is absent.

(4) Excretion: Excretory system consists of two lateral canals with branches bearing flame cells (protonephridia).

(5) Nervous system: Nervous system consists of a pair of anterior ganglia with longitudinal nerve cord.

Importance of platyhelminthes: The parasitic forms of flukes and tapeworms are very harmful for man, e.g., tapeworm, liver fluke, the blood fluke of cattle etc.

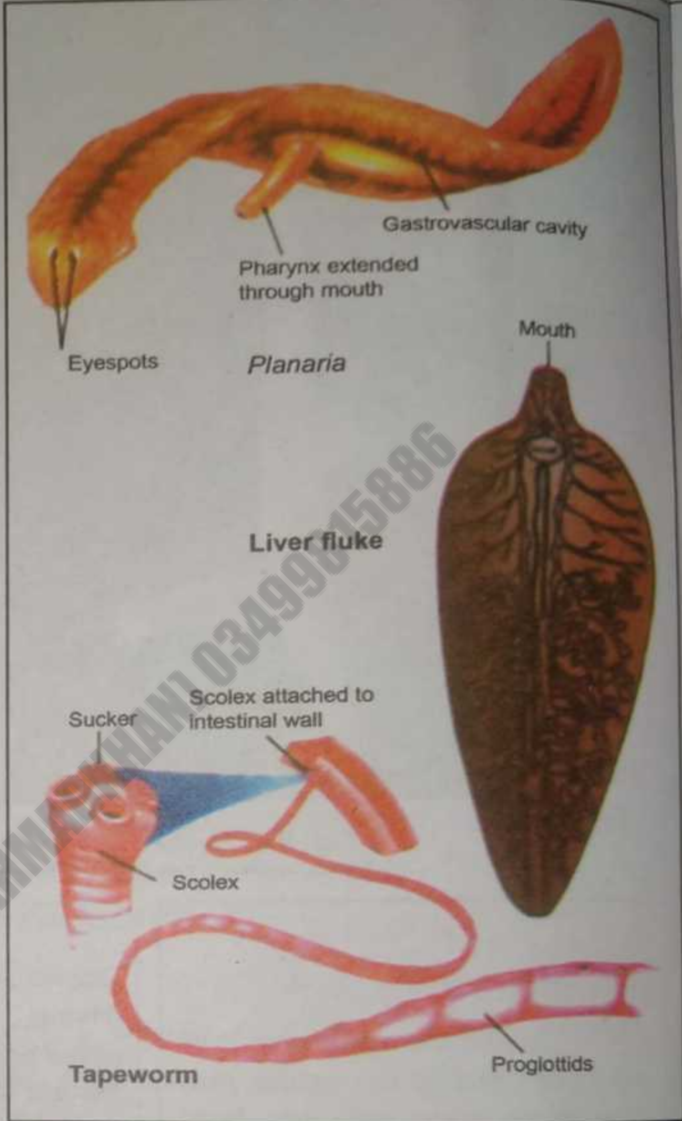


Fig: 9.11: Flatworms

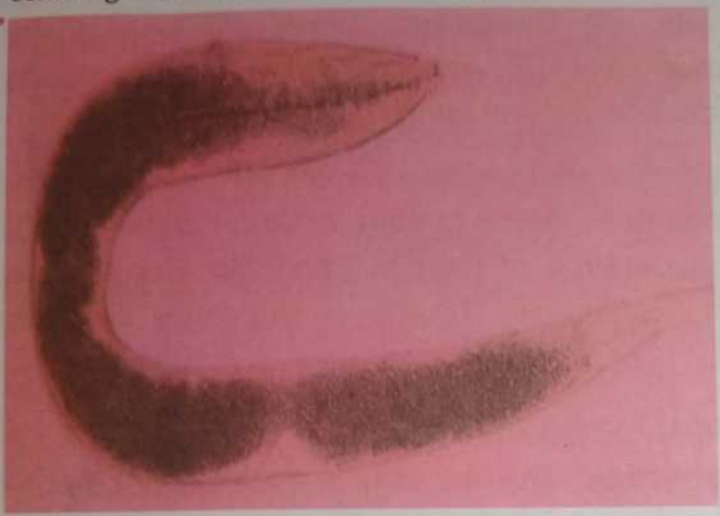
4. PHYLUM ASCHELMINTHES (roundworms) / NEMATODA

General characteristics of phylum aschelminthes: The roundworms are free living or parasites, and live in soil, roots, human and animal intestine and muscles. Most roundworms are less than five cm long and many are microscopic but some parasitic roundworms are more than one metre in length.

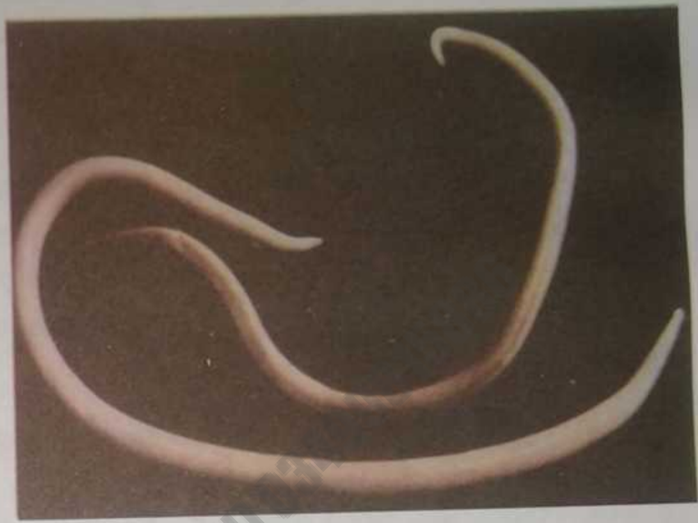
The worms exhibit bilateral symmetry, having three germ layers. Body is cylindrical, tapering at both ends. Muscular layer is not continuous. It is divided into four longitudinal quadrants: two - dorsolateral, two - ventrolateral. The body cavity is pseudocoelom. Most nematodes are dioecious. Fertilization is internal.

Evolutionary adaptations in aschelminthes: (1) Digestion: Digestive system is complete. Digestive tract is a straight tube with mouth and anus at opposite ends of the body. **(2) Respiration:** Respiratory organs are absent. **(3) Transport:** Circulatory organs are absent. **(4) Excretion:** Excretory system consists of canals and protonephridia. **(5) Nervous system:** It consists of a ring of nerve tissue and ganglia around the pharynx with longitudinal nerve cords connected by transverse nerves.

Importance of aschelminthes: *Ascaris lumbricoides* is an intestinal parasite of man. Pinworms (*Enterobius vermicularis*) are parasites in the human caecum, colon and appendix causing insomnia and loss of appetite.



Pinworms *Enterobius vermicularis* (Female)



Ascaris

Fig: 9.12: Nematodes

5. PHYLUM MOLLUSCA (soft bodied animals)

General characteristics of phylum mollusca: They are free living or sessile, and live in freshwater, marine and land (in moist places). The molluscs exhibit bilateral symmetry, are triploblastic, coelomate, soft and unsegmented animals. Body is divided into; head ventral muscular foot dorsal visceral region. The whole animal is covered in an envelope called **mantle**. It secretes the shell. The shell may be external (snail), internal (cuttle fish) or even absent (octopus). Mouth cavity may have a tongue like structure called **radula**, e.g., Cuttle fish, snail. Coelom is divided into sinuses. Sexes may be separate, e.g., *Unio* or united, e.g., *Helix*. The development takes place through **trochophore larvae**.

The examples of molluscs are snail, slug, Oyster, freshwater mussel and Octopus etc.

Snail

Freshwater Mussel

Fig. 9.13: Molluscs

Evolutionary adaptations in molluscs: (1) Digestion: Digestive system is complex having rasping organ radula and anus usually emptying into mantle cavity.**(2) Respiration**: Gaseous exchange takes place by gills, lungs mantle or body surface.**(3) Transport**: Open circulatory system consists of heart and blood vessels. **(4) Excretion**: There are one or two metanephridia, which open into the pericardial cavity.**(5) Nervous system**: The nervous system consists of paired cerebral, pleural, pedal and visceral ganglia with nerve cord.

Economic importance of molluscs: Shell of freshwater mussels are used in button industry. Shells are also used for making ornaments. Some oysters make valuable pearls, e.g., pearl oyster. Clams, oyster, mussels are source of food in Far East, Europe, and America. Slugs are injurious in garden and cultivation. Toredo a shipworm damages wooden parts in ships.

6. PHYLUM ANNELIDA (segmented worms)

General characteristics of phylum annelida: The annelids are called segmented worms. They are free living (Earthworm) or ectoparasite (leech). They are found in soil, freshwater and marine e.g., *Nereis*. Body is metamerically segmented. Coelom is a true

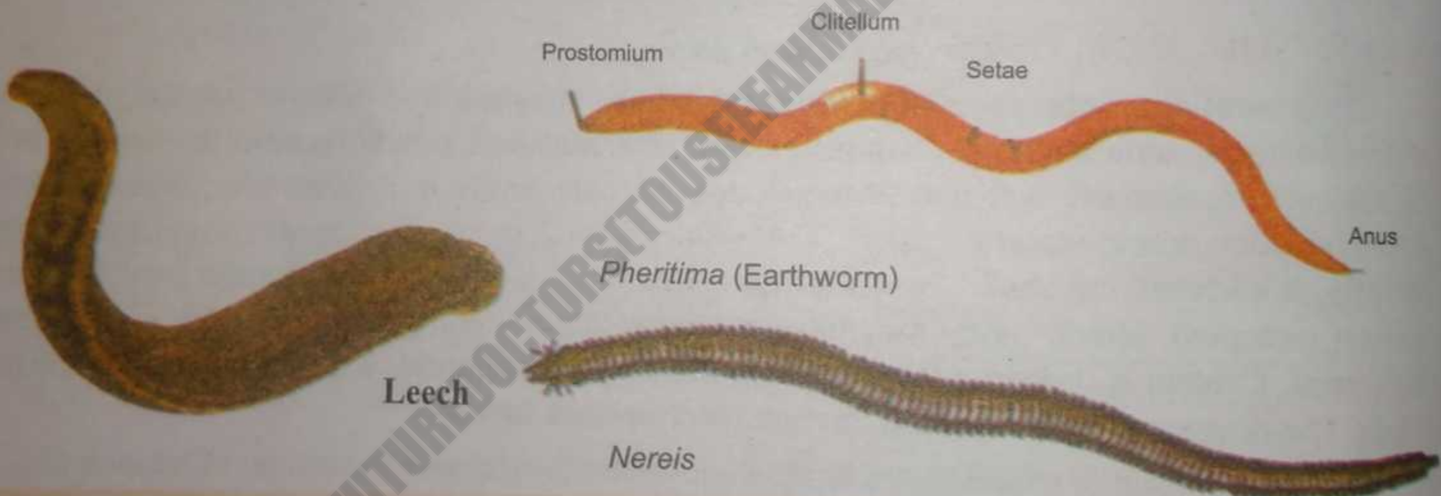


Fig: 9.14: Annelids

coelom. It is separated into compartments. The coelomic fluid of the adjacent chamber is mixed. The coelomic fluid serves as a hydrostatic skeleton also. The body wall contains circular and longitudinal muscles which help in locomotion. The organs of locomotion are chitinous **chaetae** or **setae**. **Parapodia** is present in the body wall of *Nereis*. The common mode of reproduction is sexual. Most of the annelids are hermaphrodite e.g., earthworm, leech. Sexes are separate in some annelids, e.g., *Nereis*. Fertilization is external. Development is direct or indirect through **trochophore larvae**. Regeneration is common in annelids. The examples of annelids are *Nereis*, *Pheritima* (Earthworm), *Hirudo* (Leech).

Evolutionary adaptations in annelids: (1) Digestion: Digestive system is in the form of an alimentary canal. It extends throughout the body. It has two openings the mouth and the anus. The mouth is surrounded by prostomium. **(2) Respiration**: Respiratory system is absent and respiration takes place through the moist skin. **(3) Transport**: Annelids are the first group in the animal kingdom having definite closed blood vascular system which runs throughout the body. **(4) Excretion**: Excretion takes place by nephridia. These are ciliated organs present in each segment. **(5) Nervous system**: Central nervous system is present, which extends throughout the body.

Economic importance of annelids: Polychaetes form an important food item for many edible fish. Earthworms help in soil improvement. Leech is an ectoparsite to man and cattle.

7. PHYLUM ARTHROPODA (animals with jointed legs)

General characteristics of phylum arthropoda: The arthropods are called joint footed animals. They are free living or parasites and are found in all types of habitat. The body is segmented. Some are worm like and others are flying insects. Segments are modified, specialized and fused. Symmetry is bilateral; head, thorax and abdomen variously distinct or fused. Body is covered by **chitin**. It is flexible at many places to allow articulation.

> **Science Titbits**
> **Origin of Arthropods**: It is believed that the arthropods and annelids have a common origin, as both have appendages, a segmented body and cuticle.

> **Science Titbits**
> What are the secrets of insect success? The body plan is modified and specialized in so many ways that insects have been able to adapt to a number of life styles. They have ability to fly. Protective mechanisms include: body is covered by cutin, mimicry, protective colouration and aggressive behaviour. The larvae and pupae do not have to compete with adults for food or habitats.

There are several pairs of appendages. Coelom is not present as the main body cavity. It is reduced and is called **haemocoel**, because it is connected with the blood vascular system. Alimentary canal has two openings, the mouth and anus.

Skeleton is exoskeleton, formed chiefly of chitin. Muscles are attached to exoskeleton for locomotion. Sexes are separate in arthropods. The male and female arthropods are often unlike. The reproductive organs and ducts are paired. The testes produce sperms and ovaries produce eggs. Fertilization is mostly internal. Development takes place through **metamorphosis**.

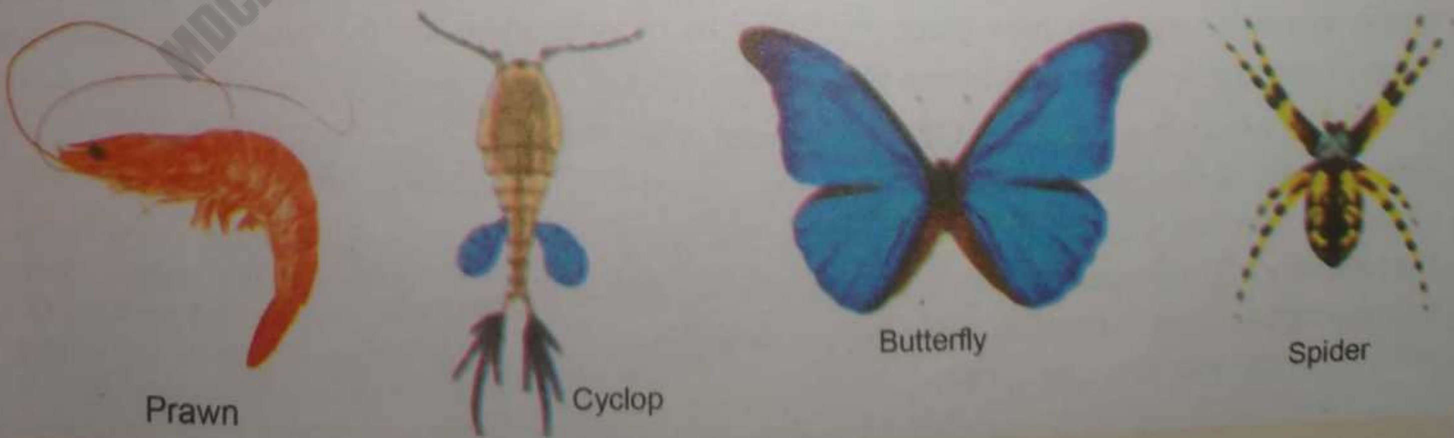


Fig: 9.15: Arthropods

Evolutionary adaptations in arthropods: (1) Digestion: Digestive system is complete, mouthparts modified from appendages and adapted for different methods of feeding. **(2) Respiration**: In insects respiratory system consists of air tubes called trachea. Spiracles are the openings of the main tubes to the exterior. Arthropods have a variety of respiratory organs. Aquatic forms have gills. Terrestrial forms have book lungs (e.g. spiders) or air tubes called trachea. **(3) Transport**: Circulatory system consists of dorsal contractile heart (blood sinuses). **(4) Excretion**: In insects the excretory organs are called Malpighian tubules, and the nitrogenous wastes are excreted in the form of solid uric acid. **(5) Nervous system**: Nervous system is highly developed. There is a brain and a ventral double nerve cord. There is a ganglion in each segment from which nerves arise.

Economic importance of arthropods: Lobsters, crayfish and prawns are eaten. Some crustaceans act as intermediate hosts for human parasites, e.g., Cyclops carry larvae of a nematode, the Guinea worm. Honey and bee's wax are produced by the honeybee and silk by silkworms. Insects aid in the production of fruits, seeds and vegetables by pollinating the flowers. Fruit fly (*Drosophila*), cockroach, grasshopper are abundantly used as laboratory animals for scientific learning and research. **Insects** destroy field crops, fruit trees and timber plants. They spread diseases among human beings. Bees and wasp's sting, mosquitoes, lice and fleas bite and suck blood. Scorpions and a few spiders are poisonous and sting.

8. PHYLUM ECHINODERMATA (spiny skinned animals)

General characteristics of phylum echinodermata: They are free living; some are attached to the substratum. The echinoderms are exclusively marine. Most are found at the bottom along the shorelines in shallow seas.

Body is covered by delicate epidermis. The echinoderms are triploblastic coelomates and exhibit radial symmetry in adult. Echinoderms have an endoskeleton consisting of a spine bearing calcium rich plates. The spines, which stick out through the delicate skin, account for their name. The mouth is on the oral side and anus is on the aboral side. There is a central disc from which arms radiate. The body may be flattened like biscuit, (cake urchin), star-shaped with short arm (starfish) globular (sea urchin), star-shaped with long arms (brittle star) or elongated (sea cucumber). **Coelom** consists of canals and spaces, and one of which forms **water vascular system** (see glossary). Organs of locomotion are the **tube feet**. These are present along the edges of grooves present in the arms.

The sexes are separate. The fertilization is external. The larvae such as **bipinnaria** and **brachiolaria** are complex and exhibit bilateral symmetry, autotomy and regeneration. The regeneration is shown by the adult and larval stages. The examples are starfish, sea cucumber, sea lily, brittle star and sea urchin.

> **Science Titbits**
>
> Echinoderms show close resemblance with chordates. Both: (1) have mesodermal skeleton. (2) are deuterostomous, (3) have similar early development. That is why echinoderms have been placed closest to phylum chordata.

Evolutionary adaptations in echinoderms: (1) Digestion: Digestive system is usually complete, axial or coiled anus is absent in ophiuroids. (2) **Respiration**: Respiration is performed by dermal branchiae, tube feet, respiratory tree e.g., sea cucumber and bursae e.g., spiny brittle star. (3) **Transport**: Blood vascular system is much reduced. (4) **Excretion**: Excretory organs are absent. (5) **Nervous system**: Nervous system includes a circumoral nerve rig and radial nerve-cords. There is no brain.

Economic importance of echinoderms: Many echinoderms are used as food. Dried skeleton of echinoderms are used as fertilizer because of their high percentage of calcium and nitrogen. Starfishes act as scavengers and thus clean seawater. They cause damage to oyster beds. The stinging sea urchins are poisonous.

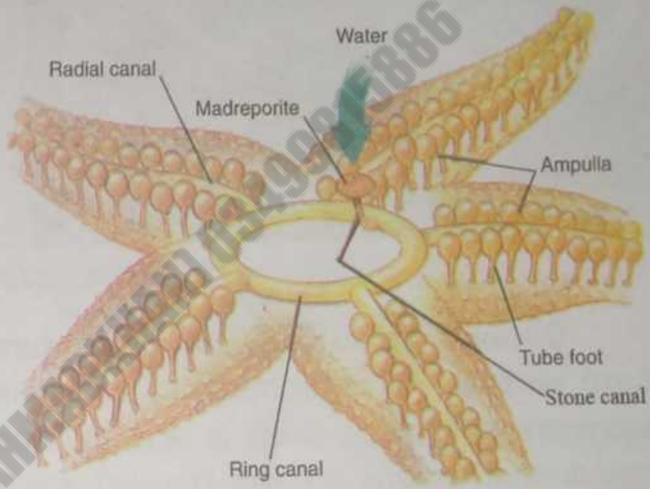


Fig: 9.16 (a): Echinoderm: Star fish and water vascular system

Cake urchin

Sea urchin (spines removed)

Sea urchin (with spines)

Sea cucumber

Brittle star

Fig: 9.16 (b): Echinoderms

9. PHYLUM HEMICHORDATA (acorn worm)

They show characteristics of both echinoderms and chordates and both phyla belong to the group deuterostome branch of animal kingdom. Hemichordates are also called **prochordates** because of their close relationship to chordates. Examples: *Balanoglossus*, *Saccoglossus*.

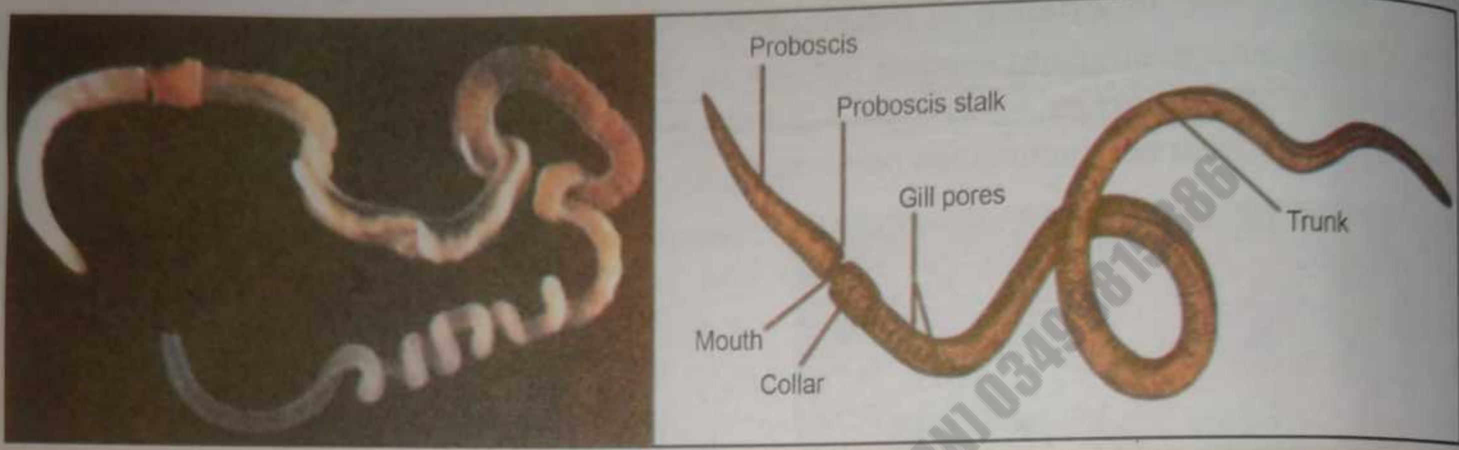


Fig: 9.17: *Saccoglossus and Balanoglossus*

General characteristics of phylum hemichordata: The hemichordates are called **acorn worms**. All hemichordates are marine. Some are solitary, naked and slow moving, others are sedentary. Body is soft and unsegmented and has a worm like form. Body has three distinct regions: proboscis, collar and trunk.

Symmetry is bilateral and hemichordates are **triploblastic**. Body cavity is a **true coelom**. Excretory system comprises of a glomerulus situated in the proboscis and connected with blood vessels. There are no nephridia. Sexes may be separate or united. Fertilization is external. Development may include free swimming larval stage.

Evolutionary adaptations in hemichordates: (1) Respiration: It occurs by gill slits connecting the pharynx with outside as in chordates. **(2) Circulatory system:** It includes a dorsal heart and two longitudinal vessels, a dorsal and a ventral, interconnected by small lateral vessels. Blood is colourless and without corpuscles. **(3) Nervous system**: It is diffused, consisting of an epidermal plexus of nerve cells and nerve fibres.

10. PHYLUM CHORDATA

The representatives of the phylum chordata called the chordates, are the most familiar, adaptable and successful and the most widely distributed animals, showing diversity of form, habitat and habits.

Characteristics of Chordates

All the chordates possess four basic characteristics, which are: (a) notochord (b) dorsal hollow nervous system (c) gill slits (d) post anal tail.

Notochord: The notochord is a solid unjointed rod located in the mid-dorsal line between the gut and the central nervous system outside the coelom. The notochord serves as an axial endoskeleton, giving support to the body and providing space for muscle attachment.

In some lower chordates the notochord persists throughout life, but in higher chordates it is partly or wholly replaced in the adult stage by a jointed backbone or vertebral column.

Dorsal Hollow Central Nervous System: The central nervous system of all the chordates consists of a single, tubular fluid filled, nongangliated nerve cord, situated along the mid dorsal line above the notochord and outside the coelom.

Gill Slits: The gill slits (pharyngeal pouches) are paired perforations on the lateral sides of the anterior part of the body, leading from the pharynx to exterior.

Post anal tail: It extends beyond anus; present at least in embryo; regresses (passage back, reversion) into tail bone in humans.

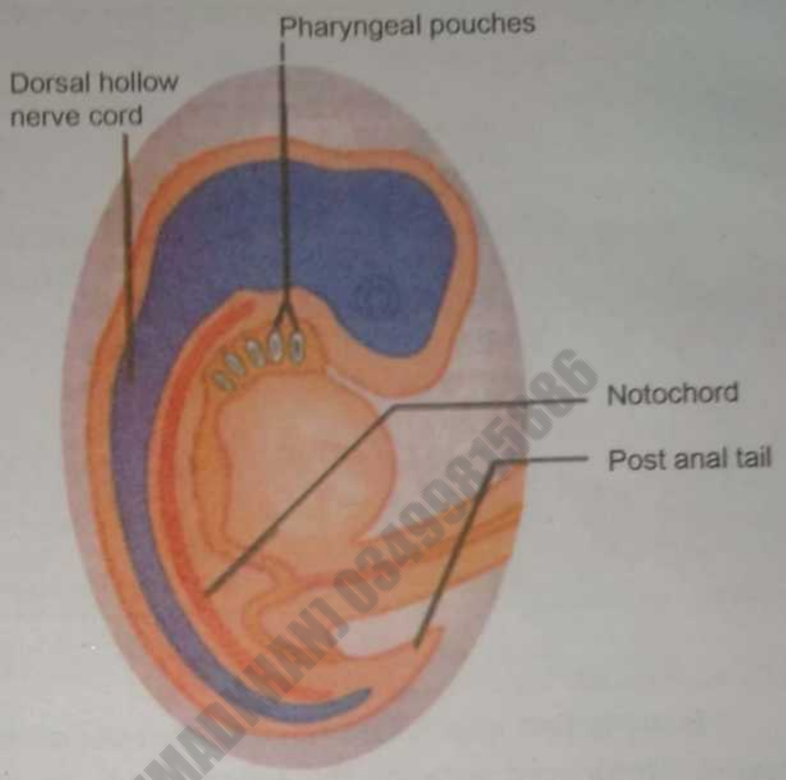


Fig: 9.18: Main features of the chordates, as shown in a generalized embryo

Classification of Chordates

The phylum chordata has been subdivided into two groups: (a) **Protochordata (Acrania)** in which brain is not enclosed in bony case (b) **Craniata** in which brain is enclosed in a bony case and notochord has been replaced by vertebral column.

(a) Group Protochordata (Acrania)

Protochordata has been divided into two sub-phyla: (i) Subphylum urochorda, (ii) Subphylum cephalochordata.

i. Subphylum Urochordata

The body is covered by a covering called **tunic** so they are called **tunicates**. On the outside are two projections: the **incurrent siphon** which corresponds to the anterior end of the body and **excurrent siphon** that marks the dorsal side. Larva has a mid-dorsal supporting rod, the **notochord**, in the tail, so the group has been named urochordata. The notochord usually disappears during metamorphosis, so that adult has no skeleton. The examples of urochordates are *Ascidia*, *Halosymthia*, etc.

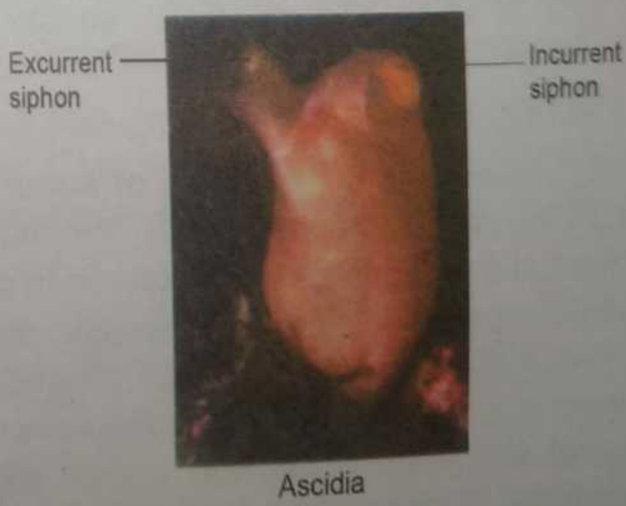


Fig: 9.19: Urochordates

Table 9.1 CLASSIFICATION OF PHYLUM CHORDATA

- **Phylum Chordata**
  - Group - Acrania (No Cranium)
    - Subphylum - Urochordata (tunicates)
    - Subphylum - Cephalochordata (lancelets)
  - Group - Craniata (Cranium is present)
    - Subphylum - Vertebrata
      - Super class Agnatha (jawless fishes)
        - Class Myxini
        - Class Cephalospidomorphi
      - Super Class Gnathostomata (jawed fishes and all tetrapods)
        - Class Chondrichthyes
        - Class Osteichthyes
        - Class Amphibia
        - Class Reptilia
        - Class Aves
        - Class Mammalia

ii. Subphylum Cephalochordata

Body is fish like. It has no head but tail is present. Notochord extends the entire length of the body. There is no organ for respiration. The Example of cephalochordate is: *Amphioxus*.

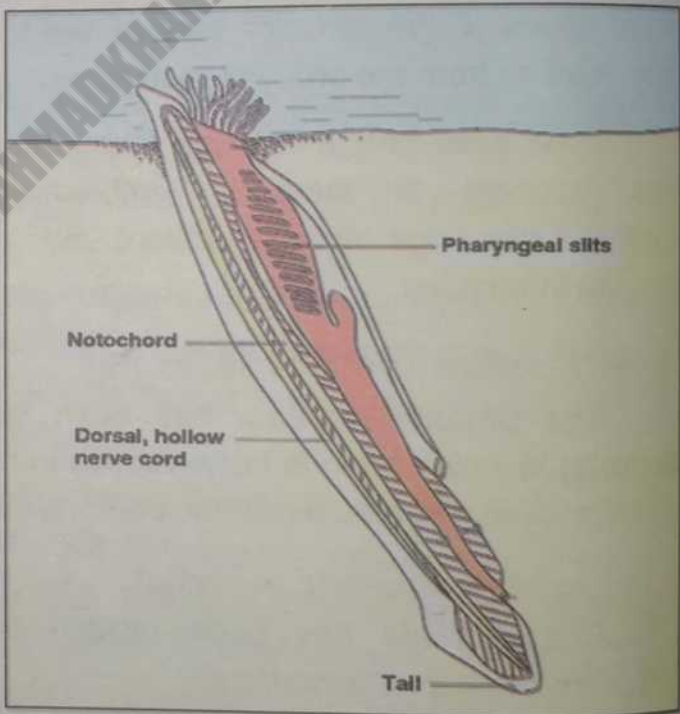


Fig: 9.20: *Amphioxus*

(b) Group Craniata

Craniate has one subphylum i.e., vertebrata.

Subphylum Vertebrata

The characteristics that give the member of this group the names "vertebrata" and "craniata" are spinal column of vertebrae, which forms the chief skeletal axis of the body, and a brain case or cranium. Subphylum vertebrata is divided into two super classes:

(a) Agnatha (b) Gnathostomata

a. SUPER CLASS AGNATHA (Jawless fishes)

General characteristic of super class agnatha: It is divided into two classes: Myxini and Cephalospidomorphi. Body slender, eel-like, and rounded with naked skin. There are no paired appendages and no dorsal fin in class **Myxini**. There are one or two median fins and no paired appendages in class **Cephalospidomorphi**. The caudal fin extends anteriorly along the dorsal surface. Skeleton is fibrous and cartilaginous and the notochord is persistent. Biting mouth with two rows of eversible (to turn outwards) teeth in class Myxini and the oral disk is sucker like and tongue with well-developed teeth in class Cephalospidomorphi. Sexes are separate. Fertilization is external and there is no larval stage. The examples of agnatha are Hagfish, and Lamprey.

Evolutionary adaptations in super class agnatha: Buccal funnel and toothed tongue form a device for blood sucking in absence of jaws. There are five to sixteen gills for respiration in class Myxini and seven pairs of gills each with external gill opening in class Cephalospidomorphi. Dorsal nerve cord with differentiated brain.

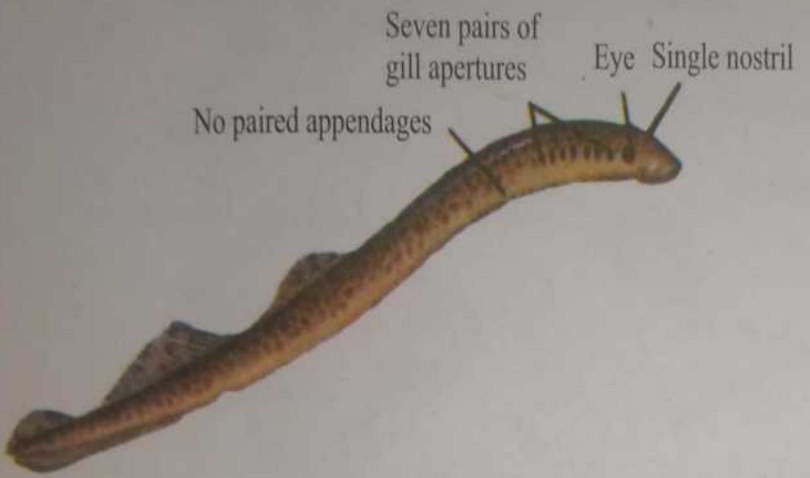


Fig. 9.21: (a) Sea lamprey *Petromyzon marinus*

(b) The Atlantic hagfish *Myxine glutinosa*

> ***Jaws Evolve***
> The gnathostomates have jaws. The tooth bearing bones of the head. Jaws are believed to have evolved from the first pair of gill arches of agnathans.

b. SUPER CLASS GNATHOSTOMATA

It is divided into six classes: Chondrichthyes, Osteichthyes, Amphibia, Reptilia, Aves and Mammalia.

1. CLASS CHONDRICHTHYES (Cartilaginous fishes)

General characteristics of class chondrichthyes: Body is laterally compressed and spindle (fusiform) shaped. Mouth is ventral. Olfactory sacs are not connected to mouth cavity.

Skin is tough and covered with minute **placoid scale**. The pectoral and pelvic fins are paired. There are two dorsal fins. The caudal fin is **heterocercal** (see glossary). Endoskeleton is entirely cartilaginous. Digestive tract leads into the cloaca. Stomach is J shaped. The circulatory system consists of two-chambered heart. There is one atrium and one ventricle. There are 5-7 pairs of aortic arches. Respiratory system includes 5-7 pairs of gills, without operculum. Swim bladder is absent. Sexes are separate. Gonads are paired. Fertilization is internal. Most forms are oviparous or viviparous. It includes the sharks, dogfishes, rays, skates and chimaeras.

Evolutionary adaptations in class chondrichthyes: Spindle shaped body, slippery skin, presence of scales on the body protect the animal. Ventral mouth is suited for capturing prey at the bottom of the sea. Internal fertilization, nourishment and protection of the embryo in the mother's body are evolutionary adaptive feature.

> **Science Titbits**
> Vertebrates are distinguished, in particular by, having endoskeleton, closed circulatory system, paired appendages, efficient respiration and excretion, high degree of cephalisation.

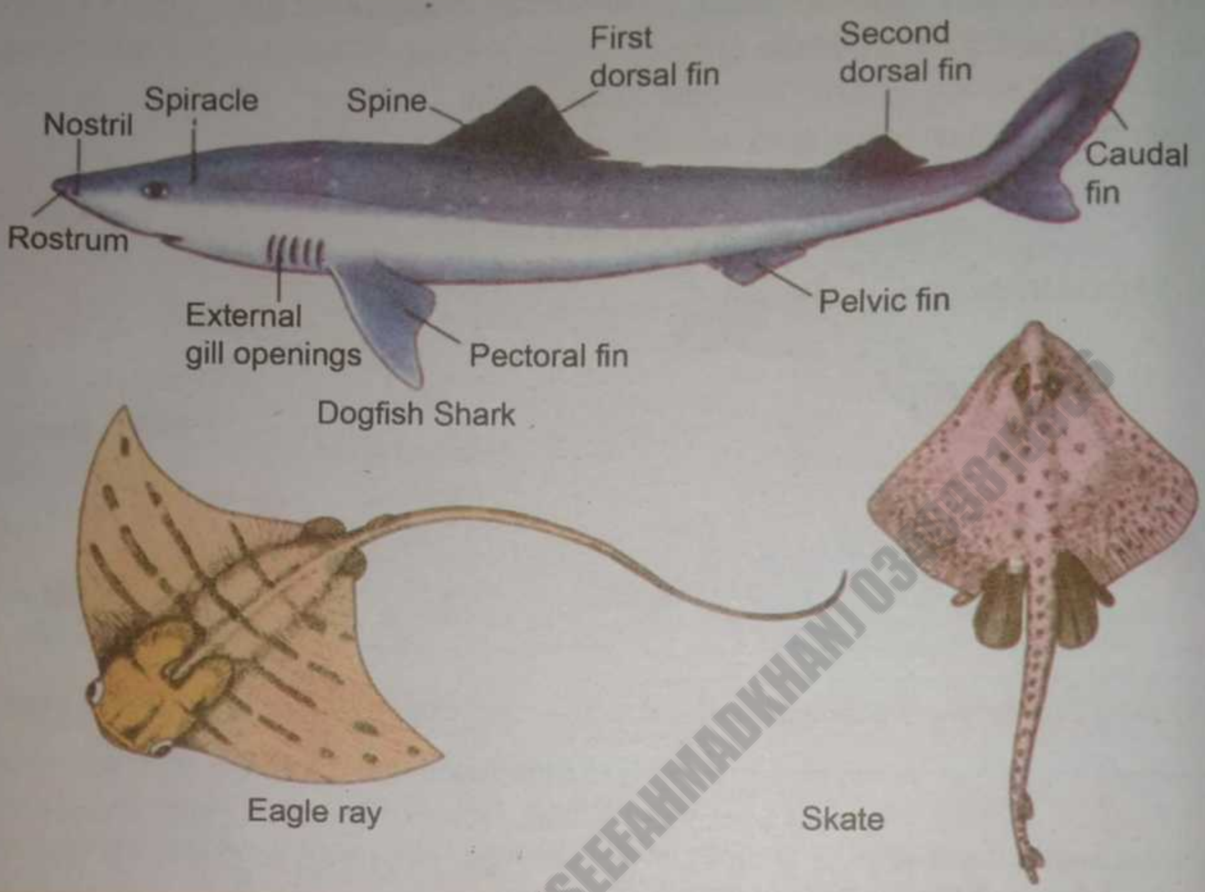


Fig. 9.22: Chondrichthyes

2. CLASS OSTEICHTHYES (Bony fishes)

General characteristics of class osteichthyes: Body is usually spindle-shaped and streamlined for active movement through water. Endoskeleton is partly or wholly bony. Vertebrae are numerous. Pelvic girdle is often absent. Notochord persists in a greatly reduced form.

Skin usually contains dermal scales embedded in the dermis. Both median and paired fins are present. Pelvic and pectoral fins are paired while dorsal fin is single. The caudal fin is **homocercal** (see glossary). Mouth is usually terminal, i.e., anterior end often bears numerous teeth. Jaws are well developed. Anus is present and cloaca is absent. The four pairs of gills are supported by a **bony arch**. They are covered by **operculum**. Spiracles are mostly lacking. **Swim bladder** is usually present with or without connection with the pharynx. Swim bladder helps in buoyancy. Heart is two chambered, having only one atrium and one ventricle. There are four pairs of **aortic arches**. Red blood cells are oval and nucleated. Brain has ten pairs of cranial nerves. Sexes are separate. Gonads are paired. Fertilization is generally external. Most forms are **oviparous** (egg laying), some are **ovoviviparous** (see glossary) or even **viviparous**. (producing living young)

Evolutionary adaptations in class osteichthyes: Body is laterally compressed spindle shaped and has slimy skin, strong segmental muscle for efficient swimming device. **Gills** help in respiration. **Air** or **swim bladder** enables the fish to easily shift from one depth to another. **Gill rakers** check the loss of food. Lack of teeth in the jaws is correlated to the herbivorous diet.

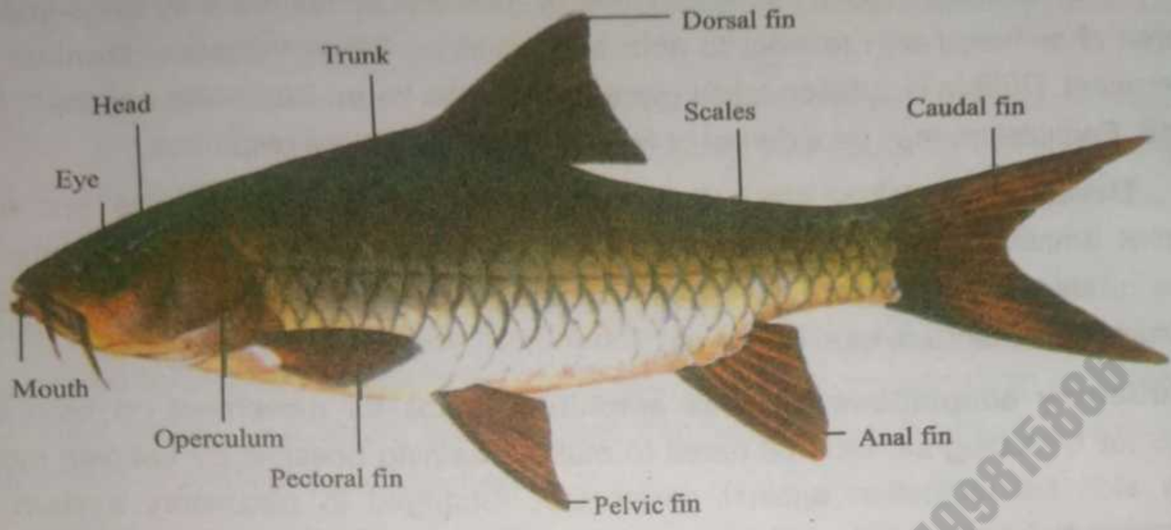


Fig: 9.23: *Labeo rohita*

Fig: 9.24: Sea horse

Fig: 9.25: Lobe-finned fish, *Latimeria*, is a living Fossil.

Limbs Evolve

All the animals which are called tetrapods have four limbs. The lobe-finned fishes of the Devonian period are ancestral to the amphibians, the first tetrapods. Animals that live on land use limbs to support the body, especially since air is less buoyant than water. Lobed-finned fishes and early amphibians also had lungs and internal nares as means to respire air.

3. CLASS AMPHIBIA

General characteristics of class amphibia: Body varies considerably in forms, is divisible only into head and trunk. Most have two pairs of pentadactyl limbs with 4-5 or fewer digits. Some are without legs, e.g., Caecilians. Webbed feet often present, e.g., frogs. Skin is often smooth, moist and rich in glands. It is highly vascular. Scales are generally absent. In some glands are poisonous, chromatophore pigment cells are present in the skin.

Critical Thinking

What limits the ability of amphibians to occupy the full range of terrestrial habitats and allows other terrestrial vertebrates to live in them successfully?

In larval stage respiration takes place by **gills** and in the adults by lungs and skin. Heart is three chambered with respect to atria and ventricle. **Sinus venosus**, **truncus arteriosus** are present. Double circulation takes place through the heart. Sexes are separate. Gonads are paired. Fertilization may be external or internal. Most forms are oviparous.

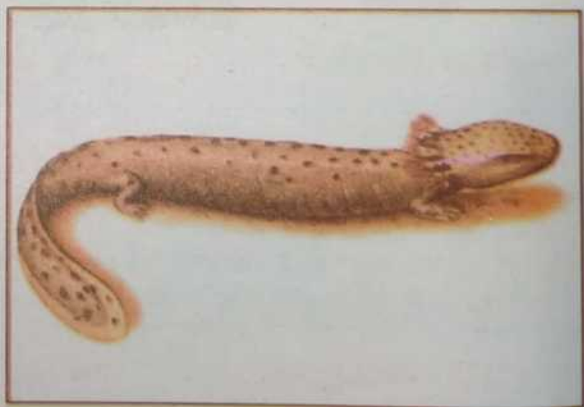
Development takes place through **metamorphosis**. Amphibians are **anamniotes** (without amnion). Body temperature is variable, i.e., poikilothermic (ectotherms) and most forms undergo hibernation in winter. The examples of amphibians are frogs, toads, salamanders, caecilian, mud puppy etc.

Evolutionary adaptations in class amphibia: Limbs for movement on solid substratum. Lungs for breathing air. Internal nares to make breathing possible by keeping mouth closed. Slimy skin for protection against desiccation. Changed in circulatory system to provide respiration by lungs and skin. There is reduction in bones to make the body lighter.

A Female Caecilian

Spotted Salamander

Longtail Salamander



Common Mud Puppy *(Necturus)*

Fig: 9.26: Amphibians

Transition from Aquatic to Land Habitat

Amphibians are on the borderline between aquatic and true terrestrial animals. The animals live in moist condition or in water. So the amphibians are not a successful group owing to their dependence on water as habitat, reproduction and development.

4. CLASS REPTILIA

General characteristics of class reptilia: There are two pairs of pentadactyl limbs, each typically with five digits. Skin is rough, cornified and dry, which is adapted to land life. Heart is incompletely four chambered, having two atria and partly divided ventricle. Crocodiles have completely four chambered heart. Reptiles are cold blooded animals, i.e., piokilothermic (ectotherms) and hibernate in winter. Sexes are separate. Gonads are paired. Fertilization is internal. Most forms are oviparous. Eggs are large, amniotic and have large yolk eggs. Eggs are enclosed by leathery or limy shell for protection. Embryo is protected by three embryonic membranes known as **amnion**, **allantois** and **chorion**. The examples of reptiles are tortoise, lizard, snake, crocodile and alligator etc.

Evolutionary adaptations in class reptilia: Reptiles show the advancement over the amphibians in having:

(a) A dry skin which enables them to live away from water.

(b) Separation of oxygenated and deoxygenated blood in the heart.

(c) A neck movable independent of the body.

(d) Better mechanism of breathing.

(e) Fertilization is internal.

(f) Egg with shell for protection on land.

Tortoise

Lizard

Corel Snake

Alligator

Fig: 9.27: Reptiles

5. CLASS AVES

General characteristics of class aves: Body of aves is streamlined and is boat shaped. It is divisible into a head, neck, a trunk and a tail. Neck is very long and tail very short. There are two pairs of pentadactyl limbs. The forelimbs are modified to form wings. The hind limbs are large, strong and adapted for perching, walking or swimming. Each foot usually bears four toes armed with horny claws. The skin is covered by an epidermal horny exoskeleton of **feathers** all over the body and scales on the feet. Due to air spaces skeleton is light. Skull has large sockets. Jaws extend into horny beak. Teeth are absent. Heart is four chambered, having two atria and two ventricles. There is only right aorta. It curves to the right side and then bends backward. Birds are endothermic. Respiration takes place only by lungs.

Kiwi

Penguin

Duck

Parrot

Fig: 9.28: Birds

The Amniote Egg Evolves

It is adaptive for land animals to have a means of reproduction that is not dependent on external water. Reptiles practice internal fertilization and lay eggs that are protected by a shell. The amniote egg contains extraembryonic membrane, which protect the embryo. One of the membranes, the amnion, is a sac that fills with fluid and provides a "private pond" within which the embryo develops. Reptiles, birds and mammals are called amniotes

A system of thin walled air sacs lying among the viscera maintains the supply of fresh air through the lungs. Voice box the **syrinx** lies at the junction of the trachea and bronchi. Alimentary canal has muscular structure called gizzard, which is used for crushing food. Excretory system consists of a pair of kidneys. The ureters open into the cloaca and the urinary bladder is absent. The urine is semisolid and uric acid is main nitrogenous waste. Sexes are separate. Fertilizátion is internal. Eggs are large with much yolk. Only one ovary and oviduct is functional. Some birds have secondarily lost the power of flight and are called running birds, e.g., ostrich, kiwi, etc.

Evolutionary adaptations in class aves: An insulated covering over the body is present. Better aeration of blood in the lungs, taking place during both inspiration and expiration. Complete separation of venous and arterial blood in the heart. A regulated body temperature keeps the aves equally active all the year round. Patterns of behaviour, such as care for the young ones, nest building, courtship and affection for the mate and migration, which are practically unknown in reptiles.

6. CLASS - MAMMALIA

General characteristics of class mammalia: Body is variously shaped and divisible into a head, a neck, a trunk and a tail. There are two pairs of pentadactyl limbs. These are variously adapted for walking, running, burrowing and swimming or flying. Skin is glandular, mostly covered by hair. **Coelom** is completely divided into anterior smaller thoracic cavity and posterior larger cavity by a muscular partition the diaphragm, which is present only in the mammals. Endoskeleton is fully ossified. Skull has two **occipital condyles**, large **cranium**. External ear or pinna is present. There is a chain of three bones in the ear incus, malleus and stapes. Mammals have deciduous and permanent teeth. Heart is four chambered. Only left aortic arch is present. Red blood cells are non-nucleated. Mammals are warm blooded (endothermic) animals. Voice apparatus is well developed, and consists of **larynx** and **epiglottis**. Mammals give birth to their young ones. Mammals feed them on milk produced by mammary glands of mother.

Mammals are classified into three subclasses: (1) Prototheria-Egg laying mammals. (2) Metatheria-Pouched mammals. (3) Eutheria-Placental mammals.

SUB-CLASS PROTOTHERIA - The Monotremes

The subclass Prototheria is a connecting link between reptiles and mammals and provides evidence of evolution and origin of mammals from reptiles. Certain members of this sub-class are adapted for aquatic life, e.g., Duck bill platypus, which has a bill similar to that of a duck and has webbed toes. The mammalian feature of the monotremes is that the female has mammary glands and they feed their youngs. The reptilian features include the presence of cloaca and cloacal opening (instead of separate opening for digestive and urinogenital system). Monotremes are found in Australia. The examples of monotremes are Duckbill platypus and Echidna-spiny ant eater.

Duckbill Platypus   Spiny Ant Eater

Fig: 9.29: The Monotremes

SUB CLASS METATHERIA – The Marsupials

The females have an abdominal pouch the **marsupium**, where they rear their young. The young one's when borne are immature. The nipples are in the pouch. The mother feeds the young ones and carries them in the pouch till they are matured enough. The Marsupials are found in Australia and America. The examples of marsupials are: opossum, kangaroo and Koala.

Kangaroo   Koala

Fig: 9.30: The Marsupials

SUB-CLASS EUTHERIA – The Placentalis

Development of young one takes place inside the body of the mother. The young's are borne fully developed. Developing placental mammals are dependent on **placenta** (an organ of exchange between maternal blood and fetal blood.) So these mammals are called **placental mammals**. Nutrients are supplied to the growing offspring, and wastes are passed to the mother for excretion. The young ones are born at a relatively advanced stage of development.

All the placental mammals have maximum mammalian characteristics. In some hair have been modified into scales in pangolin, and spines in porcupine. Examples of the placentalis are man, whale, elephant, horse, rat, mice, bat, dolphin, cat, tiger, lion, monkey, gorilla etc.

Evolutionary adaptations in class mammalia: A regulated body temperature. This makes them independent of environmental change, keeping active throughout the year. Complete separation of venous and arterial blood in the heart. More efficient mechanism of respiration due to the presence of a diaphragm. An active life and a high rate of metabolism.

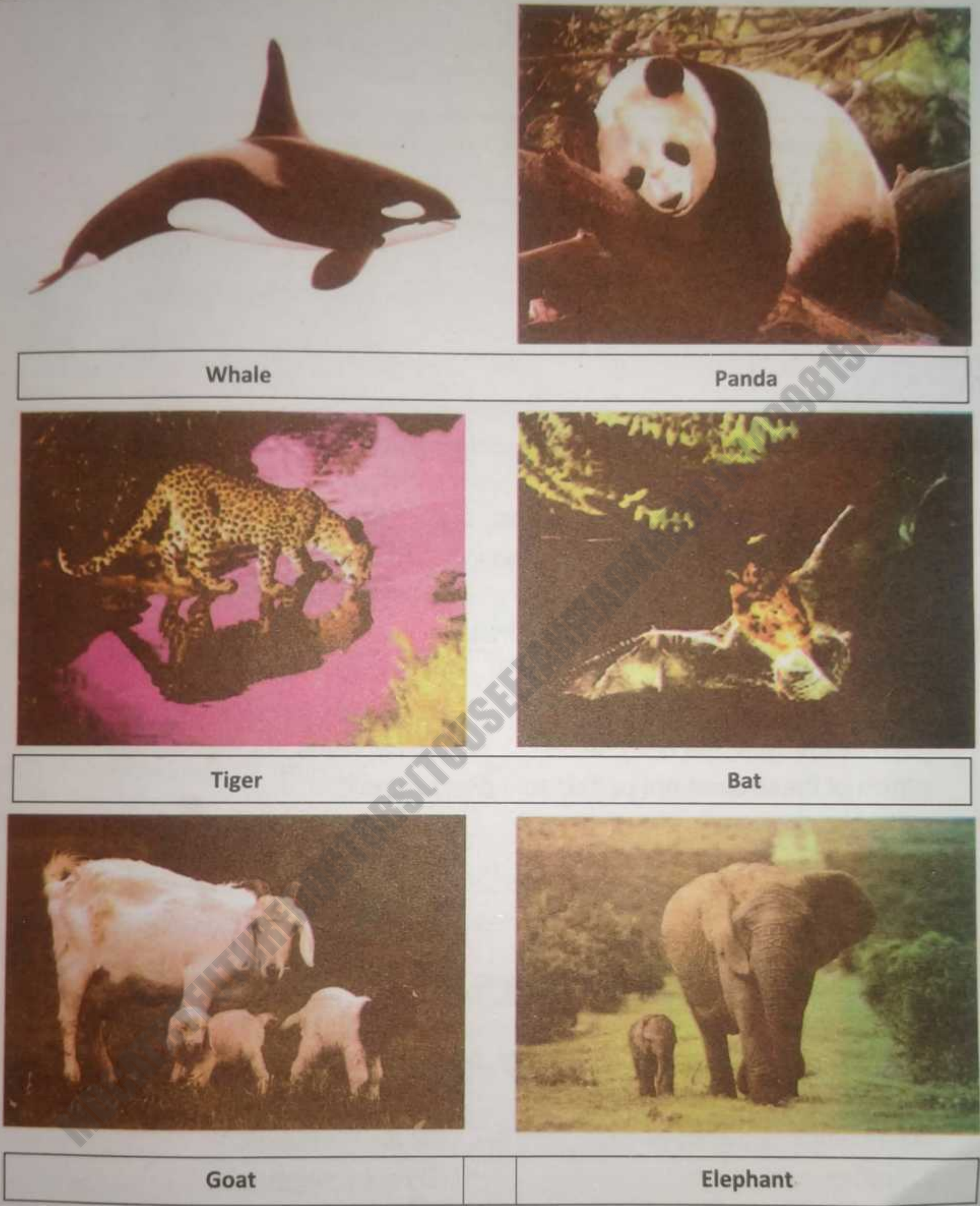


Fig: 9.31: The Placentalis

A separate respiratory passage that avoids interference in breathing during feeding. Better developed senses of smell, sight and hearing. A more highly developed nervous system. Large cerebrum and cerebellum provide for better coordination in all activities and for learning and retentive memory. Patterns of behaviour, such as care and nursing of the young ones present.

Activity

Classifying the given invertebrates into phyla and given chordates into classes by using classification key

Exercise

MCQs

1. **Select the correct answer**

(i) All animals are
(A) autotrophs (B) heterotrophs (C) unicellular (D) motile

(ii) Which of the following is not included in grade bilateria
(A) cnidarians (B) nematodes (C) annelids (D) molluscs

(iii) Which of the following class of animals includes the first verteberates to appear on Earth?
(A) agnatha, the jawless fishes (B) chondrichthyes, the sharks
(C) osteichthyes, the bony fishes (D) tunicates, the sea squirts

(iv) Which of these does not pertain to a protostome?
(A) spiral cleavage (B) blasto pore—anus
(C) schizocoelom (D) annelids

(v) Sponges belong to the phylum.
(A) aschelminthes (B) arthropoda (C) porifera (D) mollusca

(vi) Which of the following is not a parasite
(A) annelida (B) nematode (C) platyhelminthes (D) porifera

(vii) Which of the following most clearly demonstrates the evolutionary relationship between annelids and arthropods?
(A) a complete digestive tract (B) an exoskeleton
(C) radial symmetry (D) body segments

(viii) Reptiles are much more extensively adapted to life on land than amphibians in that reptiles
(A) have shelled eggs (B) have a complete digestive tract
(C) are endothermic (D) go through the larva stage

(ix) Amphibians arose from
(A) cartilaginous fish (B) jawless fish
(C) ray finned (D) bony fishes with lungs

(x) Which of these does not pertain to a deuterostome?
(A) blastopore is associated with the anus (B) spiral cleavage
(C) enterocoelom (D) echinoderms and chordates

(xi) Which of the following has a gastrovascular cavity?
(A) sponges (B) earthworms (C) roundworms (D) flatworms

(xii) Which of the following is not a subphylum of chordata
(A) hemichordata (B) urochordata (C) cephalochordate (D) vertebrata

Short Questions

2. Write distinct features of animals.
3. Name the four criteria for animal classification.
4. Classify animals on the basis of presence and absence of tissue.
5. Differentiate the diploblastic and triploblastic levels of organization.
6. To what life style is radial symmetry an adaptation?
7. To what life style is bilateral symmetry an adaptation?
8. Describe the body layers of sponges.
9. What are nematocysts?
10. Give three features of platyhelminthes for parasitic mode of life.
11. Give three distinguishing features of Aschelminthes.
12. How locomotion takes place in Annelids?
13. Write five salient features of phylum Arthropoda.
14. List any four harmful roles of insects.
15. List the similarities between echinoderms and chordates.
16. What does the term amphibian mean? Why amphibians are not considered a very successful group of vertebrates?
17. Describe the ways, which amphibians are adapted to life on land, and in what ways they are still restricted to a watery or moist environment.
18. List the adaptations that distinguish reptiles from amphibians and help them adapt to life in dry terrestrial environment.
19. Give an example of ectothermic and endothermic animals.
20. Name two phyla of animals that are radially symmetrical and two that are bilaterally, symmetrical.
21. List the vertebrate class (or classes) in which we find each of the following:
(a) A skeleton of cartilage (b) A two-chambered heart (c) The amniotic egg
(d) A four chambered heart (e) Lungs supplemented by air sacs (f) Placenta
22. Identify the phyla that have the following characteristics:
(a) radial symmetry (b) acoelomate (c) pseudocoelomate
(d) alternation of sexual and asexual stages (e) cnidocytes

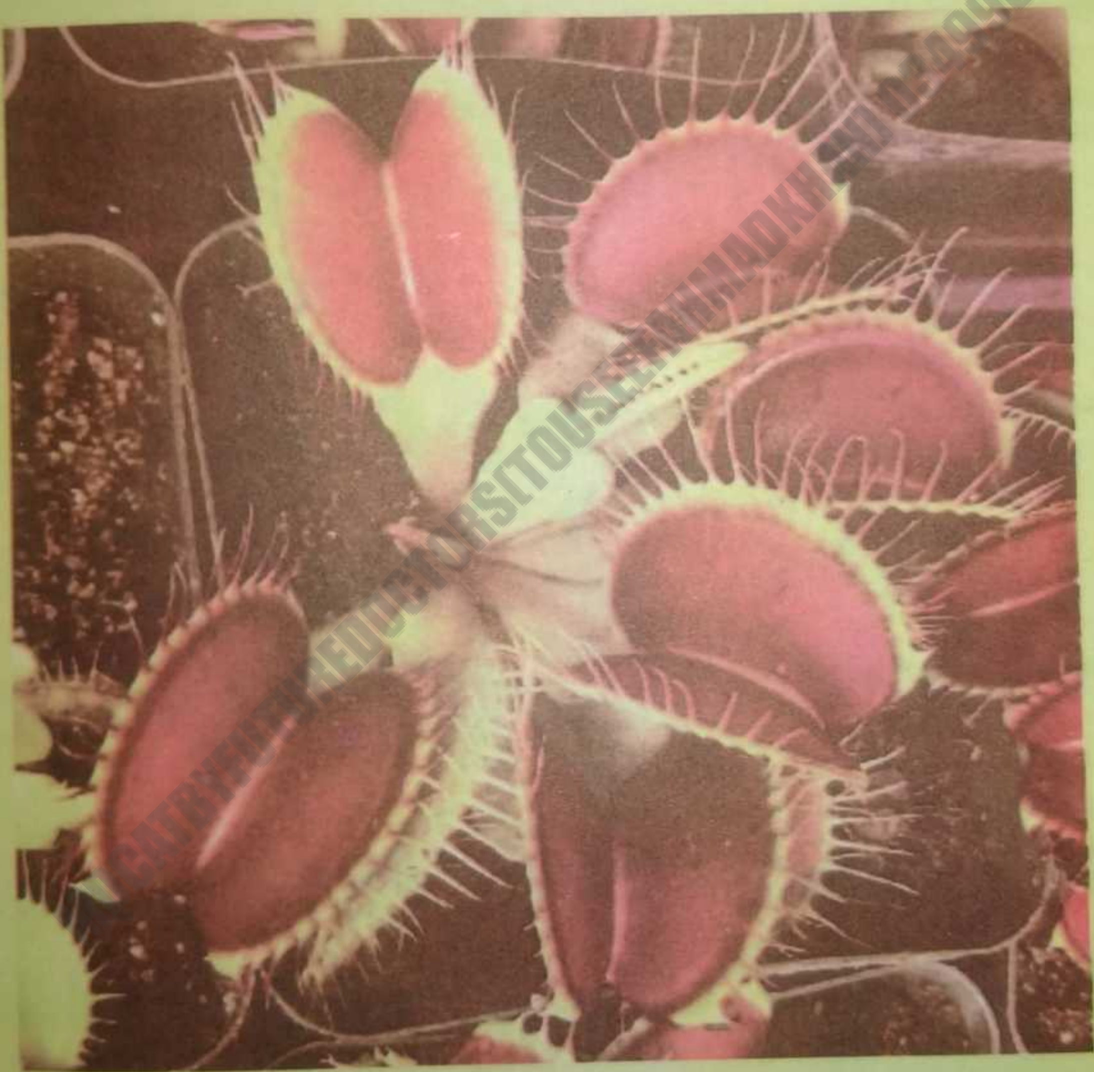
23. Write three main differences between prototheria, metatheria and eutheria.
24. How do mammals differ from birds? And what adaptations do they share?
25. Define/Describe/Explain briefly:
animals, parazoa, eumetazoa, diploblastic animals, triploblastic animals, radial symmetry, bilateral symmetry, coelom, blastula, protostomes, deuterostomes, nematocyst, mesoglea, zooid, radula, trochophore larva, parapodia,haemocoel, metamorphosis, water vascular system, protochordata, notochord, swim bladder, amnion, placenta.
26. Write the difference between:
(a) diploblastic and triploblastic animals (b) radial symmetry and bilateral symmetry
(c) acoelomate and pseudocoelomate (d) pinacoderm and choanoderm
(e) spongocoel and gastrovascular cavity (f) hydroids and medusa
(g) endotherm and ectotherm

Extensive Questions

27. Describe the criteria of animal classification.
28. Differentiate between pseudocoelomates, acoelomates and coelomates. Classify coelomates into protostomes and deuterostomes.
29. Describe the general characteristics, economic importance and examples of the following;
(a) Sponges (b) Cnidarians (c) Platyhelminthes (d) Aschelminthes (Nematodes)
(e) Molluscs (f) Annelids (g) Arthropods (h) Echinoderms
30. Describe the evolutionary adaptations for digestion, gas exchange, transport, excretion and co-ordination in the following phyla:
(a) Porifera (b) Cnidaria (c) Platyhelminthes (d) Aschelminthes (Nematoda)
(e) Mollusca (f) Annelida (g) Arthropoda (h) Echinodermata
31. List the general characteristics, evolutionary adaptations and give examples of the phylum *Hemichordata*.
32. Describe the four basic characteristics of the phylum chordata.
33. Describe the general characteristics, evolutionary adaptations and give examples of super class Agnatha.
34. Describe the general characteristics, evolutionary adaptations and give examples of the following classes:
(a) Chondricthyes (b) Osteichthyes (c) Amphibia
(d) Reptilia (e) Aves (f) Mammalia
35. Describe the characteristics and give examples of subclass:
(a) Prototheria (b) Metatheria (c) Eutheria
36. Arthropods and vertebrates are highly successful groups of animals on land. What characteristics shared by arthropods and vertebrates are adaptive to a land existence?

SECTION 3

Life Processes



Carnivorous plant: Venus flytrap

10

FORM AND FUNCTIONS IN PLANTS

After completing this lesson, you will be able to

- List the macro and micronutrients of plants highlighting the role of each nutrient.
- State the examples of carnivorous plant.
- Explain the role of stomata and 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 structures with functions.
- 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.
- Define osmotic adjustment.
- Explain movement of water into or out of cell in isotonic, hypotonic, and hypertonic conditions.
- Describe osmotic adjustments in hydrophytic (marine and freshwater), xerophytic and mesophytic plants.
- Explain the osmotic adjustments of plants in saline soils.
- List the adaptations 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.

You have studied in previous classes that organ and organ system level of organization is poorly developed in plants than animals. This is probably due to less range of functions and activities in plants than animals, because plants, unlike animals, lead a static (non-motile) life and therefore, they face comparatively less number of stimuli. However, plants must possess certain important functions, which are required for the survival such as specific nutritional requirements, exchange of gases, mechanisms by which they transport water, mineral and organic nutrients, homeostasis, support, growth and development and various growth responses. This chapter deals with all these functions.

10.1 NUTRITION IN PLANTS

All those substances that provide necessary elements to the organism for growth and metabolism are called **nutrients** that may be organic or inorganic. The term **nutrition** is applied to all the processes that are involved in uptake of nutrients from the environment and their utilization in growth or various metabolic activities of the body. Plants are autotrophs as they obtain inorganic nutrients such as water, carbon dioxide and certain minerals form the environment and convert them into organic compounds.

10.1.1 Plant Nutrients, their Role and Deficiencies

Sixteen elements have been found essential for plant growth. Nine of these are required in fairly large quantities and are therefore known as **macronutrients**. These include carbon, hydrogen, oxygen, nitrogen, phosphorus, potassium, sulphur, calcium and magnesium. The remaining seven elements are needed in traces or small amounts for normal plant growth and development that are known as **micronutrients**. These include iron, boron, manganese, copper, molybdenum, chlorine and zinc.

Table 10.1 Mineral nutrition in plants

Macronutrients	Major Functions
Carbon, Hydrogen, Oxygen	Component of carbohydrates, lipids, protein and nucleic acid molecules
Nitrogen	Component of proteins, nucleic acids, chlorophyll and enzymes
Phosphorus	Component of nucleic acids, phospholipids, ATP and NADP.
Calcium	Component of cell wall, involved in membrane permeability, enzyme activator.
Magnesium	Component of chlorophyll, acts as enzyme activator
Sulphur	Component of certain amino acids and vitamins.
Potassium	Osmosis and ionic balance, opening and closing of stomata, enzyme activator
Micronutrients	**Major Functions**
Chlorine	Activator of enzymes, involved in photosynthesis.
Iron	Activator of enzymes, components of cytochromes, feridoxin, plastoquinone, assists in the manufacture of chlorophyll and other biochemical processes.
Manganese	Activator of enzymes, needed for chlorophyll production.
Copper	Activator of enzymes, component of plastocyanin, helps plants to metabolize nitrogen.
Zinc	Activator of enzymes, used in development of enzymes and hormones. It is used by the leaves and needed by legumes to form seeds.

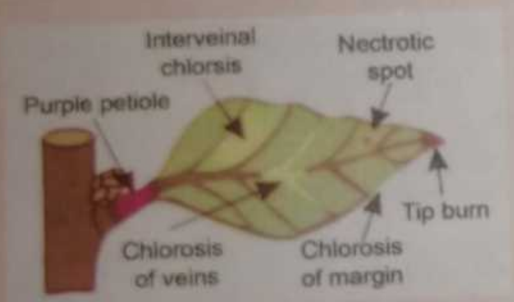
All these elements have specific functions in plant body therefore; the deficiency of any one of them can cause serious complications that are generally called **deficiency diseases**. For example: deficiency of nitrogen or magnesium causes yellowing of leaves called **chlorosis**. The deficiency of phosphorus causes stunted root growth and deficiency of potassium causes leaf margins yellow or brown and pre-mature death of plant.

> **Science Tidbits**
>
> **Hydroponic culture** is one of the most useful methods to test whether a certain element is essential for plant or not. In this method, plants are cultured or grown on net, which is placed on the surface of aerated water containing measured quantity of specific nutrients. The samples of water are analyzed time to time to determine which nutrient, the plant has absorbed.

The nutrients may become deficient in the soil if a particular crop is grown again and again in the same soil. Therefore, **crop rotation** (cultivation of different crops alternatively in the same soil) or **addition of fertilizers** in the soil are possible remedies for this problem. The table 10.1 shows the major functions of each macro and micronutrients of the plant.

Science, Technology and Society Connections

- **Identify some major symptoms of mineral deficiencies in plants, e.g., necrosis, chlorosis, stunted growth etc.**



Necrosis: It is the death of a part of plant body. It is due to deficiency of:
Calcium, magnesium, copper and molybdenum.
Chlorosis: It is the yellowing of the green parts of a plant which show lack of chlorophyll due to mineral deficiency of nitrogen, and magnesium.
Stunted growth: It is less than normal growth due to the deficiency of phosphorus, sulphur, potassium in plants.

Carnivorous or insectivorous plants are true photosynthetic autotrophs but they also feed upon insects because they usually grow in places where nitrogenous salts are not readily available, e.g., marshy areas. Actually, they use insects and other small organisms as their source of nitrogen. Such plants have some modified leaves that are used to capture and digest insects. These plants also have certain symbiotic bacteria, which help them to digest insect proteins. The examples are Pitcher plant, Venus flytrap, Sundew etc.

Fig: 10.1: (a) Pitcher plant, (b) Venus flytrap. (c) Sundew

10.2 GASEOUS EXCHANGE IN PLANTS

In bioenergetics, you have studied that respiration occurs at two levels, i.e., organismic and cellular level. The respiration that occurs at organismic level is called **exchange of gases**. The purpose of this gaseous exchange is to enable the organism to perform cellular respiration, which utilizes oxygen and releases carbon dioxide during the breakdown of complex organic compounds. Exchange of gases between organism and its environment is carried out by diffusion. In the absence of special organs, every cell of plant carries out the exchanges of oxygen and carbon dioxide according to its needs. This exchange of gases mainly occurs through two main openings, the stomata and lenticels.

10.2.1 Role of Palisade and Spongy Mesophyll in Exchange of Gases

Mesophylls are special types of parenchymatous cells (thin walled living cells) which are present between the two epidermal layers of leaves. These cells are modified to carry out photosynthesis.

Types of mesophyll in dicot and monocot leaves

In dicots, there are two distinct layers of mesophyll, the **palisade mesophyll** and the **spongy mesophyll**. The palisade mesophyll are elongated and compactly packed cells with no intercellular spaces between them. The epidermis beside palisade mesophyll is called **upper epidermis**. On the other hand, spongy mesophyll are loosely packed cell with large intercellular spaces. The epidermis beside spongy mesophyll is called **lower epidermis**. Such leaves, in which upper and lower epidermises can be differentiated because of the presence of two types of mesophyll cells, are called **bifacial leaves**. In monocots, the leaves are **monofacial** as only spongy mesophyll cells are present between both epidermises. The mesophyll cells are metabolically active cells of the plant therefore; they are rapidly involved in exchange of gases. The passage for this exchange of gases through mesophyll tissue is provided by the stomata.

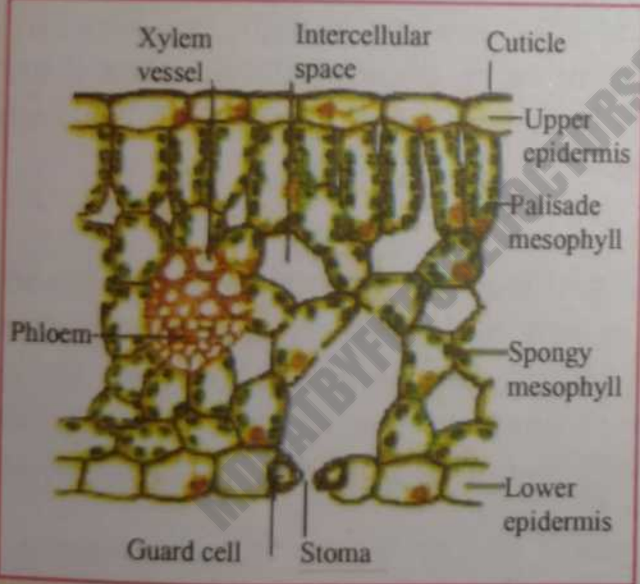


Fig. 10.2: T.S of bifacial leaf

10.2.2 Relationship of Stomata and Transpiration with Exchange of Gases

Stomata are small biconvex shaped openings present in leaf epidermis. A stomatal opening is formed by two, kidney or bean shaped guard cells, which are specialized epidermal cells of leaf. In bifacial leaves, more stomata are distributed in lower epidermis as intercellular spaces are present along this epidermis. Whereas, isobilateral leaves have equal number of stomata in both epidermises.

The **transpiration** is the loss of water in the form of vapours through aerial (above the ground) parts of the plants mainly through the stomata. It is not only responsible for transportation of water and minerals but also plays a vital role in the exchange of gases. During day light, the stomata are widely open and provide a wide passage for the exchange of gases.

10.2.3 Pattern of Exchange of Gases between Plant and Environment

In daytime plants are involved in both photosynthesis and respiration but at night only respiration does occur. Therefore, pattern of gaseous exchange is different in day and night.

Exchange of gases in daytime

In daytime, since the rate of photosynthesis is much faster than the rate of respiration so the carbon dioxide released from respiration does not fulfill the photosynthetic need. Hence, plants import carbon dioxide from the environment. Similarly, the oxygen released from photosynthesis is much more than the need for respiration; hence, it is exported out of the plant body.

Exchange of gases at night

Plants begin to perform exchange of gases just like animals at night i.e., they absorb oxygen and release carbon dioxide to the environment as no photosynthesis takes place at night. Now oxygen required for respiration is absorbed from environment and the carbon dioxide produced from respiration is released outside.

Compensation point of photosynthesis

At the time of dawn (sunrise) and dusk (sunset) the rate of photosynthesis becomes equal to the rate of respiration due to low intensity of light. In this situation, the carbon dioxide produced from respiration is sufficient to carry on photosynthesis and the oxygen released from photosynthesis is consumed in respiration. Therefore, the net gaseous exchange between plant and its environment is completely stopped. This is known as **compensation point** of photosynthesis.

10.3 TRANSPORT IN PLANTS

The roots of a plant not only anchor the plant body in the soil but also absorb minerals and water from the soil. These nutrients are first absorbed by root epidermal cells from where these are moved to the xylem and then through xylem these materials are ultimately reached to the leaves. The leaves utilize these nutrients in photosynthetic activity. After photosynthesis, organic solutes are produced that also have to move to different parts of the plant body. All these movements of materials are generally refers to as **transport in plants**.

10.3.1 Movement of Water between Plant Cells and their Environment

The uptake or loss of water by cells takes place by osmosis. The term **osmosis** is specifically applied to the movement of water from the region of its higher concentration to the region of its lower concentration through semipermeable membrane. The movement of water into the cell is called **endosmosis** while the movement of water out of the cell is called **exosmosis**. The movement of water into or out of the cell exhibits three kinds of water relations such as water potential, solute potential and pressure potential.

Water potential (ψ_w)

Water potential is a measure of the potential energy in water that enables it to move from one place to another. Potential or pressure is denoted by the Greek letter ψ (psi) and is expressed in units of pressure (pressure is a form of energy) called **Mega Pascal (MPa)**. In this way, water potential is represented by ψ_w. Water potential of a medium is directly proportional to the concentration of water in that medium; therefore, pure water has highest water potential. Water potential of pure water is designated a value of **zero.** Water potential of all the solutions or the cells must be less than zero i.e., in negative range.

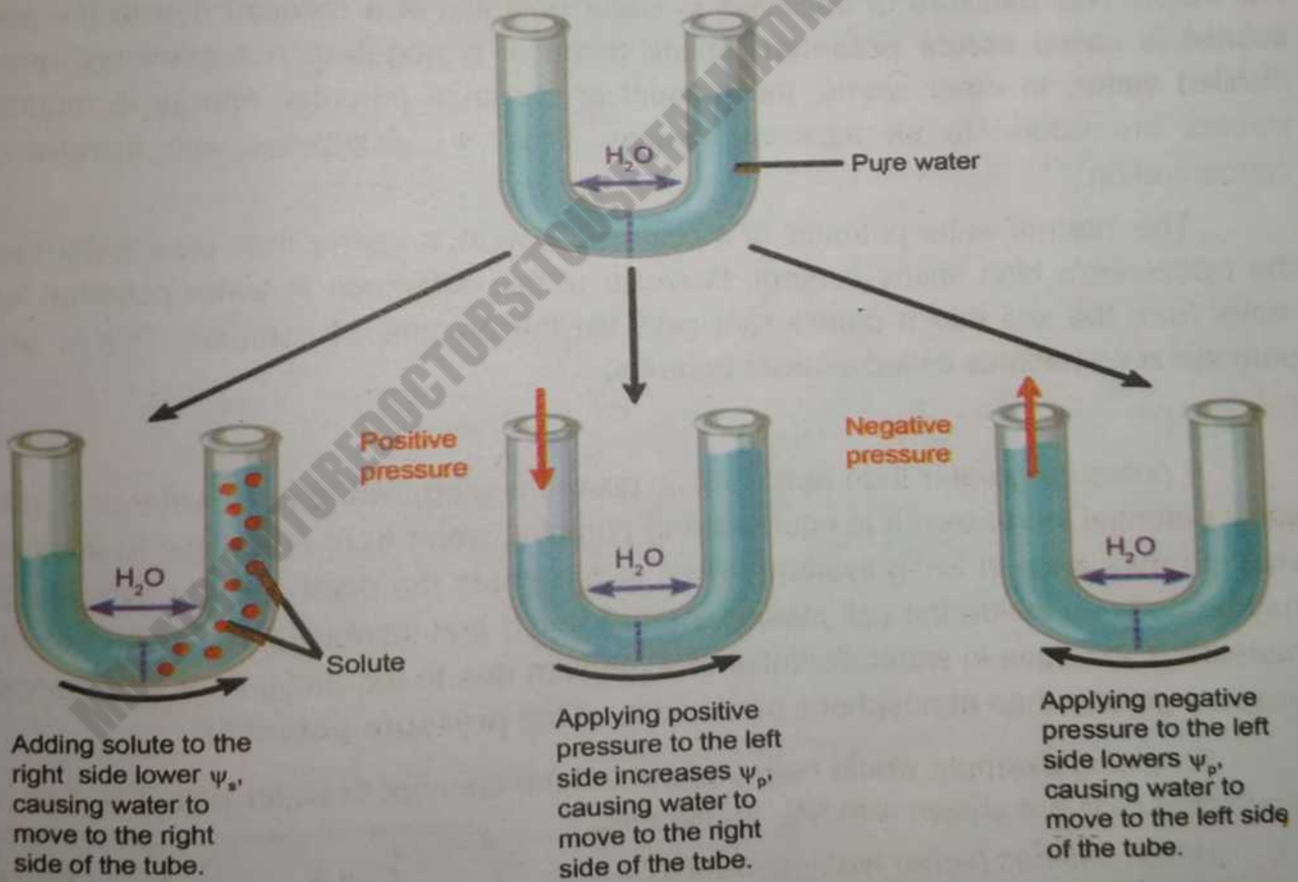


Fig: 10.3: Changes in ψ_w of the two adjacent systems and their effects: In this example a semipermeable membrane is placed between two aqueous systems in a U shaped tube, water will move from a region of higher to lower water potential until equilibrium is reached. Solutes concentration and pressure greater than atmospheric pressure (positive pressure) influence total water potential for each side of the tube and, therefore, there will be a difference between total water potential on each side. Water moves in response to the difference in water potential between two systems (the left and right sides of the tube).

The water potential in plant solutions is mainly influenced by solute concentration and pressure greater than atmospheric pressure. Water potential can be broken down into its individual components using the following equation:

$$\Psi_w = \Psi_s + \Psi_p$$

where

Ψ_s = solute potential

Ψ_p = pressure potential

As the individual components change, they raise or lower the total water potential of a system. When this happens, water moves to equilibrate, moving from the system or compartment with a higher water potential to the system or compartment with a lower water potential. Therefore, for water to move through the plant from the soil to the air (a process called transpiration), the conditions must exist as such:

Ψ_w of soil > Ψ_w of root > Ψ_w of stem > Ψ_w of leaf > Ψ_w of atmosphere.

Solute potential (ψ_s)

Solutes reduce water potential by consuming some of the potential energy available in the water. This measure of decrease in water potential of a medium due to the addition of solutes is called **solute potential**. Solute potential is negative in a plant cell and zero in distilled water. In other words, the amount of available potential energy is reduced when solutes are added to an aqueous system. Thus, Ψs decreases with increasing solute concentration.

The internal water potential of a plant cell is more negative than pure water because of the cytoplasm's high solute content. Because of this difference in water potential, water will move from the soil into a plant's root cells via the process of osmosis. This is why solute potential is sometimes called osmotic potential.

Pressure potential (ψ_p)

If pressure greater than atmospheric pressure is applied to pure water or a solution, its water potential increases. It is equivalent to pumping water from one place to another such a situation may arise in living system. When water enters the plant cells by osmosis, pressure may be build up inside the cell making the cell turgid and increasing the water potential. This measure of increase in water potential of a medium due to the addition of water or due to the pressure greater than atmospheric pressure is called **pressure potential**

Following example would help understand the concept of water potential. Two adjacent vacuolated cells are shown with Ψ_w, Ψ_s, and Ψ_p

Cell A	Cell B
Ψ_w = -1400 KPa	Ψ_w = -600 KPa
Ψ_p = 600 KPa	Ψ_p = 800 KPa
Ψ_s = -2000 kPa	Ψ_s = -1400 kPa

i. Which cell has higher water potential?

ii. In which direction will water move by osmosis?

iii. What will be the water potential of the cells at equilibrium?

iv. What will be the solute potential and pressure potential of the cells at equilibrium?

10.3.2 Uptake of Water by Roots and Pathways

The cell wall of epidermal cells of roots is freely permeable to water and other minerals. The cell membrane is differentially permeable. From root hairs water enters the epidermal cells by osmosis. The water moves along the concentration gradient. It passes through cortex, endodermis, and pericycle and reaches the xylem vessels. There are three pathways taken by water to reach the xylem tissues:

(a) The apoplast pathway, (b) The symplast pathway, (c) The vacuolar pathway.

Apoplast pathway

The **apoplast** is the system of adjacent cell walls, which is continuous throughout the plant. When water moving through spaces in the cell walls reaches the endodermis, its progress is stopped by **casparian strips**, (a band of suberin and lignin bordering four sides of root endodermal cells). This is called **apoplast pathway**.

Symplast pathway

Movement of cell sap that involves cytoplasmic connection of adjacent cells is termed as **symplast pathway**. The **symplast** is the system of interconnected protoplast in the plant. The **cytoplasm** of neighbouring **protoplast** is linked by the **plasmodesmata.** Once water and any solutes it contains is taken into the cytoplasm of one cell it can move through the symplast without having to cross further membranes. Movement might be aided by cytoplasmic streaming. The symplast is an important pathway of water movement.

Vacuolar pathway

In the **vacuolar pathway** water moves from vacuole to vacuole through neighbouring cells, crossing the symplast and apoplast in the process and moving through membranes and tonoplast by osmosis. It moves down a water potential gradient.

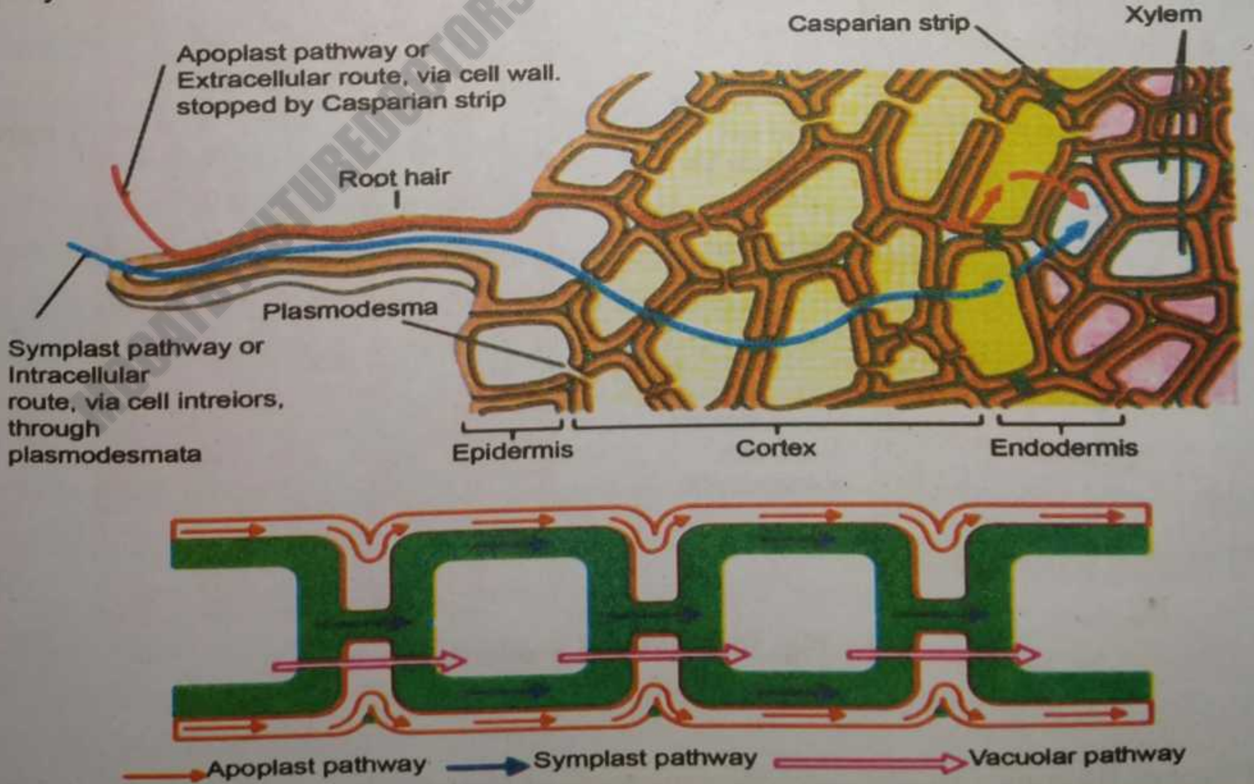


Fig. 10.4: Pathway of water

10.3.3 Structure and Function of Xylem and Phloem

There are two types of conducting tissues in plants, namely xylem and phloem. These tissues constitute the vascular tissues. Xylem conducts mainly water and minerals from the roots up to other parts of the plants. Phloem conducts organic food from the leaves both up and down the plant.

Components of xylem and their functions

Xylem is a complex and permanent tissue that consists of four cell types; the tracheids, vessel elements, xylem fibres and xylem parenchyma. **Tracheids** are dead, elongated cells with tapering ends and lignified walls. They have mechanical strength and give support and also involve in conduction of water and minerals. These cells are universally present in xylem tissue of all vascular plants, which are therefore, called **tracheophytes**. **Xylem vessels** are dead, very long, highly thick walled tubular structures formed by the fusion of several vessel cells (vessel elements) end to end in a row. **Vessel elements** are shorter than tracheids but they form pipeline in plant body as they are placed one above the other. Xylem vessels are only found in angiosperms where they are involved in conduction of water and minerals and also provide mechanical support to the body. **Xylem fibres** are also dead but narrow, highly elongated, highly thick walled cells with tapering ends. They are mainly responsible for mechanical support to the plant body. The only living cells of xylem are **xylem parenchyma**, which are thin walled, broad cells and are involved in the storage of water and minerals temporarily during conduction.

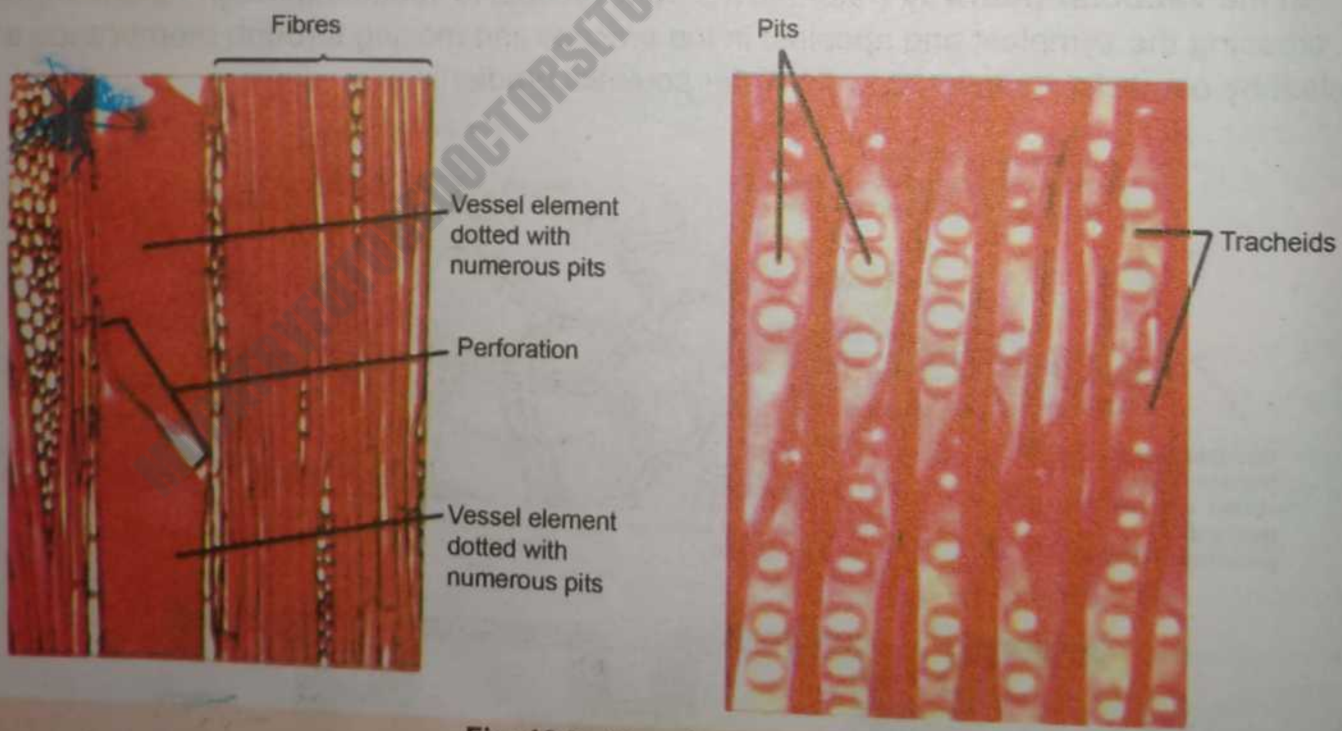


Fig: 10.5: Vessels and tracheids

Components of phloem and their functions

Phloem tissues are also complex permanent tissues that are composed of three living cells (sieve tube elements, companion cells and the phloem parenchyma) and one dead cell

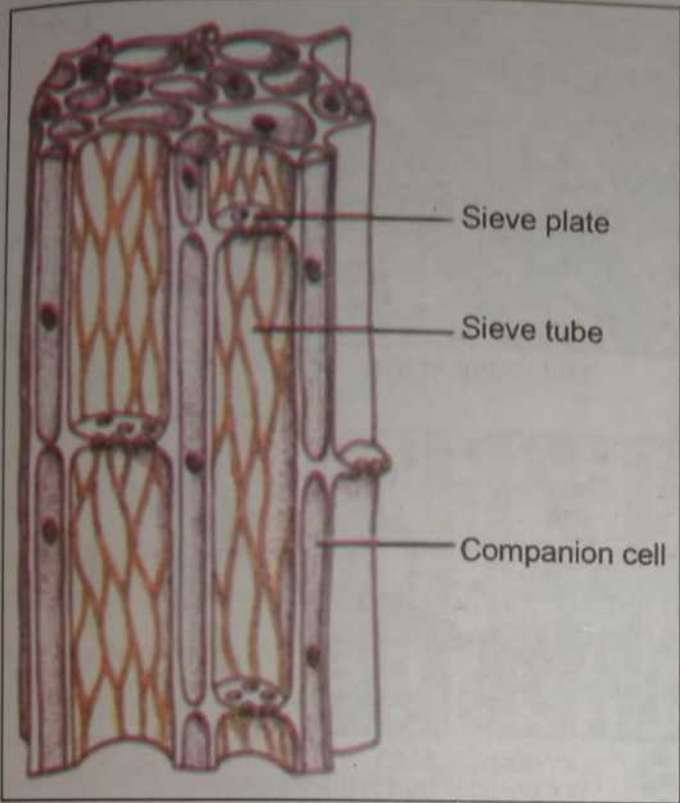


Fig: 10.6: Phloem

(phloem fibre). **Sieve tubes** are the long tube like structures, which translocate solutions of organic solutes (sucrose) throughout the plant body. These are formed by the end-to-end fusion of cells called sieve tube elements. **Sieve tube elements** are thin walled living cells but do not have nuclei, actually, their nuclei are lost as they mature. These cells are narrow at the centre and wide at the ends. A transverse or oblique pore bearing partition, the **sieve plate**, separates two successive sieve tube elements. Due to the absence of nuclei, the functions of sieve tube elements are controlled by adjacent **companion cells**. The sieve elements and companion cells, together form a functional unit that act as conducting channels and are involved in transport of organic solutes. Companion cells provide energy to sieve tube elements for their activities. Like xylem tissue, phloem also possesses parenchyma and fibre cells. Phloem parenchymas are storage cells and phloem fibres are very much thick walled supporting cells.

10.3.4 Ascent of sap

Water and minerals are absorbed by the root epidermal cells of soil from where these substances are first moved to the root xylem cells and then to the leaves. This upward movement of water and dissolved mineral from root to the leaves through xylem tissue is called **ascent of sap.** Since this movement occurs against the gravity therefore, a considerable force is required to conduct water and minerals in tall heighted plants. The most acceptable theory that explain this movement is generally called TACT theory.

TACT theory

According to this theory, four factors such as **T**ranspiration pull, **A**dhesion, **C**ohesion and **T**ension (TACT) are combined to form a collective force that is mainly responsible for ascent of sap

1. Transpiration pull

When stomata are open, the water molecules move from the region of high water potential (intercellular spaces of leave) to a region of low potential (in the air). This evaporation of water is called **transpiration**. In the same way the dry intercellular spaces pull water from surrounding cells which in turn pull the water from the xylem tissue. Thus, the phenomenon of transpiration develops a pulling force, the **transpiration pull** that compels the water and minerals to move upward through the xylem.

2. Adhesion

Adhesion is the attractive force between water molecules and other substances. Because both water and cellulose are polar molecules so there is a strong attraction for water within the hollow capillaries of the xylem. Adhesion of the string of water molecule to the wall of the xylem cells assists upward movement of the xylem sap counteracting the downward gravity. Adhesion also helps to hold water in the xylem when transpiration is not occurring.

3. Cohesion and tension

Water molecules attract one another, forming weak hydrogen bonds. This attraction among water molecules is called **cohesion** and the hydrogen bonds formed between them are termed as **tension**.

Mechanism of TACT force

The column of water molecule within the xylem is at least as strong and as unbreakable as a steel wire of the same diameter. Hydrogen bonds among water molecules provide the cohesion that holds together the 'string' of water extending the entire height of the plant within the xylem. As long as transpiration continues, the string is kept **tense** and is pulled upward as one molecule. The bulk flow of water to the top of a plant is driven by solar energy since evaporation from leaves is responsible for transpiration pull.

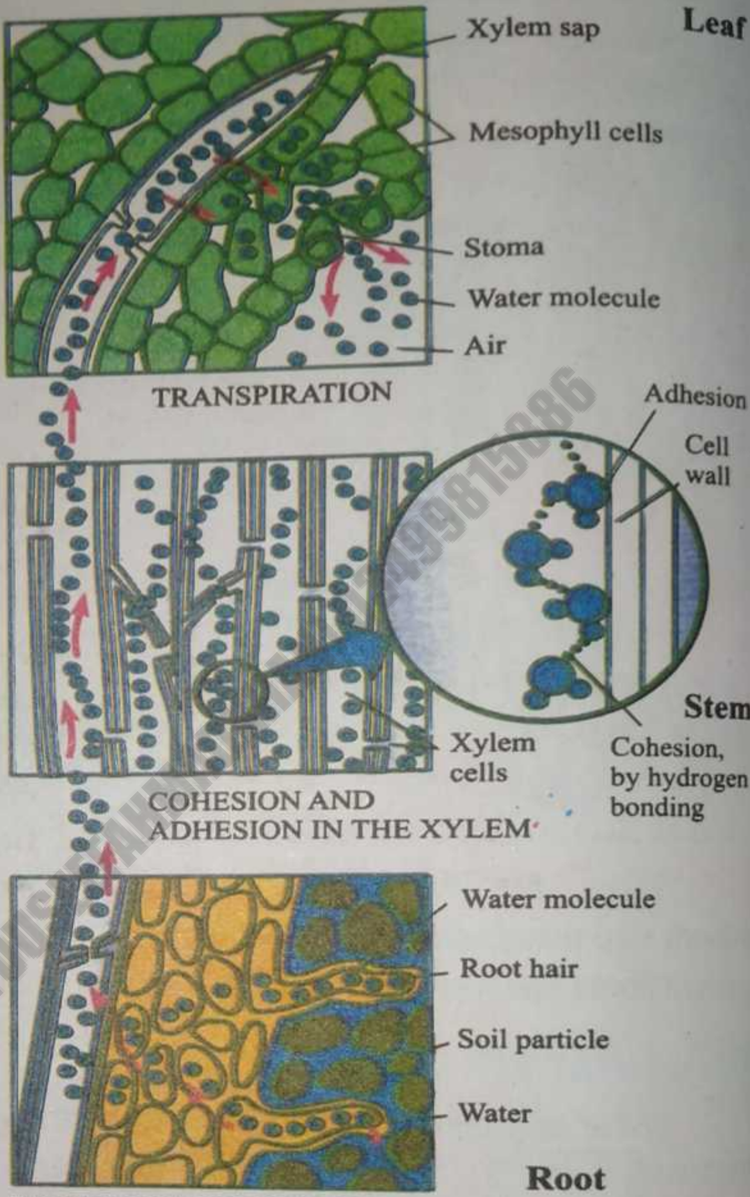


Fig. 10.7: Movement of water in xylem through TACT Mechanism

10.3.5 Opening and Closing of Stomata

You have already studied the structure and distribution of stomata in section 10.2.2. Stomata are generally open in day and close at night. The opening and closing of stomata depends upon the changes in the turgidity of guard cells. When guard cells are turgid, the stomata are fully opened but when they become flaccid, the stomata are closed. There are two theories, which may explain the opening and closing of stomata: (a) Starch sugar interconversion theory, (b) K^+ ions Influx/efflux theory.

Starch sugar interconversion theory

According to this theory, the guard cells are the only photosynthesizing cells of leaf epidermis because they have high chlorophyll content than the surrounding epidermal cells. In the morning when plant is exposed to light, the process of photosynthesis is started. As the concentration of glucose (sugar) is increased, the solute potential and water potential of guard cells become low (more negative). Since, the surrounding epidermal cells have high water content at that time so water begins to move from surrounding epidermal cells to the guard cells. The entry of water into the guard cells makes them tugid and thus, stromata are opened.

In the evening when the process of photosynthesis is stopped, the concentration of glucose is decreased because some glucose has been consumed in respiratory activities of guard cells, some of it is transformed into sucrose so that it can be transported to other parts, and the remaining glucose is converted into insoluble starch and is stored for later use. The decrease in glucose concentration causes an increase in water potential of the guard cells. In this way, water begins to move from guard cells to surrounding epidermal cells. Due to loss of water guard cells become flaccid, thus stomata are closed.

K+ ions Influx/efflux theory

According to this theory, the start of photosynthetic activity in the morning when plant is exposed to light, causes a decrease in level of CO_2 in the guard cells. Low level of CO_2 favours or stimulates the influx (inward movement) of K^+ ions (shown in red dots in the fig. 10.8) into the guard cells from the surrounding epidermal cells by active transport. At the same time, malic acid is ionized into malate$^-$ ions and H^+ ions due to the exposure of blue light (a part of visible light). The accumulation of H^+ ions causes decrease in pH of guard cells, which are then pumped to surrounding epidermal cells in order to maintain the pH of guard cells. The incoming K^+ ions are combined with malate$^-$ ions to form potassium malate which is highly soluble in water thus decreases the water potential of the guard cells. In this way water begins to move from surrounding epidermal cells to guard cells. The entry of water into the guard cells makes them turgid and thus, stomata are opened.

In the evening, the photosynthetic activity is stopped and level of CO_2 rises in guard cells. High level of CO_2 favours or stimulates the efflux (outward movement) of K^+ ions (shown in red dots in the fig. 10.8) from the guard cells into the surrounding epidermal cells by active transport. At the same time, malic acid is reformed by the combination of malate$^-$ ions and H^+ ions as there is no exposure of blue light now. Due to the absence of potassium malate, the water potential of the guard cells are increased. In this way, water begins to move to surrounding epidermal cells from guard cells. The loss of water from the guard cells makes them flaccid and thus, stomata are closed.

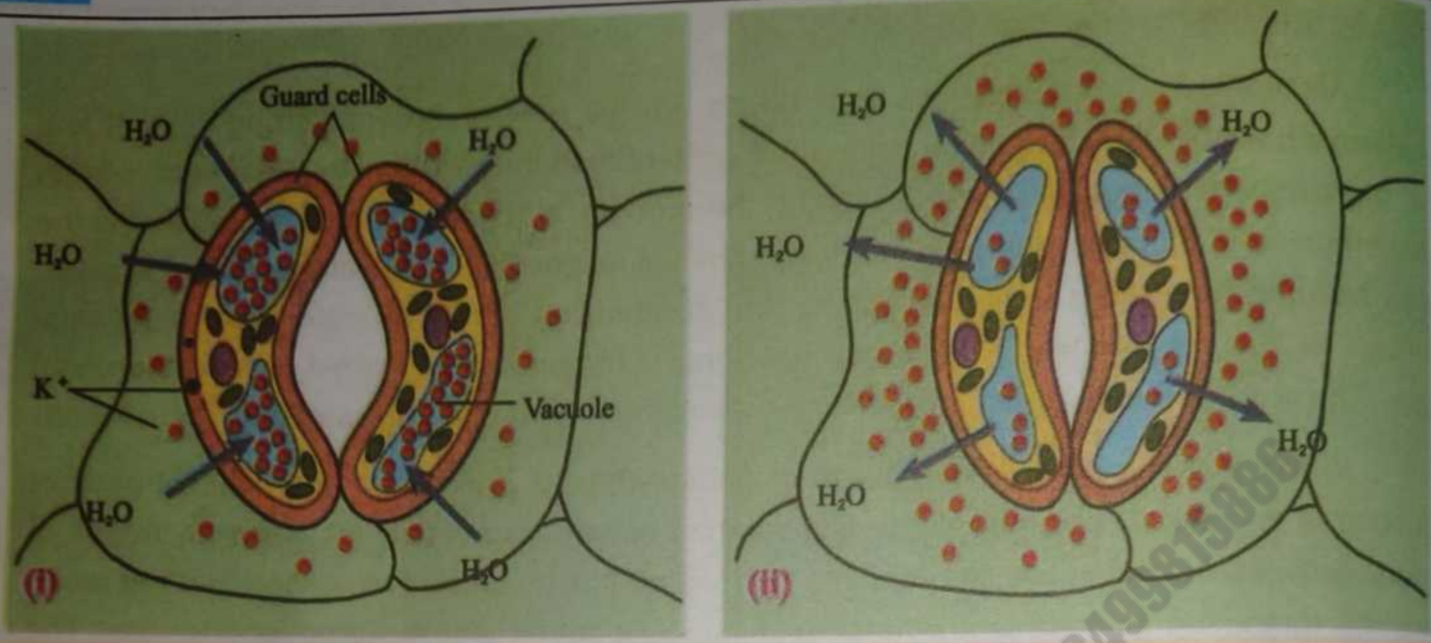


Fig: 10.8: (i) Stomata opening (ii) Stomata closing

10.3.6 Translocation of organic solutes

The movement of prepared food (organic solutes) to different parts of the plant body through phloem tissue is called translocation of organic solutes.

Pattern or direction of translocation

Like ascent of sap, this movement cannot be characterized as upward or downward movements, because prepared food is to move to different directions. Therefore, in order to define the direction of this movement it is usually said that translocation always occurs from a **source** towards a **sink**. The term source is applied to the area of supply of food such as food manufacturing organ or storage organ (when it supplies the food). The term sink is used for the area of utilization of food such as metabolizing organ or storage organ (when it stores the food). Leaf is purely a source while fruit is particularly a sink on the other hand root and stem act as both source, and sink.

Composition of translocating fluid (Phloem sap)

The studies of composition of phloem sap have revealed that it consists of 10-25% dry matter. The 90% of this dry matter is sucrose (cane sugar), while remaining are other organic compounds.

Mechanism of translocation

The most acceptable theory that explains the mechanism of translocation of organic solutes is the **pressure flow** or **mass flow theory**. According to this theory, the sugars produced in **source regions**, such as photosynthesizing leaves or storage places are loaded into the phloem's sieve tube elements by the companion cells. The active transport increases the concentrations of sugars in the phloem, thus water potential is decreased. As a result, water moves to phloem by osmosis from the nearby

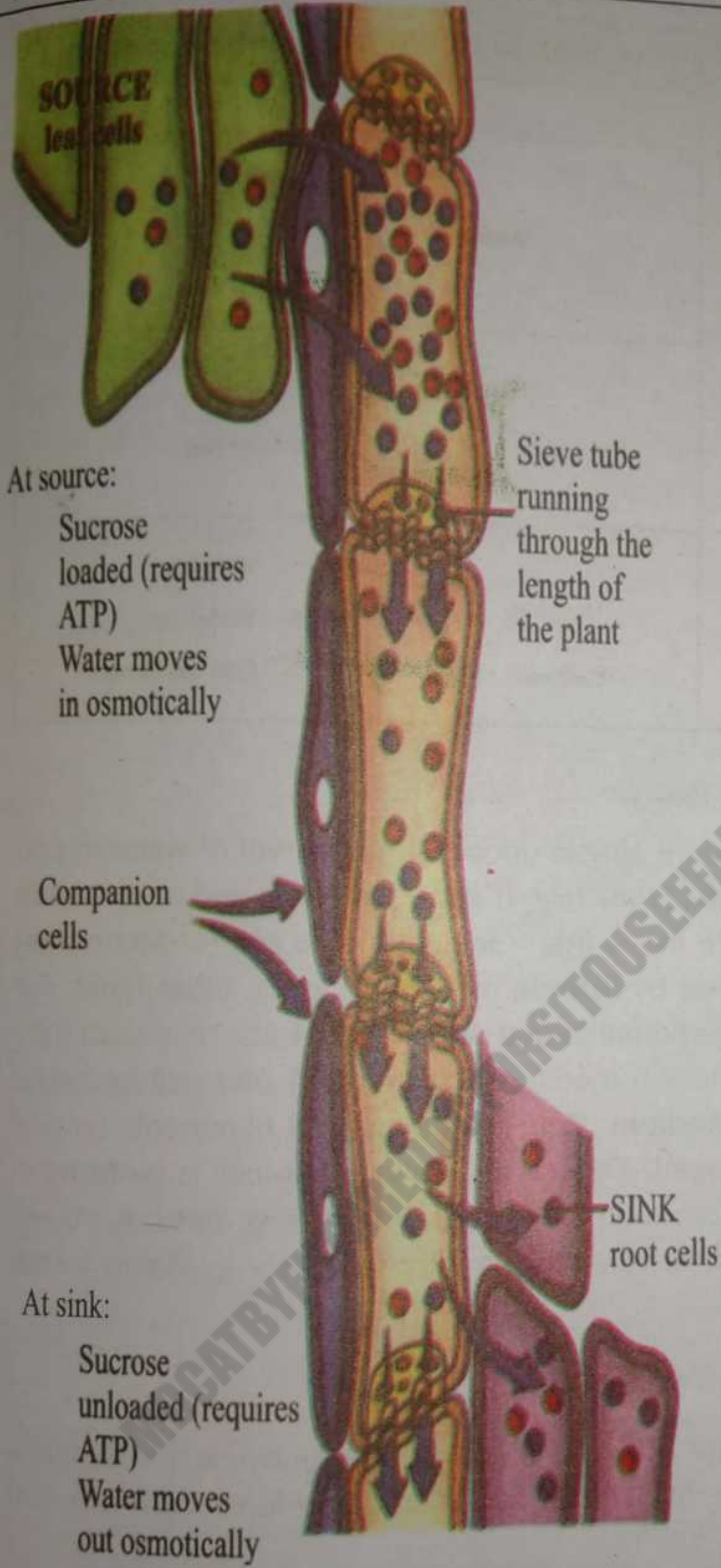


Fig: 10.9 Pressure flow Mechanism for Phloem Transport: Sugar is actively loaded into the sieve tube at the source. As a result, water moves into the sieve tubes by osmosis. At the sink, the sugar is actively unloaded and water leaves the sieve tube by osmosis.

xylem cells and increases hydrostatic pressure in the phloem cells, which pushes forcibly the sugary solution away from the leaf (**source**). The pressure gradient from source to sink causes translocation from the area of higher hydrostatic pressure (the source) to the area of lower hydrostatic pressure (the sink). When this solution is reached to the sink such as roots, the root cells actively absorb the organic solutes from this solution. The loss of solutes in phloem sap causes an increase in water potential so the water from the phloem flows back to the xylem tubes.

10.4 HOMEOSTASIS IN PLANTS

Homeostasis is the ability to maintain a steady state within a constantly changing environment that contributes towards the success of living systems. The outer environmental conditions such as water availability, nutrients and temperature often show fluctuations that also affect these components within plant body. Plants have several adaptations to cope with these challenges. Here you are going to learn about osmotic adjustment (osmoregulation) and thermoregulation in plants.

10.4.1 Osmotic adjustment (Osmoregulation)

The maintenance of water and solute level in the body is called osmotic adjustment or osmoregulation. Water and solute relations establish three kinds of osmotic situations such as hypotonic, hypertonic and isotonic.

Table: 10.2 Movement of water in and out of the cells in different osmotic conditions

Medium and its effect	Plant cell
Hypotonic • Water potential is higher than cell sap • Solute concentration is lower than cell sap • Endosmosis i.e., movement of water inward.	
Hypertonic • Water potential is lower than cell sap • Solute concentration is higher than cell sap • Exosmosis i.e., movement of water outward.	
Isotonic • Water potential is same as in cell sap • Solute concentration is same as in cell sap • No net movement of water	

Movement of water in different osmotic conditions

Different osmotic conditions cause different effects upon net movement of water in and out of the cells. If a cell is kept in a medium which has higher water potential and lower solute concentration than cell sap, the water begin to move from medium to the cell **(endosmosis)** and cell becomes turgid. Such medium is called **hypotonic medium**. On the other hand, if a cell is kept in a medium which has lower water potential and higher solute concentration than cell sap, the water begin to move from cell to the medium **(exosmosis)** and cell becomes flaccid. Such medium is called **hypertonic medium**. Both hypotonic and hypertonic type of osmotic conditions compel for osmotic adjustment. The ideal situation for a cell is **isotonic** in which water potential of both cell and outer environment is equal, therefore, there is no net movement of water in and out of the cell. However, this situation is rarely available to the plants in natural environment.

Osmotic adjustments in plants of different environment

Based upon availability of water, plants are classified into hydrophytes, mesophytes and xerophytes. Each group exposed in different osmotic conditions therefore, show different osmotic adjustments.

Hydrophytes

The plants that are found in the area where abundant water is available, are called **hydrophytes**. Aquatic plants of freshwater habitats are example of such plants. These plants are exposed in hypotonic conditions so face problem of flooding (excess of water). Such plants show highest rate of transpiration due to broad leaves with large surface area and distribution of stomata on upper epidermis, which are kept open day and night. These plants do not store water and either have very thin cuticle or almost none, on their surface.

Mesophytes

The plants that are found in the area where moderate supply of water is available are called **mesophytes**. Common crop plants such as wheat, rice corn are example of such plants. These plants are exposed in nearly isotonic conditions so face no drastic problem of flooding (excess of water) or dehydration (deficiency of water). Such plants show moderate rate of transpiration due to medium sized leaves with distribution of stomata on lower epidermis, which are generally open in day and close at night. However, these plants can close their stomata even in day. These plants store a very small amount of water, have very thin cuticle on their surface.

Critical Thinking

In tropical climates, many tall plants shut stomata during the hot days and open at night. If their stomata are closed during day, why doesn't the water within the plant fall down the stem?

Xerophytes

The plants that are found in the area where very little amount of water is available are called **xerophytes**. Desert plants such as cactus, opuntia are example of such plants. These plants are exposed to severely hypertonic conditions so face extreme degree of dehydration. Such plants show very reduced rate of transpiration due to narrow needle like leaves or due to complete modification of leaves into spines. They have stomata in depressions (**sunken stomata**), which are generally close in day and open at night. These plants store a very high amount of water therefore; they are also called **succulent plants**. They have very think cuticle on their surface.

Table: 10.3 Comparison of osmotic adjustment in different groups of plant

Features	Hydrophytes	Mesophytes	Xerophytes
Habitat	Aquatic	Terrestrial (moderate)	Terrestrial (severely dry)
Osmotic conditions of medium	Hypotonic	Nearly isotonic	Strong hypertonic
Problems faced by plant	Flooding	No drastic problem	Severe dehydration
Rate of transpiration	Very high rate	Medium rate	Very low rate
Stomatal distribution	On upper epidermis	On lower epidermis	Sunken stomata
Stomatal opening	Stomata remain open all the time	Open in day and close at night	Close in day and open at night
Thickness of cuticle	Very thin or none	Less thick	Very thick
Storage of water	None	Little storage	Succulent

10.4.2 Osmotic Adjustments of Plants (halophytes) in Saline Soils

A saline soil is characterized by the presence of excessive salt concentration. High saline soils are characteristics of salt marshes. Saline soils due to very low water potential create a physiological drought i.e., plants are unable to absorb water even water is available in the soil. Therefore, plants living in saline environments (**halophytes**) have adapted mechanisms to deal with this problem.

Halophytes respond to salinity by taking up sodium and chloride at high rates and then accumulating these ions in the vacuoles of the leaf cells, keeping the salt concentration in the cytoplasm and organelles at a low level that does not interfere with the functions of their enzymes and metabolic machinery of their leaves. These plants use the accumulated salt for osmotic adjustment to the low water potential in the soil.

On the other hand some halophytes do not uptake salts form soil; instead, they make osmotic adjustment by accumulating their own dissolved substances compatible with enzymes and metabolism. These **"compatible solutes"** are mostly organic compounds such as the nitrogenous compounds glycine and, in some plants, sugar alcohols, such as sorbitol.

10.4.3 Thermoregulation in plants

All organisms for optimum activity of their enzymes require a suitable temperature. Thermoregulation is a type of homeostasis by which an organism is able to perform necessary adjustment in response to low and high temperature stress. Plants also have certain adaptations that enable them to tolerate against low and high temperature changes.

Adaptations in plants to cope with the low temperature stress

Low temperature affects the fluidity of cell membrane because lipids of the membranes become locked into crystalline structures, thus membranes become porous which affect the transport of solutes. The structure of membrane proteins is also affected. In addition, freezing temperature also causes ice crystal formation with in cytoplasm that interferes with the metabolic activities of the cell.

In order to prevent crystallization in cell membrane, plants **increase the proportion of unsaturated fatty acids** (which have low freezing point), which help membrane to maintain structure at low temperature and the crystal formation is inhibited. In order to prevent crystallization within cytoplasm, the plants native to cold regions such as oaks, maples, roses and other have adapted to bring **changes in solute compositions** of the cells which causes cytosol to super cool without ice formation, although ice crystals may form in the cell wall.

These adaptations of plants to low temperature stress require time because of this reason rapid chilling to plants is more stressful than gradual drop in air temperature.

Adaptations in plants to cope with the high temperature stress

High temperature stress causes excessive evaporative loss of water by transpiration that may leads to dehydration and ultimately wilting (loss of turgor). It also causes denaturation of enzymes and damages the metabolism therefore, harms or kills the plants.

In hot areas, the plants develop a shiny cuticle, which reflects much of the incident light. Thus preventing the heat absorption and overheating by the plant. The leaves contain numerous stomatal openings, which allow the loss of water (transpiration), and remove the heat from the plant. However, very high temperature i.e., above 45°C, plants close their stomata to prevent the water loss. Therefore, most plants have adapted to survive in such high temperature stress situations by synthesizing large quantities of special proteins called **heat shock proteins**. Since these proteins are heat tolerant, so they embrace enzymes and other proteins thus help prevent denaturation.

10.5 SUPPORT IN PLANTS

When the life started on land from water, one of the very important needs for the organisms was to gain some sort of support and strength for keeping their bodies in shapes. Plants also have variety of mechanism for support. Such as, turgor mechanism in parenchyma cells, mechanical tissues (thick walled e.g., collenchyma and sclerenchyma), arrangement of vascular bundles and secondary growth.

10.5.1 Role of turgor mechanism in support

In plants the **parenchyma** cells have large central vacuoles, which are filled with water. The water causes pressure on the surrounding walls, when the cells are turgid. This pressure on the walls keeps the cells, stiff and hard and is called **turgor pressure**. In herbaceous plants where the specialized supporting tissues are not common, the turgidity of the cells provides support and strength and it grows uprightly.

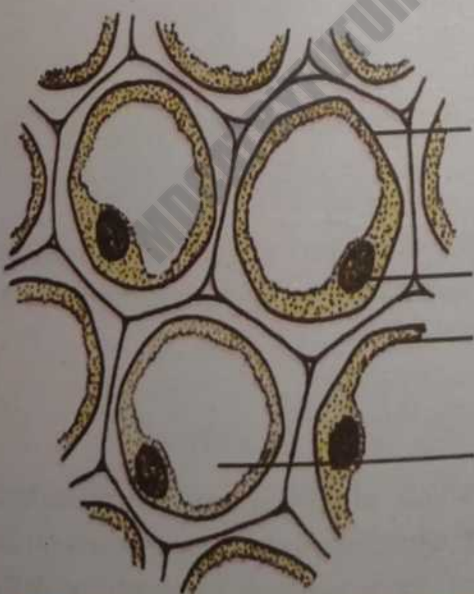


Fig: 10.10: Collenchyma

10.5.2 Role of mechanical tissues in support

The term mechanical tissues is used for the tissues of thick walled cells i.e., collenchyma and sclerenchyma.

Collenchyma

The **collenchyma** is characterized by the extra cellulose deposition at the corners of these cells. It is a mechanical tissue, providing support particularly in young plants, herbs and leaves etc., (where secondary growth does not occur) collenchyma is living so it can grow and stretch freely. In stems and petioles it plays more important role in support because of its location in peripheral regions near epidermis.

Sclerenchyma

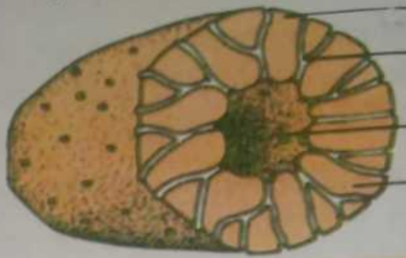
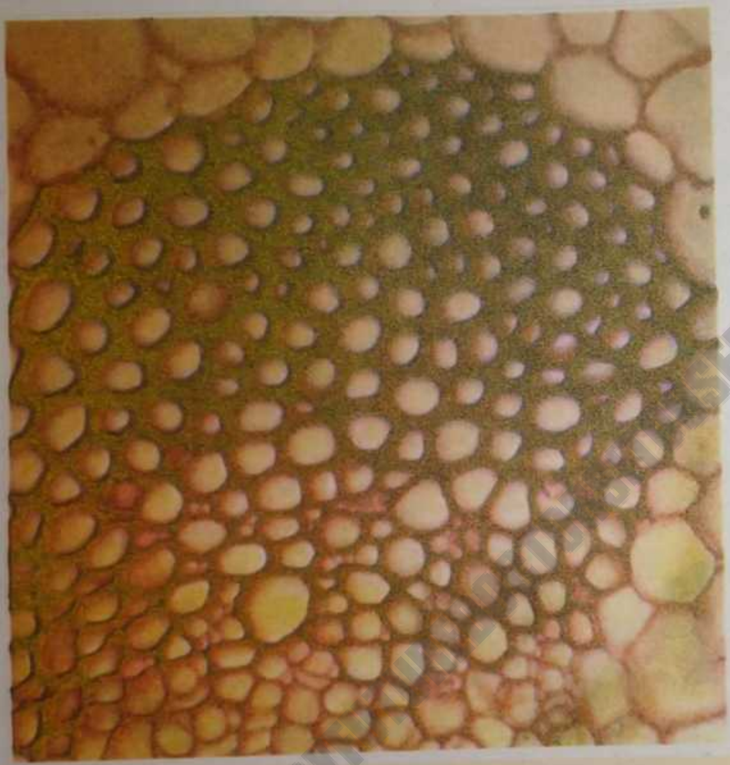


Fig: 10.11: T.S. of sclereids

Sclerenchyma tissues are solely means for giving support and mechanical strength for the plants. The mature cells are dead due to the formation of very thick secondary lignified wall. The sclerenchyma is of two types, i.e., fibres and sclereids. Fibres are elongated cells and sclereids are roughly spherical or variously shaped cells otherwise both have heavily thickened walls with lignin and with great tensile strength. **Fibres** are found in the pericycle of stems forming a solid rod of tissue. Fibres also found in xylem and phloem tissues. **Sclereids** are common in fruit wall and seed coats.



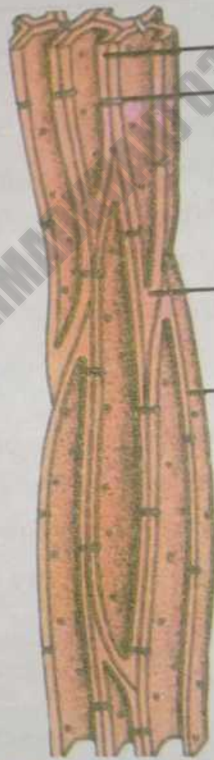


Fig: 10.12: (a) T.S. of sclerenchyma cells (b) L.S. of sclerenchyma cells

10.5.3 Arrangement of vascular bundles

In dicot plants, vascular bundles are arranged in the form of ring in stem. As compared to monocot plants in which vascular bundles are scattered in the stem, the ring arrangement of vascular bundle in dicot plants also provide support to the plant body.

10.6 GROWTH AND DEVELOPMENT IN PLANTS

Development is a programmed series of changes by which an organism is converted from simpler to form that is more complex. The growth is part of development process which is characterized by an irreversible increase in the size and mass of an organism. In plants growth and development involve four phases: cell division (production of new cells), cell elongation (enlargement of cell size), cell maturation and differentiation (cells structurally and functionally become specialized to perform particular functions). Plants add new organs like, branches, leaves, roots etc throughout life. This unique pattern is called **continuous growth**.

10.6.1 Meristematic tissues (Meristems)

In lower plants, the entire plant body is capable of growing, but in higher plants, growth is limited to certain regions known as growing points that possess specialized tissues for growth, the **meristematic tissues** or **meristems**. The cells remain forever young and divide actively throughout the life of the plant in these tissues. When a meristematic cell divides in two, the new cell that remains in the meristem is called an **initial**, and the other is called the **derivative**. As repeated mitotic divisions of the initial cells add new cells, the derivatives are pushed farther away from the zone of active division. They stretch, enlarge and differentiate into other types of tissues as they mature. Meristematic cells are generally small and cuboidal with large nuclei, small vacuoles, and thin walls. A plant has two major kinds of meristems: the apical meristem and lateral meristem.

Apical meristems

These are located at the tips of roots and shoots. Cell divisions and subsequent cellular enlargement in these areas lengthen the above and below ground parts of the plant. Since, these meristem are present in plants right from embryonic life, therefore, they are also known as **primary meristems**.

Lateral meristems

Lateral meristems are cylinders of dividing cells on lateral sides in stems and roots of dicots and gymnosperms and increase their thickness and diameter. These meristems are derived from apical meristem after embryonic life therefore; they are also called **secondary meristem**. Vascular cambium, cork cambium, and intercalary meristem are the types of lateral meristems. Some plants grow in diameter by producing new tissues laterally from a cylinder of tissue called the **vascular cambium**, which extends throughout the length of the plant from

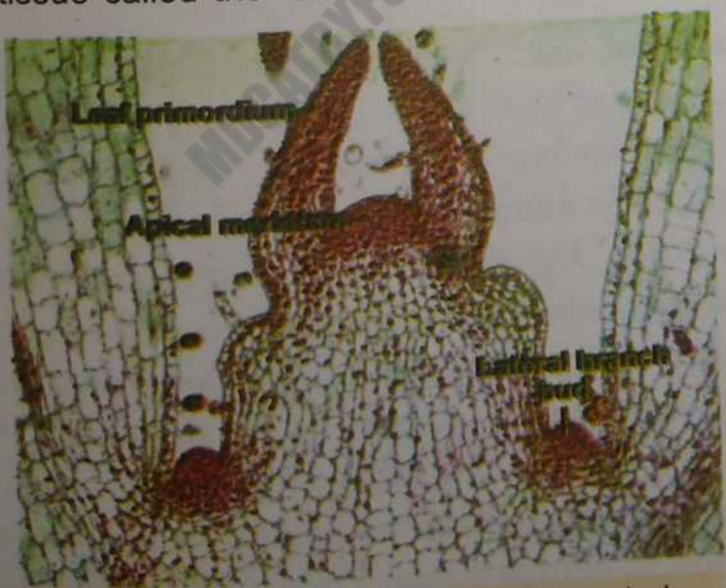


Fig: 10.13: Photomicrograph of shoot, apical

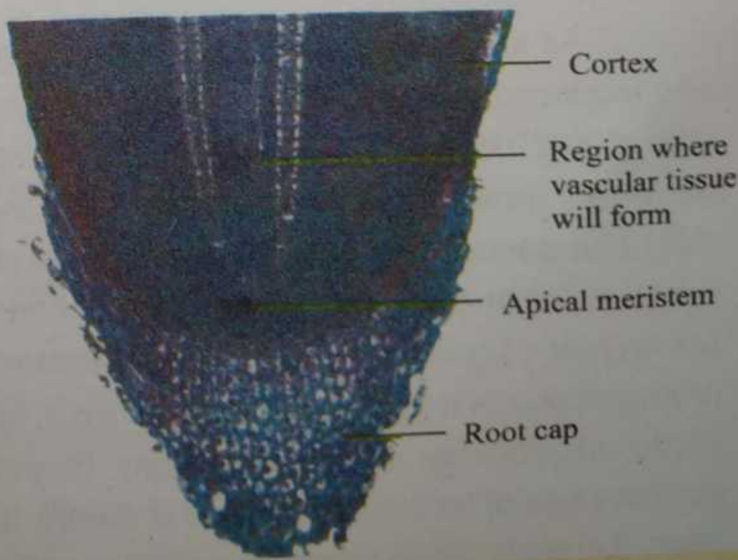


Fig: 10.14: Photomicrograph of root apical the tips of the shoots to the tips of the roots. **Cork cambium** is found in the bark of roots and stems of woody plants where they contribute in width of plant body. **Intercalary meristems** originate from apical meristems but they are separated from them and are located along the stems near the nodes. Growth in these tissues give rise side branches, leaves and lateral buds that grow up to a certain size. Tissues produced by cell divisions of the any lateral meristem are secondary tissues.

10.6.2 Types of plant growth

Based upon origin there are two types of plant growth: Primary growth and secondary growth.

Primary growth

When a plant starts its life after germination of seed, it begins to increase its length first, this increase in length of root and shoot is therefore, called **primary growth**. It remains continue throughout the life of a plant however the rate of growth may vary in different periods of life. Primary growth is carried out by the cell division in **apical meristem**.

Secondary growth

The increase in thickness and diameter of a plant is called **secondary growth**. This is characteristic of stems and roots of dicots and gymnosperms where it contributes a significant role in support of the plant body. All the tissues that are produced during secondary growth are called **secondary tissues**. Similarly, the tissues that are already present in plant before the onset of secondary growth are called **primary tissues**.

10.6.3 Role of lateral meristems in secondary growth

Two lateral meristems i.e., cork cambium and vascular cambium mainly participates in secondary growth.

Role of vascular cambium

As the plant grows lengthwise by the activity of apical meristem, vascular cambium is also produced. It is present in vascular bundle between primary xylem and primary phloem. Its rate of cell division is faster than cork cambium therefore it contributes more tissues in secondary growth. It adds two new tissues in plant body: **secondary xylem** (towards its inner side) and **secondary phloem** (towards its outer side). The rate of production of secondary xylem is faster than secondary phloem and it is produced in two different ways during the whole year of growth. In autumn and winter seasons, comparatively smaller sized cells are produced due to deficiency of water while in spring and summer seasons, larger sized cells are produced probably due to availability of water. Because of this differential growth pattern distinct rings of smaller and larger cells are formed, which represent the growth of one whole year, therefore these rings are called **growth rings** or **annual rings**. You can determine the age of plant by counting the number of these growth ring as each ring is formed in one year.

Role of cork cambium

The cork cambium or phellogen generally originates from outer most layer of primary cortex. It adds two new tissues in plant body during secondary growth: secondary cortex (towards its inner side) and cork (towards its outer side beneath the epidermis). The cork cells become dead after sometimes due to which epidermis also becomes dead. Therefore, the outer surface of mature trees looks rough.

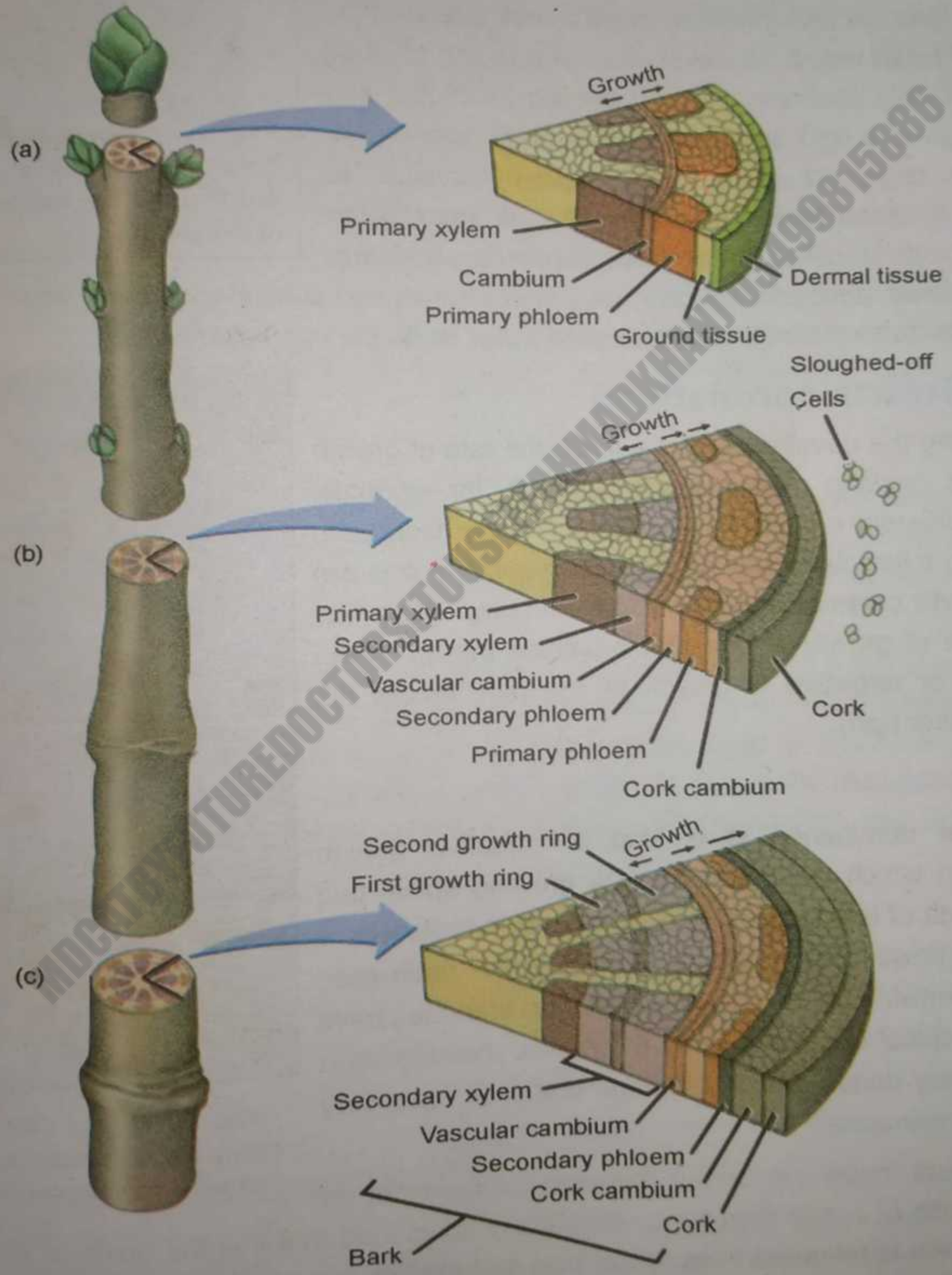


Fig: 10.15: Secondary growth

Wood and bark

During secondary growth, the bulk of tissues added laterally (inner to the vascular cambium) is mainly secondary xylem and is called **wood**. The inner region of wood (some secondary xylem, primary xylem and central most tissue, the pith) is blocked by the deposition of wastes in later life and therefore gives a dark appearance. It is called **heart wood**. However, the outer region of wood (consist of only secondary xylem) remain functional and therefore gives a light appearance. It is called **sap wood**. The outer region of stem from vascular cambium to epidermis is called **bark**. The portion of bark inner to the cork cambium is called **inner bark** (secondary phloem, primary phloem, pericycle, endodermis, primary cortex and secondary cortex) while the portion of bark outer to the cork cambium is called **outer bark** (cork and epidermis).

Critical Thinking

Transverse section of stem: Can you find out the approximate age of this plant?

10.6.4 Growth correlations

During the development of a plant, the rate of growth at different growing points is not constant, for example, growth of different meristem sometime influence upon each other. Such interactions among different growing points are called **growth correlations**. These growth correlations may be **positive** (if growth of one part promotes the growth of other part) or **negative** (if growth of one part inhibits the growth of other part).

Apical dominance

Apical dominance is a kind of negative growth correlation in which the presence of a growing apical bud inhibits growth of lateral buds. It is also found in roots where lateral root growth is inhibited by growth of the main root. The plants showing tall height with short side branches have very strong apical dominance and the plants showing short height and very dense growth of lateral branches have very little apical dominance.

Fig: 10.16: (a) A plant showing strong apical dominance (b) A plant showing weak apical dominance

Botanists have performed several experiments to study the cause of apical dominance and finally concluded that it is the auxin (a plant growth regulator) which is released from apical bud and inhibits the growth of lateral buds. It is also revealed that **cytokinin** produced by lateral buds (another plant growth regulator) works antagonistically to the **auxins** in apical dominance, thus neutralizes the influence of apical bud on lateral buds. It means that plants having strong apical dominance produce more auxins from apical bud and less cytokinin from lateral buds. Similarly, the plants having weak apical dominance produce less auxins from apical bud and more cytokinin from lateral buds.

10.7 GROWTH RESPONSES IN PLANTS

Plants generally adjust themselves to changing environment by growth. The changes in plant shape or functions are often regulated by **plant hormones** (growth substances) produced in response to environmental factors. The plant hormones act at the level of cells to induce cell division, enlargement or cell maturation.

10.7.1 Plant Growth Regulators

Plants are co-ordinated by chemicals commonly known as **plant hormones**, which necessarily move from their sites of synthesis to the sites of action, and because their effects are usually on some aspect of growth, they are called **growth regulators**. Five major types of growth regulators are recognized (a) auxins (b) gibberellins (c) cytokinins (d) abscisic acid (e) ethene. Auxins, gibberellins and cytokinins are called **growth promoters** because of their general role in promotion of growth while abscisic acid and ethene are called **growth inhibitors**.

Auxins

An auxin or **indole-3-acetic acid** (IAA), was the first plant hormone identified. It is manufactured primarily in the shoot tips (in leaf primordia and young leaves), in embryos, and in parts of developing flowers and seeds. They are mainly responsible for cell elongation.

Gibberellins

The gibberellins are widespread throughout the plant kingdom, and more than 75 have been isolated, to date. Rather than giving each a specific name, the compounds are numbered, for example, GA1, GA2, and so on. **Gibberellic acid 3 (GA3)** is the most widespread and most thoroughly studied. The gibberellins are especially abundant in seeds and young shoots where they control stem elongation by stimulating both cell division and elongation.

Cytokinins

These are named because of their role in cell division (cytokinesis), the cytokinins have a molecular structure similar to adenine. Naturally occurring **zeatin**, isolated first from corn (*Zea mays*), is the most active of the cytokinins. Cytokinins are found in sites of active cell division in plants, for example, in root tips, seeds, fruits, and leaves.

Abscisic acid

Its principal effect is inhibition of cell growth. ABA increases in developing seeds and promotes dormancy. If leaves experience water stress, ABA amounts increase immediately, causing the stomata to close.

Science Titbits

Different **cytokinins: auxin** ratios change the nature of organogenesis. If kinetin (cytokinins) is high and auxin low, shoots are formed; if kinetin is low and auxin high, roots are formed. Lateral bud development, which is retarded by auxin, is promoted by cytokinins.

Table: 10.4 A comparison of effects of plants growth regulators on different plant parts

Part Affected	Auxins	Gibberellins	Cytokinins	Abscisic Acid	Ethene
Stem	• Promote cell enlargement behind apex. • Promote cell division in cambium.	• Promote cell enlargement in the presence of auxin • Promote leave growth.	• Promote cell division in apical meristem and cambium • Promote leave growth.	Inhibit growth during stress, e.g., drought, salinity and water logging.	Inhibit growth during stress, e.g., drought, salinity and water logging.
Root	• In low conc. promote growth • In high conc. inhibit growth • Promote growth from cuttings and calluses	Nil	• Inhibit primary root growth • Promote lateral root growth	Nil	Inhibit root growth
Floral buds	Promote bud initiation	Promote bud initiation	• Promote bud initiation • Promote lateral bud growth • Break bud dormancy	Promote bud initiation	Promote bud initiation
Flowering	Nil	• Promote in long day plants • Inhibit in short day plants • Acts as substitute for red light • Antagonistic to Abscissic acid	Nil	• Promote in short day plants • Inhibit in long day plants • Acts as substitute for far red light • Antagonistic to gibberellins	Promote in pineapple
Apical dominance	Promote	Enhance the action of auxin	Inhibit	Nil	Nil
Fruit growth	Promote ripening	Promote ripening	Promote ripening	Nil	Promote ripening
Parthenocarpy	Rarely promote	promote	Rarely promote	Nil	Nil
Leaf senescence	Delay	y	Delay	Promote	Nil
Seed dormancy	Nil	BreakDela	Break	Promote	Nil
Abscission	Inhibit	Inhibit	Inhibit	Promote	Nil
Stomatal opening	Nil	Nil	Promote	Inhibit	Nil

Ethylene or ethene

Ethylene or ethene is a simple gaseous hydrocarbon produced from an amino acid and appears in most plant tissues in large amounts when they are stressed. It diffuses from its site of origin into the air and affects surrounding plants as well. Ethylene stimulates the ripening of fruit and initiates abscission of fruits and leaves.

10.7.2 Growth movements in plants (Tropic Movements)

The plants as their characteristics do not show locomotion, but the individual plant organs may show movements by change in differential growth in response of various stimuli (internal or external). In this section, you are going to learn about **tropic movements** or **tropisms** that are either towards or away from certain external stimuli such as light, force of gravity, touch and chemical.

Phototropism

Phototropism is the movement of plants parts, either towards (positive) or away (negative) from light source. Such movements are found in shoots and roots. Shoots show positive phototropism (grow upward above the ground) and roots show negative geotropism (grow downward under the ground).

Geotropism

Geotropism (gravitropism) is the movement of plants parts, either towards (positive) or away (negative) from force of gravity. Such movements are also found in shoots and roots. Shoots show negative geotropism (grow upward above the ground) and roots show positive geotropism (grow downward under the ground).

Thigmotropism

Thigmotropism is the movement due to the touch stimulus. Such movements are shown by climbing plants that require any supportive structure such as a wall, a wooden stick or rod or even a rope to climb over.

Chemotropism

In **chemotropism** the stimulus is a chemical (nutrients). Such movement is shown by fungal mycelium in which hyphae show more growth towards the nutrients.

10.7.3 Photoperiodism

Light exerts its influence on living organisms through variation in intensity, quality and day length. Total duration of light in the whole day is called **photoperiod** and its effect on the development of flowers in some plants is called **photoperiodism.** This behavior is found in some plants in which due to the exposure of appropriate photoperiod their vegetative buds are transformed into floral buds and the flowers are begin to produce. If such plants do not get required, photoperiods their vegetative growth remains continue but flowers are not produced.

Classification of plants based upon photoperiodism

Plants are classified into three main groups on the basis of how photoperiodism affects their flowering.

Short-day plants: These plants flower when the photoperiod is less than a certain critical length. e.g., Maryland mammoth, cocklebur, chrysanthemum, tobacco etc.

Long-day plants: These plants flower when the photoperiod exceeds from the critical length e.g., spinach, sugar beet, Henbane snapdragon, cabbage, spring wheat etc.

Day-neutral plants: These plants can flower in any photoperiod after a considerable vegetative growth. The flowering is not affected by variation in day length or darkness in these plants. e.g., tomato, pansy, bean, sweet pea, rose, etc.

Concept of critical photoperiods

The concept of critical lengths of photoperiod for both long day and short day plants is different and its duration is also variable for every plant even they belong to the same group. For example, for **tobacco, 14 hours** photoperiod is seemed to be critical and for **cocklebur 15.5 hours** photoperiod is critical, however both are short day plants. Actually, length of critical photoperiod depends upon the level and relative proportion of two forms of phytochromes (will be discussed later in this section) in plant body. Critical photoperiod for short day plant can be defined as "the maximum length of day, which is required to stimulate/induce flowering in a short day plant". Examples have already been given. Similarly, "critical photoperiod for long day plant can be defined as the minimum length of day, which is required to stimulate/induce flowering in a long day plant". For example, for henbane 11 hours photoperiod is critical.

Significance of dark periods over photoperiods

Now it has been discovered that the actual stimulus for flowering is the uninterrupted dark period rather than the light period. Therefore, it is really the length of dark period which is critical. For example, if a short day plant (e.g., cocklebur) is grown in appropriate short days (less than 15.5 hours), but its long nights (more than 8.5 hours) are interrupted by short light periods, flowering is prevented. Similarly, a long day plant (e.g., henbane) can flower in inappropriate short days (less than 11 hours), if its long nights or dark periods (more than 13 hours) are interrupted. Therefore, the short day plants are actually **long night plants** and long-day plants are **short-night plants**.

Effect of quality of light and discovery of phytochromes

Further night interruption experiments on short day and long day plants have revealed that beside dark length the quality (wavelengths) of light is also important in promotion or inhibition of flowering. For example, cocklebur a short day plant, will not flower if its long nights are interrupted but experiments revealed that **red light** (660 nm wavelength) was effective in preventing flowering and the **far red light** (730 nm wavelength) reversed the effect of red light. It was also demonstrated that if more than one type of light exposures were given to interrupt the night, the last light treatment always determines the response. The behaviour of long day plants was opposite in these experiments.

Based upon above observation, researchers concluded that there must be some kind of photoreceptors in plants, due to which plants respond differently to these lights. This struggle finally leads to the discovery of these photoreceptor pigments in the form of **phytochromes**.

Mechanism of Photoperiodism

The mechanism of photoperiodism depends upon the rate of interconversion and the accumulation of either form of phytochromes. Phytochromes are blue-green pigment, which are involved in photoperiodism as photoreceptor. They are protein in nature but also contain an iron containing non-protein part.

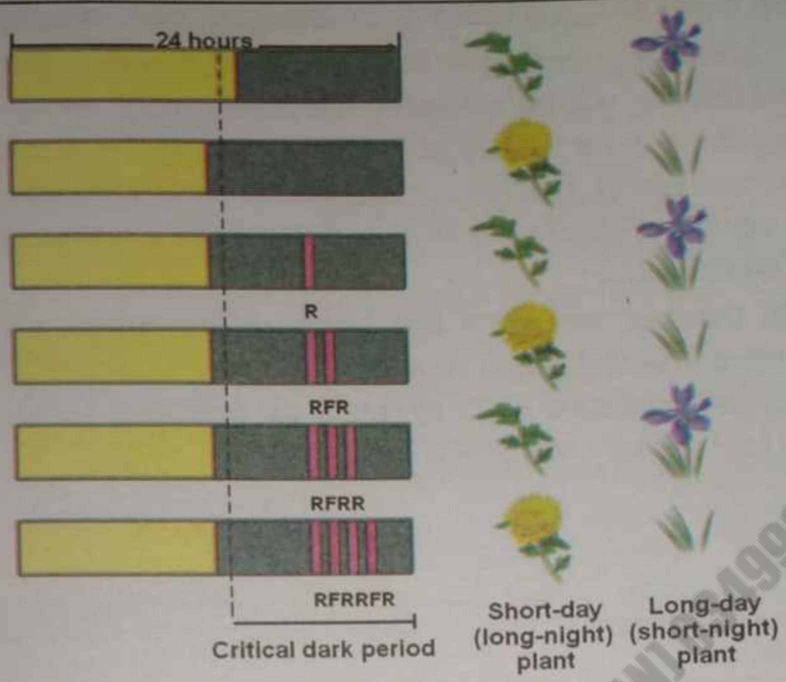


Fig: 10.17: Phytochrome detects varying periods of day length and darkness.

Interconversion and action of phytochromes

Phytochrome is a blue green leaf pigment that alternately exists in two forms: Pr (Phytochrome red) absorbs red light (of 660 nm wave length) and is converted to Pfr Pfr (Phytochrome far-red) absorbs far-red light (of 730 nm wave length) and is converted to Pr Direct sunlight contains more red light than far-red light; therefore Pfr is present more in plants during the day. Far-red light are invisible heat radiations that are present in both day and night, but conversion of Pfr to Pr occurs mainly at night. The rate of this conversion (Pfr to Pr) provides a biological clock to the plants to determine the length of their night.

A short day plant requires a low ratio of Pfr to Pr. A night longer than critical length results in accumulation of Pr so the Pfr to Pr ratio becomes low. On the other hand a long day plant requires a high ratio of Pfr to Pr. A night shorter than critical length results in less formation of Pr so the Pfr to Prratio becomes high.

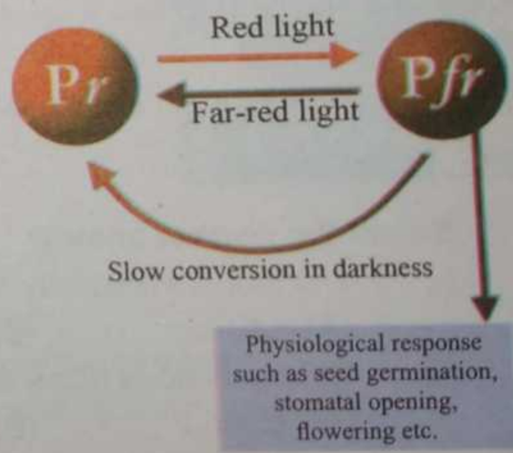


Fig: 10.18: Interconversion of two forms of phytochromes

Role of florigen hormone

The specific ratios of P_{FR} (P_{730}) to P_R (P_{660}) at the end of nights (discussed above) trigger the production of a particular hormone in plants known as **florigen**, which transforms the vegetative buds into floral buds, thus flowers are produced.

10.7.4 Vernalization

The promotion of flowering by exposure to low temperature is known as **vernalization**. The low temperature stimulus is received by the shoot apex of a mature plant or embryo (not by the leaves as in **photoperiodism**). Although the exact **temperature** and amount of time required varies among species, most vernalization temperature occurs between 0°C to 10°C, but temperature around 4°C is found to be most effective. Vernalization is the requirement of **biennial plants** (the plants that complete their life cycle during any months of two different calendar years). For example, **winter wheat** is a biennial plant, which is sown in October or November and harvested in June or July of the next year. If it is sown in February or March like **spring wheat** (annual plant), it will show vegetative growth but will not flower. However, it can flower even it is sown in February or March, if its seeds are exposed to several weeks of low temperatures (4°C) stimulus.

In some plants, the requirement of **low temperature** period is absolute, meaning that they will not flower without vernalization. Low temperature stimulates production of **vernalin** hormone that transforms vegetative buds to the floral bud thus flower are produced. It has been now discovered that vernalin is actually **gibberellin**.

Activity

1. Demonstration of the evolution of CO_2 from leaf discs placed in dark and light, with the help of indicator (hydrogen carbonate)
2. Microscopic observation of the slide of LS of a dicot stem, identifying and drawing vessel element, vessel, and phloem sieve tubes
3. Locating annual rings in the log of a tree and calculation of the age of a plant by counting number of annual rings
4. Demonstration of phototropism, geotropism and thigmotropism in plants
5. Demonstration of the folding of leaf after touch in *Mimmosa pudica*

Exercise

MCQs

1. **Select the correct answer**

(i) It is found essentially in organic compounds
(A) calcium (B) nitrogen (C) carbon (D) phosphorus

(ii) Chlorosis does occur due to the deficiency of
(A) sulphur (B) magnesium (C) phosphorus (D) calcium

(iii) Carnivorous plants use insects as a source of
(A) water (B) glucose (C) oxygen (D) nitrogen

(iv) Most of the uptake of water and minerals from soil takes place through
(A) cortex (B) root cap (C) xylem (D) root hair

(v) Symplast is the movement of water through
(A) vacuoles (B) cell walls (C) cytoplasm of cells (D) interspaces

(vi) Guard cells are the only cells of epidermis, which have
(A) vacuole (B) chloroplasts (C) cytoplasm (D) leucoplasts

(vii) The sugar moves through phloem mostly in the form of
(A) glucose (B) sucrose (C) maltose (D) lactose

(viii) Succulent tissues are formed in
(A) hydrophytes (B) thallophytes (C) mesophyll (D) xerophytes

(ix) A researcher, who wants to study the composition of a plant's sap, inserts a capillary tube into the phloem. What causes the sap to flow out of the tube?
(A) capillarity (B) hydrostatic pressure
(C) root pressure (D) transpiration stream

Short Questions

2. What are carnivorous plants? Give examples.
3. How exchange of gases takes place in plants? What is the purpose of gaseous exchange?
4. Draw and label T.S. of bifacial leaf.
5. What is the role of transpiration in exchange of gases in plants?
6. Write a shot note on: (a) hydrophytes (b) mesophytes (c) xerophytes
7. What is the role of turgor mechanism for support in plants?
8. Describe the types of plant growth.
9. Classify plants based upon photoperiodism.
10. What is critical photoperiod?
11. What are phytochromes?
12. Why support is needed in terrestrial life?
13. What are the types of movement in plants in response to stimuli?
14. Write the differences between:
(a) apoplast pathway and symplast pathway.
(b) cohesion and adhesion
(c) endosmosis and exosmosis
(d) hypotonic and hypertonic solution
(e) mesophytes and xerophytes
(f) collenchyma and sclerenchyma
(g) primary growth and secondary growth

Extensive Questions

15. Describe the exchange of gases between plants and environment.
16. Explain the movement of water between plant cells and their environment.
17. Describe the movement of water through roots.
18. Describe the ascent of sap in xylem through TACT mechanism.
19. Explain the mechanism of opening and closing of stomata.
20. Describe the translocation of organic solutes in plants.
21. Describe osmotic adjustment in plants of different environment.
22. Describe adaptations in plants to cope with low temperature and high temperature stress.
23. What is the role of mechanical tissue to support in plants?
24. Describe meristematic tissues in plants.
25. Describe the role of lateral meristems in secondary growth.
26. What is photoperiodism? Explain the mechanism of photoperiodism with reference to the mode of action of phytochromes.

11

- Alimentary canal, structural and functional detail.

DIGESTION

After completing this lesson, you 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 products from the small intestine lumen to the blood capillaries and lacteals of the villi.
- Describe the component parts of large intestine with their respective roles.
- Correlate the involuntary reflex for egestion in infants and the voluntary control in adults.
- Explain the storage and metabolic role of liver.
- Describe composition of bile and relate the constituents with respective roles.
- 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.

Reading

In chapter 2 we have read about biological molecules or food. Food is necessary to sustain life. The food is utilized at the cellular level. Most of the food we eat, however, is not suitable for cellular utilization until it is mechanically and chemically reduced to forms that can be absorbed through the intestinal wall and transported to the cells by the blood. This chapter presents a general view of the digestive system, describes its anatomy, physiology and disorders related to digestive system and food habits.

11.1 DIGESTIVE SYSTEM OF MAN

Anatomically and functionally the digestive system can be divided into a tubular **gastrointestinal tract** (GIT) and **accessory digestive organs**. The organs of **GI tract** include oral cavity, pharynx, oesophagus, stomach, small intestine and large intestine. The accessory digestive organs include the teeth, tongue, salivary glands, liver, gall bladder and pancreas.

11.1.1 GASTROINTESTINAL TRACT (GIT) - Structure and Function

The GIT, which extends from the mouth to the anus, is a continuous tube. It is a locally differentiated structure. It is specialized at various points along its length, with each region designed to carry out a different role. GIT is approximately 9 m (30 ft) long. It passes across the thoracic cavity and enters the abdominal cavity at the level of diaphragm.

The digestive tube consists of four major layers: an internal mucosa and an external serosa with a submucosa and muscularis in between. These four layers are present in all areas of the digestive tract from the oesophagus to the anus.

Oral Cavity

The mouth is surrounded by the lips, cheeks, tongue and a palate and includes a chamber between the palate and tongue called **oral cavity**. The tongue nearly fills the oral cavity when the mouth is closed. Rough projections called **papillae** on the surface of the tongue cause friction; which is useful in handling the food. These papillae also contain **taste buds**. The **palate** forms the roof of the oral cavity. It consists of a hard anterior part the **hard palate** and a soft posterior part the **soft palate**. There are 32 teeth. Different teeth are adapted to handle food in different ways. The **incisors** (front teeth) are chisel shaped and their sharp edges are used to bite off relatively large pieces of food. The **canine teeth** are cone shaped and they are useful in grasping or tearing food. The **premolars** and **molars** have somewhat flattened surfaces and are specialized for grinding food particles. There are three pairs of **salivary glands:** parotid or parotis, submandibular and sublingual. These glands secrete saliva having enzyme.

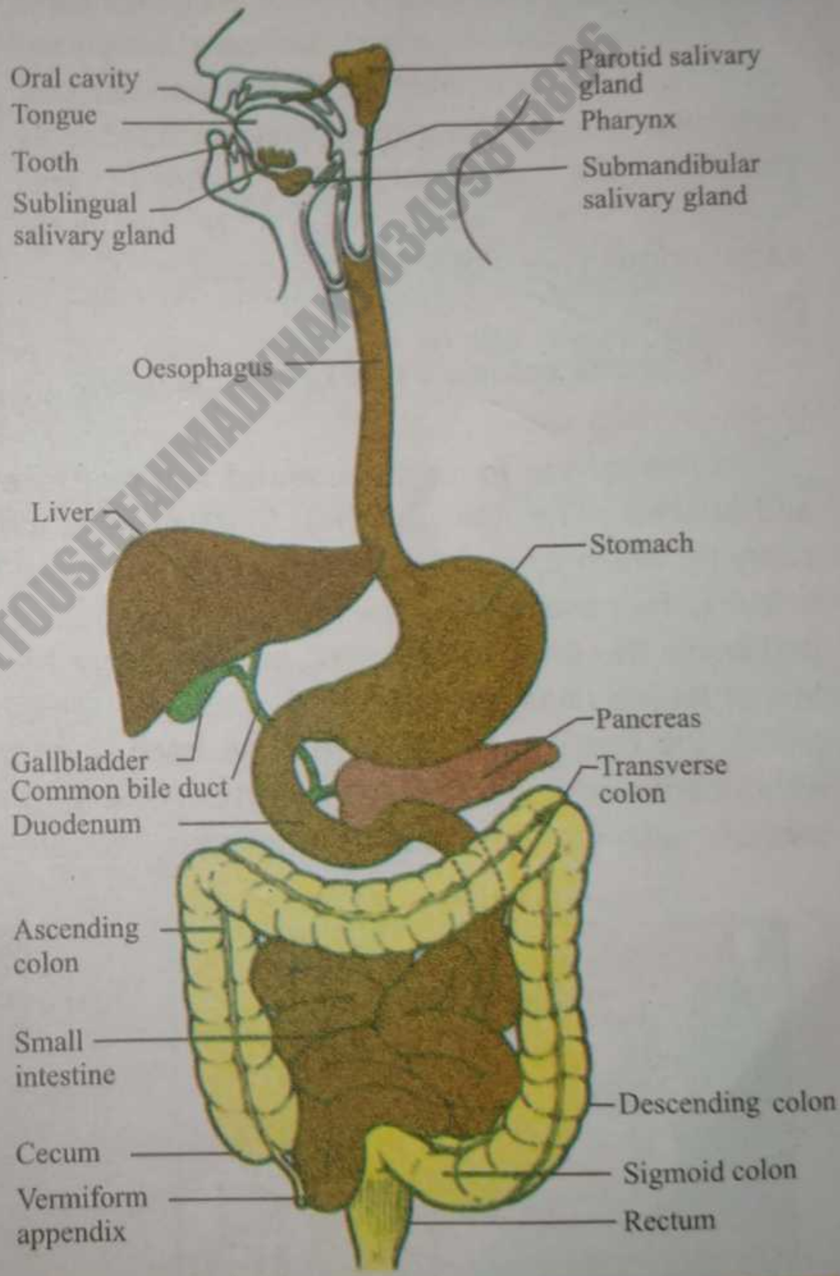


Fig: 11.1: Digestive system of man

Functions of oral cavity

In the oral cavity mechanical and chemical digestion takes place. Mechanical digestion is the physical division of a mass of food into smaller masses while chemical digestion is the chemical conversion of larger molecules into smaller molecules.

Mechanical digestion: Cooking and thorough chewing of food destroys the cellulose of starch covering and increases the efficiency of the digestive process. Food taken into the mouth is chewed, or masticated, by the teeth. Mastication breaks large food particles into smaller ones, which have a much larger total surface area for the action of digestive enzymes.

Science Titbits

Inflammation of the parotid or parotis is called parotiditis or parotitis. The most common type of parotitis, caused by a viral infection, is mumps.

Chemical digestion: Saliva is secreted by salivary glands. The watery part of saliva contains a digestive enzyme called **salivary amylase**, which breaks the covalent bonds between glucose molecules in starch and other polysaccharides to produce the disaccharides, maltose and isomaltose. Only about 3%-5% of the total carbohydrates are digested in the mouth.

Composition of Saliva (Extra reading material)

Salivary amylase digests starch. Mucin is a proteoglycan that gives a lubricating quality to the secretions of the salivary glands. Water moistens food and mucous membrane. Saliva also contains various mineral salts including chloride ions which speed up the activity of enzymes. Saliva prevents bacterial infection in the mouth as it contains lysozyme and immunoglobulin. Saliva has a pH between 6.00 and 7.0, a favourable range for the digestive action of amylase.

Pharynx

The pharynx is a cavity behind the mouth.

Swallowing

The tongue forms the chewed and moistened food into a ball like mass called **bolus** and pushes it into the **pharynx**. Muscles raise the soft palate against the back wall of the pharynx, which closes the passage between nasal cavity and pharynx, preventing food from entering the nasal cavity. The pressure of the food in the pharynx stimulates nerves in its walls that begin the swallowing reflex, an involuntary action. As part of this reflex action the voice box or **larynx** rises up to meet the epiglottis, with this action epiglottis cartilage drops over the glottis, the opening to the larynx and trachea. In this way food is passed over the trachea without entering it. If you place your hand over your larynx, you can feel it moves up when you swallow. After food enters the oesophagus, the soft palate lowers and the epiglottis is raised.

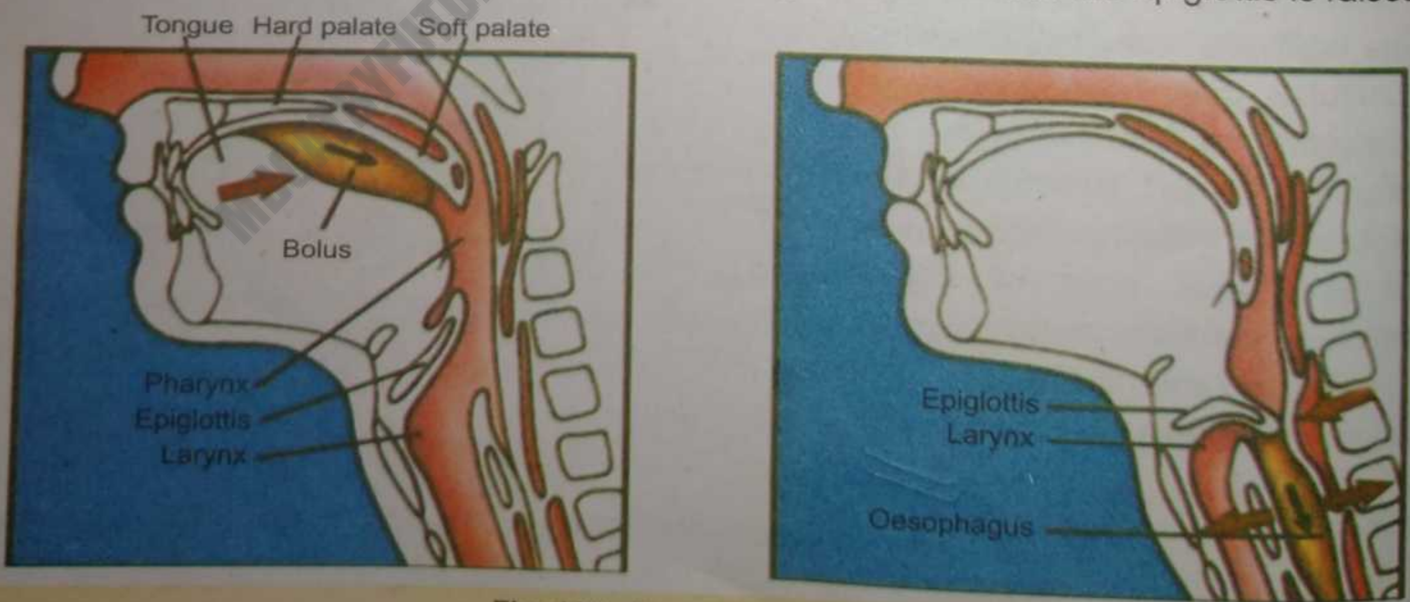


Fig: 11.2: Process of swallowing

Peristalsis

In peristalsis a wave of relaxation of circular muscles in front of food is followed by a wave of strong contraction of circular muscles behind food, propels the mass of the food through the digestive tract. As the food moves it expands the tube wall, the expansions stimulates peristalsis. Sometimes, the peristalsis become opposite in direction, called antiperistalsis that leads to vomiting.

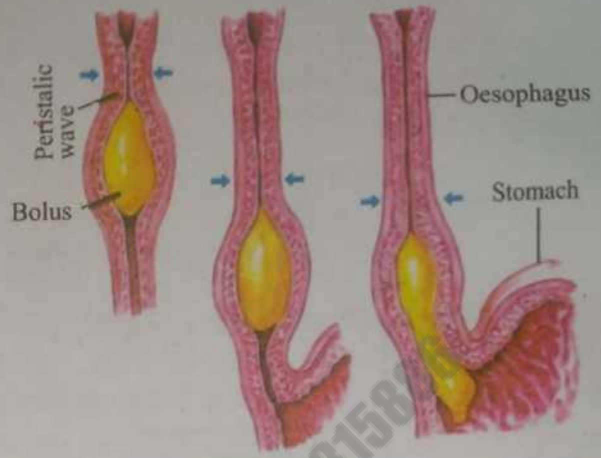


Fig. 11.3 Peristalsis

Oesophagus

The oesophagus is that part of the digestive tube that extends between the pharynx and the stomach. It is about 25 cm long. It begins at the base of the pharynx and descends behind the trachea. The oesophagus penetrates the diaphragm and is continuous with the stomach.

Function: Digestion which started in the oral cavity continues in the oesophagus. As oesophagus is a passage way so no digestion takes place here.

Stomach

The stomach is an enlarged segment of the digestive tract in the left superior part of the abdomen immediately below the diaphragm.

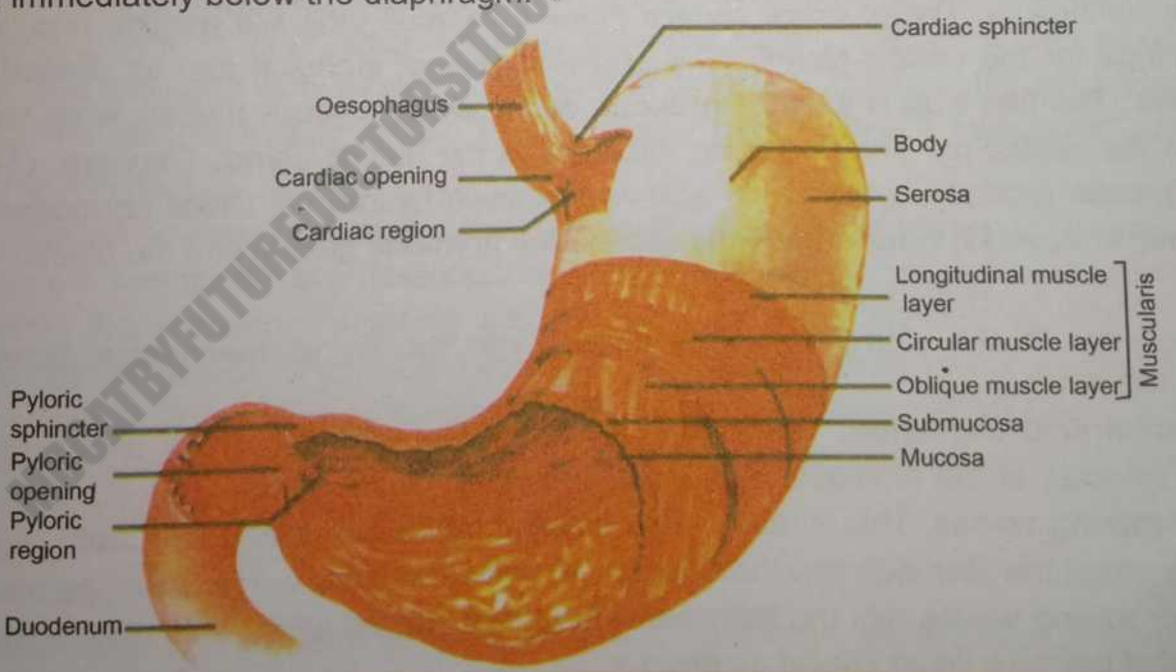


Fig: 11.4: Cutaway section of the stomach reveals muscular layers and internal anatomy

Typically J-shaped when empty, the stomach is continuous with the oesophagus anteriorly and empties into the small intestine posteriorly. The opening from the oesophagus into the stomach is the **cardiac opening** (located near the heart). The **cardiac sphincter** surround the cardiac opening. The largest part of the stomach is the **body** which narrows to form **pyloric opening**, guarded by **pyloric sphincter**.

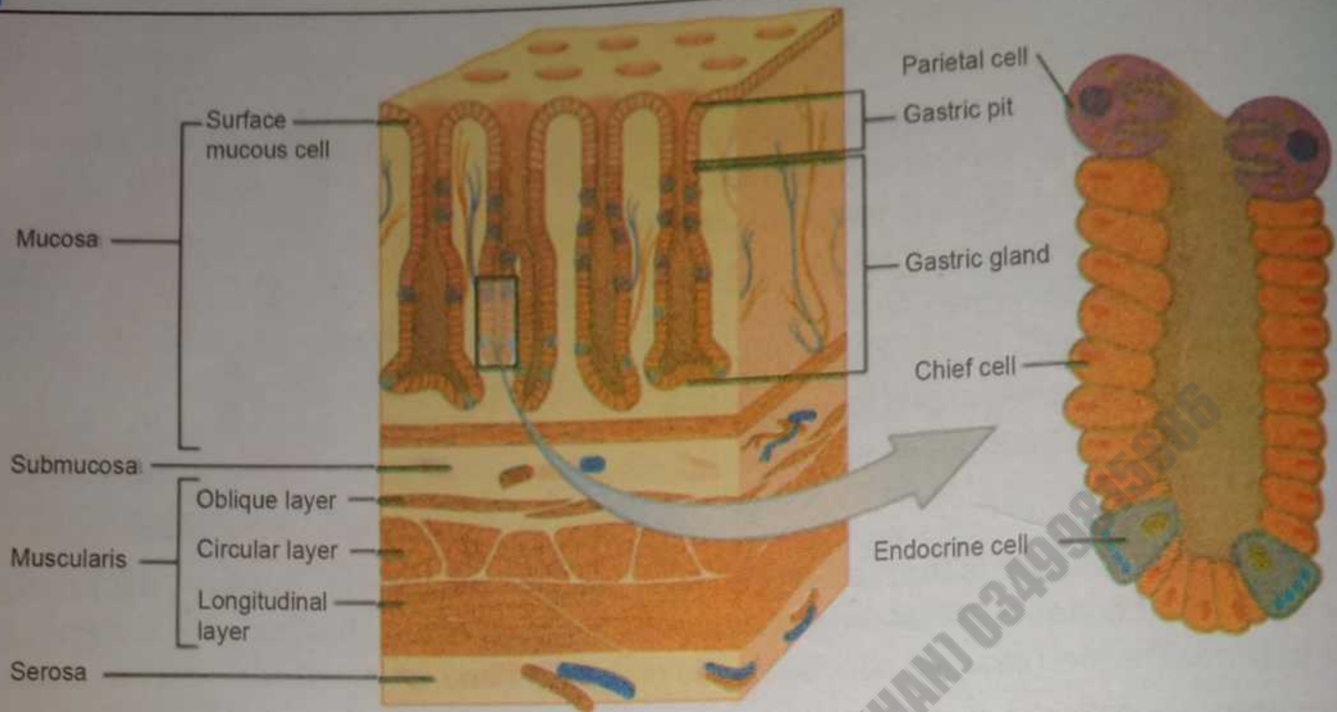


Fig: 11.5: A section of stomach wall that illustrates its histology, including several gastric pits and glands

The **serosa** is the outer most layer of the stomach. The **muscularis** of the stomach consists of three layers: an outer longitudinal layer, a middle circular layer and an inner oblique layer. The next two layers are **submucosa** and **mucosa**. The stomach is lined with simple columnar epithelium. The mucosal surface forms numerous tube like **gastric pits**, which are the openings for the gastric glands. The epithelial cells of stomach can be divided into four main types. The first type is **surface mucous cells**, which produce mucus, is on the surface and lines the gastric pit. The remaining three are in the gastric gland. They are: (1) **Parietal (oxyntic) cells** produce hydrochloric acid and intrinsic factors (2) **Chief (zymogenic) cells** secrete pepsinogen (3) **Endocrine cells** secrete the hormone gastrin into the blood.

Functions of stomach

Digestion in the stomach can be divided into two types: mechanical digestion and chemical digestion.

Mechanical digestion: The mixing action of the stomach walls allows mechanical digestion to occur in the stomach. The smooth muscles of the stomach produce contractions known as **mixing waves**. This is made more efficient by the fact that unlike other region of the alimentary canal the stomach has three layers of smooth muscles. The churning action of the stomach or mixing waves mix the boluses of food with gastric juice. This mixing leads to the production of the thick liquid known as **chyme**.

Chemical digestion: Stomach secretions include mucus, hydrochloric acid, gastrin, intrinsic factor and pepsinogen. The mucous cells secrete viscous and alkaline **mucus**. The thick layer of mucous lubricates and protects the epithelial cells of the stomach wall from the damaging effect of the acidic chyme and pepsin. **Parietal cells** in the gastric glands of the pyloric region secrete intrinsic factor and a concentrated solution of hydrochloric acid. **Intrinsic factor** is a glycoprotein that binds with vitamin B12 and makes the vitamin more readily absorbed in the ileum. **Hydrochloric acid** produces the low pH of the stomach, which is normally between 1 and 3, but is usually close to 2. Although the hydrochloric acid secreted into the stomach has a minor digestive effect on digested food, one of its main functions is to kill bacteria that are ingested with essentially everything humans put into their mouths. The low pH of the stomach also stops carbohydrate digestion by inactivating salivary amylase. The low pH also denatures many proteins so that proteolytic enzymes can reach internal peptide bonds, and it provides the proper pH environment for the function of pepsin.

Chief cells within the gastric glands secrete inactive **pepsinogen**. Pepsinogen is packaged in **zymogen** granules, which are released by exocytosis when pepsinogen secretion is stimulated. Once **pepsinogen** enters the lumen of the stomach, it is converted to **pepsin** by hydrochloric acid and previously formed pepsin molecules. Pepsin exhibits optimum enzymatic activity at a pH of 3 or less. Pepsin catalyzes the cleavage of some covalent bonds in proteins, breaking them into smaller peptide chains.

Role of nervous system and gastrin hormone on the secretion of gastric juice

Approximately 2-3 litres of gastric juice are produced each day. Both nervous and hormonal mechanisms regulate gastric secretions. Hormones that regulate stomach secretions include gastrin, secretin, gastric inhibitory polypeptide, and cholecystokinin.

The sensations of the taste and smell of food, stimulation of tactile receptors during the process of chewing and swallowing, and pleasant thoughts of food stimulate centres within the medulla that influences **gastric secretion**. Neuronal stimulation of the stomach mucosa results in the secretion of **acetylcholine**, which stimulates the secretory activity of both the parietal and chief cells and stimulates the secretion of **gastrin** from endocrine cells. Gastrin is released into the circulation and travels to the parietal cells, where it stimulates additional gastric juice secretion.

The greatest volume of gastric secretions is initiated by the presence of food in the stomach. The primary stimuli are distention of the stomach and the presence of amino acids and peptides in the stomach. Peristaltic waves occur less frequently, are significantly more powerful than mixing waves, and force the chyme near the periphery of the stomach toward the pyloric sphincter. The pyloric sphincter usually remains partially closed because of mild tonic contraction. Each peristaltic contraction is sufficiently strong to force a small amount of chyme through the pyloric opening and into the duodenum.

Small intestine

The small intestine consists of three parts: the duodenum, the jejunum and the ileum. The entire small intestine is about 6 m long.

Duodenum

It is the first part of small intestine. It is about 25 cm in length. When food enters the duodenum the secretions of pancreas and liver are poured into it. **Pancreatic juice**: The secretion of pancreas is called pancreatic juice. It is poured through the pancreatic duct. Pancreatic juice is slightly alkaline. Its pH is about 8. It neutralizes the acidic action of digestive enzymes secreted by the stomach. The important enzymes are (a) Pancreatic amylase (b) Pancreatic lipase (c) Trypsinogen (4) Chymotrypsinogen.

Pancreatic amylase: It is the starch digesting enzyme. It hydrolyses the polysaccharides to maltose and even to glucose.

Pancreatic lipase: It is the principal enzyme for the hydrolysis of fats. It hydrolyses fats to neutral fat in parts to its (i) mono and diglycerols (diglycerides). (ii) glycerol (iii) fatty acids.

Enzyme precursors

Two important enzyme precursors are found in pancreatic juice. They are trypsinogen and chymotrypsinogen. Both are the inactive forms.

Trypsinogen: The intestinal glands secrete an activator enzyme called **enterokinase**. The enterokinase converts trypsinogen into trypsin. Trypsin then activates more trypsinogen. The trypsin is the active form, which acts on proteins and converts them into polypeptides.

Chymotrypsinogen: The inactive chymotrypsinogen is converted to active form chymotrypsin by trypsin.

Bile: Bile is manufactured in liver but stored in gall bladder. Bile emulsifies fat causing them to breakdown into numerous small droplets called **emulsion**. **Emulsification** provides relative large surface area of lipid for the action of lipase enzyme and hence speed up the digestion of fats and oils.

Science Titbits

Mucus is secreted in large amount by duodenal glands, intestinal glands, and goblet cells. The mucus provides the wall of intestine with protection against the irritating effects of acidic chyme and against the digestive enzymes that enter the duodenum from the pancreas.

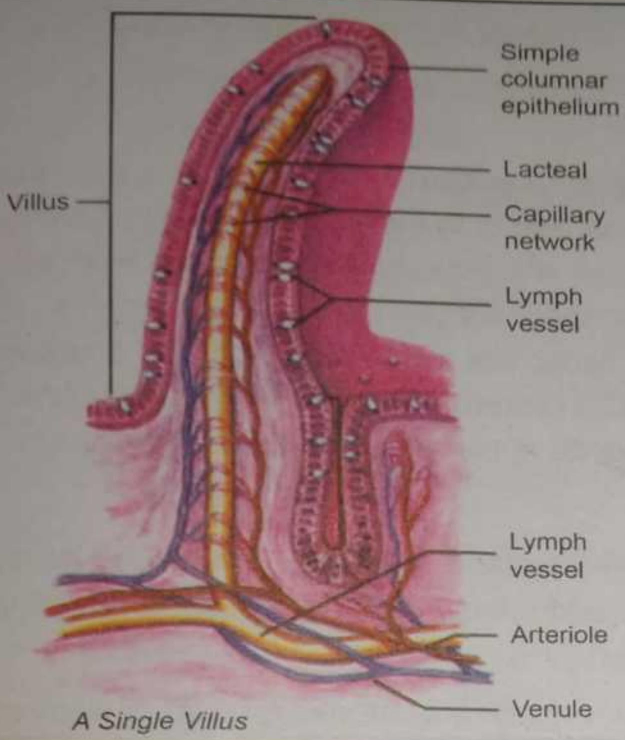
Jejunum and ileum

Jejunum is about 2.5 m long and ileum is about 3.5 m long. Here the digestion of protein carbohydrates and fats is completed. The lining of the jejunum and ileum secrete several enzymes. **Amino peptidase**: It splits polypeptides into dipetides. **Erepsin**: It splits peptides into amino acids. **Lactase**: It converts lactose to glucose and galactose **Maltase**: It converts maltose to glucose. **Sucrase**: It converts sucrose to glucose and fructose. **Pancreatic lipase**: It completes the digestion of fats into fatty acids and glycerol.

Chyle: By the action of enzymes, chyme is turned into a watery emulsion called chyle.

Absorption of digested food from the lumen of intestine

The ileum is the major site of nutrient absorption. Tiny finger like projections of the mucosa form numerous **villi**, which are 0.5-1.5 mm in length. Each villus is covered by simple columnar epithelium. It contains a blood capillary network and a lymph capillary called a **lacteal**. The structural features increase the surface area of small intestine and make it the largest part of the alimentary canal. The internal walls are folded to increase surface area for absorption. Villi and microvilli further increase surface area for absorption. To reach the blood or lymph a nutrient molecule must pass through an epithelial cell of the intestinal lining and through a cell lining the blood capillaries or lymph vessel.



Transmission electron micrograph of microvilli on the surface a villus.

Fig. 11.6: Structure of Villus

Absorption of carbohydrates

Absorption occurs by a combination of simple diffusion and active transport. The monosaccharides are transferred by facilitated diffusion to the capillaries of intestinal villi and are carried by the hepatic portal system to the liver, where non-glucose sugars are converted to glucose. Glucose enters the cell through facilitated diffusion.

Absorption of lipids

Lipids digest in to fatty acids and glycerol. After glycerol and fatty acid are absorbed by epithelial cells, they are recombined into fats within these cells. The fats are then mixed with cholesterol and proteins, forming small globules called **chylomicrons**, most of which are transported by exocytosis out of epithelial cells into lacteals. Lymph containing chylomicrons, eventually drains from the lymphatic system into large veins that return blood to the heart.

Science Titbits

Lipoproteins are referred to as high or low-density lipoproteins. A lipoprotein with high lipid content has a very low density (LDL), whereas a lipoprotein with high protein content has a relatively high density (HDL). Chylomicrons, which are made up of 99% lipid and only 1% protein, have an extremely very low density.

APPENDIX (Extra reading material)

The appendix contains a small amount of mucus associated lymphoid tissue which gives the appendix an undetermined role in immunity. However, the appendix is known to be important in foetal life as it contains endocrine cells that release biogenic amines and peptide hormones important for homeostasis for during early growth and development. Appendicitis is an inflammation of the vermiform appendix and usually occurs because of obstruction of the appendix. An appendectomy is removal of the appendix.

Absorption of protein

Individual amino acids are absorbed in epithelial cells of villi and enter in the **hepatic portal system**, which transports them to the **liver**. The amino acids may be modified in the liver or released into the bloodstream and distributed throughout the body. Most amino acids are used as building blocks to form new proteins, but some amino acids may be used for energy.

Large intestine

The junction between ileum and intestine is **ileocecal junction** guarded by **ileocecal sphincter**. The **caecum** which is the proximal end of the large intestine, is where the large and small intestines meet. Attached to the caecum is a small blind tube about 9 cm long called the **vermiform appendix**. The walls of the appendix contain many lymph nodules. The **colon** is about 1.5 m long and consists of four parts: the **ascending colon**, **transverse colon**, **descending colon**, and **sigmoid colon**. The **rectum** is a straight, muscular tube that begins at the termination of the sigmoid colon and ends at the anus guarded by sphincter.

Functions of large intestine

The large intestine performs several important functions. The major functions of the large intestine are: (a) Absorbing water and electrolytes (b) Absorption of vitamins (c) Reducing acidity and protecting from infections.

Absorbing water and electrolytes: Further digestion or breaking down of nutrients does not take place in the large intestine. The proximal half of the large intestine functions to reabsorb some of the water and electrolytes making the stools solid. The substances that remain in the tube becomes faeces, which is stored for a time in the distal portion of the large intestine.

Absorption of vitamins: The large intestine also helps in absorption of vitamins made by bacteria that normally live in the large intestine. These bacteria also produce large amounts of vitamins. The most important of these is Vitamin K and Biotin (a B vitamin).

Reducing acidity and protecting from infections: The mucosa of the large intestine also: (a) Secretes bicarbonates to neutralize the increased acidity resulting from the formation of these fatty acids and other digestive components at earlier parts of the intestines. (b) Acts as a mucosal barrier and protects from microbial infections and invasions.

Defaecation reflex in adults

When it is appropriate, a person usually can initiate the defaecation reflex (North America spelling: defecation) by holding a deep breath and contracting the adnominal muscles. The action increases the internal pressure and forces the faeces into the rectum. When the rectum is filled, its wall is distended and the defaecation reflex is triggered. As a result, peristaltic waves in the descending colon are stimulated, and the internal and anal sphincter relaxes. The external anal sphincter is signalled to relax and the faeces are forced to the outside. The defaecation reflex persists only for a few minutes and quickly dies. A person usually can inhibit defaecation voluntarily by keeping the external sphincter contracted.

Defaecation reflex in infants

In infants the defaecation reflex causes automating emptying of the lower bowel at inconvenient times during the day because of lack of conscious control exercised through voluntary contraction of the external anal sphincter.

11.1.2 ROLE OF ACCESSORY GLANDS

The accessory glands of the digestive system are liver, gall bladder and pancreas.

Liver

The liver is the largest internal organ of the body. The liver consists of two major lobes, left and right, and two minor lobes.

Composition of bile: The liver produces and secretes bile. It is stored in the gall bladder. Bile contains no digestive enzymes. Bile consists of water, bile salts: sodium glycocholate and sodium taurocholate, bile pigment, bilirubin, cholesterols, lecithin (a phospholipid) mucus, cells and cell debris.

Role of constituents of bile: Bile salts reduce the surface tension of fat globules and emulsify them into droplets and thus increase their total surface area. This process is called **emulsification**. These small droplets are then acted upon by the enzyme lipase. **Bilirubin** results from the breakdown of haemoglobin. In the intestine, bacteria convert bilirubin into pigments that give the faeces its characteristic brown colour. Some of these pigments are absorbed from intestine, modified in the kidneys and excreted in the urine, contributing to the characteristic yellowish colour of the urine. Bile salts help in the absorption of fatty acids from the intestinal tract.

> **Science Titbits**
>
> Some bacteria in the large intestine (colon) synthesize vitamin K, which is passively absorbed in the colon, and breakdown a small amount of cellulose to glucose. Gases called flatus (meaning, blowing) are produced by bacterial actions in the colon.

Secretion of bile is related to secretin hormone

Fatty acids in the lumen of the duodenum stimulate endocrine cells to release the hormone **cholecystokinin** (CCK). CCK stimulates contractions in the smooth muscle of the gall bladder allowing bile release into the duodenum.

Acidic chyme in the lumen of the duodenum stimulates other endocrine cells to release the hormone **secretin**. Secretin produced by the duodenum is carried through the circulatory system to the liver and stimulates liver to release bicarbonate into the bile.

Functions of liver

The liver performs important digestive and excretory functions, stores and processes nutrients, synthesizes new molecules and detoxifies harmful chemicals.

Storage role of liver: Hepatocytes can remove sugar from the blood and store it in the form of glycogen. They can also store fat, vitamins (A, B12, D, E, and K), copper and iron. This **storage function** is usually short-term and the amount of stored material in the hepatocytes varies, thus the cell size fluctuates during a given day.

Metabolic role of liver: Metabolism of glucose occurs in liver. Whenever needed, glucose is obtained by the hydrolysis of glycogen (glycogenolysis). Glucose is also synthesized from amino acids or fatty acids and glycerol (gluconeogenesis). Denaturation of fatty acids and phosphorylation of fats takes place in liver cells. Excess of amino acids undergo deamination producing pyruvic acid and ammonia. Ammonia produced by deamination of amino acids in hepatic cells is converted to urea (ornithine-arginine cycle).

Synthesis of vitamin A from carotene and synthesis of albumin from amino acids takes place in liver. Formation of blood proteins (like prothrombin, fibrinogen) are synthesized in liver cells. These are necessary for blood clotting. **Phagocytosis** also occurs in liver i.e., dead RBCs are destroyed. The bile pigments **bilirubin** (orange pigment) and **biliverdin** (green pegment) are formed from the breakdown of haemoglobin. Liver produces **heparin**, an enzyme that prevents clotting of blood inside the blood vessels. Red blood cells are formed during foetal life. **Detoxification** occurs in liver.

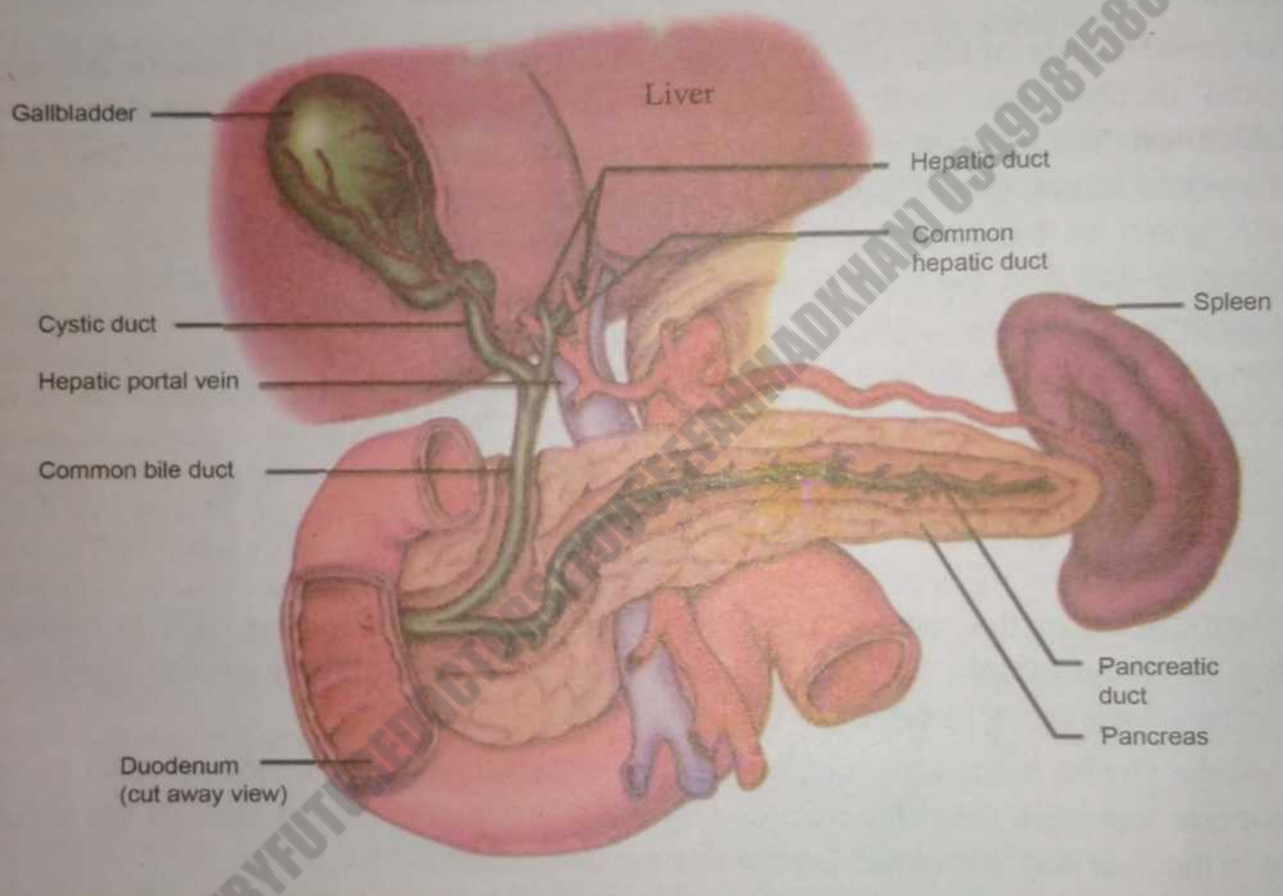


Fig: 11.7: Duct system of the major abdominal digestive glands

Gall bladder

The **gall bladder** (North American spelling: gallbladder) is a saclike structure on the inferior surface of the liver that is about 8 cm long and 4 cm wide. The gall bladder is connected to the common bile duct by the cystic duct. **Bile** is continually secreted by the liver and stored in the gall bladder

Pancreas

The **pancreas** is a complex organ composed of both endocrine and exocrine tissues that perform several functions. The pancreas consists of a head, located within the curvature of the duodenum, a body and a tail, which extends to the spleen. The endocrine part of the pancreas consists of **pancreatic islets** (islets of Langerhans).

Pancreas as an exocrine gland

The exocrine secretion of the pancreas is called **pancreatic juice** and has two major components: an aqueous component and an enzymatic component. Bicarbonate neutralizes the acidic chyme that enters the small intestine from the stomach. The **enzymatic component** of the pancreatic juice is important for the digestion of all major classes of food. The major proteolytic enzymes are **trypsin**, **chymotrypsin**, and **carboxypeptidase**.

They are secreted in their inactive forms as trypsinogen, chymotrypsinogen, and procarboxypeptidase and are activated by the removal of certain peptides from the larger precursor proteins. If these were produced in their active forms, they would digest the tissues producing them. **Trypsinogen** is activated by the proteolytic enzyme enterokinase into **trypsin**.

Trypsin then activates more trypsinogen, as well as **chymotrypsinogen** and **procarboxypeptidase**. **Amylase**, continues the polysaccharide digestion that was initiated in the oral cavity. **Pancreatic lipases**, breakdown lipids into free fatty acids, glycerides, cholesterol. **Deoxyribonucleases** and **ribonucleases**, reduce DNA and ribonucleic acid to their component nucleotides, respectively.

Secretion of pancreatic juice is related to secretin hormone

Pancreatic juice secretion is regulated by the hormones **secretin** and **cholecystokinin** which is produced by the walls of the duodenum upon detection of acid food, proteins, fats and vitamins. Pancreatic secretion consists of an aqueous bicarbonate component from the duct cells and enzymatic component from the **acinar cells**. A clear alkaline secretion of the pancreas containing enzymes that aid in the digestion of proteins, carbohydrates, and fats. The predominant effect of **secretin** on the pancreas is to stimulate duct cells to secrete water and bicarbonate. As soon as this occurs, the enzymes secreted by the **acinar cells** are flushed out of the pancreas, through the pancreatic duct into the duodenum.

11.2 DISORDERS: Digestive System and Food Habits

Here we will describe causes, prevention and treatment of the disorders related to digestive system and food habits: ulcer, food poisoning, dyspepsia, obesity, anorexia nervosa and bulimia nervosa.

Ulcer

Aetiology Peptic ulcer is classically viewed as a condition in which the stomach acids digest the mucosal lining of the GI tract itself. *Helicobacter pylori* is the most important factor in peptic ulcer disease, accounting for 90% of duodenal ulcer and 70% of the gastric ulcer. Aspirin (acetyl salicylic acid) and other non-steroidal anti-inflammatory agents are an important aetiologic factor. Peptic ulcer tends to run in families i.e., it is a hereditary disease.

Prevention: Aggravating factors such as smoking, asprin, excess intake of coffee and tea, alcohol, missing a meal are to be avoided.

Treatment: The relieving factors of ulcer are antacid and milk, vomiting relieves pain in gastric ulcer, and intake of food relieves pain in duodenal ulcer. Medicines for acid suppression are the first choice of therapy.

Helicobacter pylori (Extra reading material)

In the early 1980's an Australian medical resident named Barry Marshall firmly believed that bacteria play a role in ulcers, but physicians have always blamed the open sores on stress or prescription drug side effects. Marshall set out to prove the bacterial link. One morning in 1984, he walked into his lab, stirred a beaker full of beef soup and *Helicobacter pylori* and gulped the concoction. After five days he began to vomit. Marshall and others demonstrated that *Helicobacter pylori* is responsible for 70% of ulcer. Marshall and his co-worker Robin Varan were awarded Nobel Prize in 2005.

Nobel Prize Winner in 2005: Barry Marshall (right side) and his coworker Robin Varan

Food poisoning

It includes diarrhoea, vomiting and abdominal pain. It is an illness from indigestion of food containing toxic substances.

Aetiology: Due to the **toxins** produced by bacteria, *Salmonella* and *Campylobacter*.

Prevention: Basic hygiene should be followed. Avoid unboiled /unbottled water, ice, cubes, salads and peel on fruits. Consume freshly prepared hot food or thoroughly rewarmed food.

Treatment: Soft easily digested diet, such as soup, fruits drinks; tea and cold drinks are preferred. Oral rehydration salt (ORS) is given. Antidiarrhoeal agent such as Loperamide, antibiotics are prescribed.

Dyspepsia

Incomplete or imperfect digestion is called dyspepsia.

Aetiology: It may occur due to excessive acidity in stomach or faulty function of stomach and intestine or insufficient quality and quantity of bile secretion.

Prevention: Avoid food that worsens symptoms. Stop smoking, weight reduction, small meals, avoid alcohol, tea, fatty food, heavy lifting, bending specially after meals and late night meals to reduce reflex during sleep.

Treatment: Antibiotics to be given against this disease. Drugs which decrease HCl production such as Cimetidine; stop NSAID (Non-Steroidal Anti Inflammatory Drugs), e.g., Aspirin

Obesity

When a person has abnormal amount of fat on the body it is called obesity.

Aetiology: Excessive intake of food is responsible for obesity. Emotional disturbances, inherited tendency to obesity, disorder of the thyroid, pituitary or adrenal glands etc., can also cause obesity.

Prevention: Food should be taken according to energy intake and energy expenditure. Diet control, regular exercise can prevent obesity.

Related disorders: The distribution of fat difference can be clinically significant because upper body obesity is associated with an increased likelihood of diabetes mellitus, cardiovascular disease, and stroke. Many other diseases are associated with obesity like angina, heart failure, anaemia, arthritis, etc. Obesity shortens life expectancy.

Bulimia nervosa

Symptoms: It is a neurotic disorder in slightly older girls. It is characterized by bouts of over eating fattening food such as fried food or cream cakes. This voracious (eating in large quantity) eating followed immediately by self-induced vomiting, fasting or purging (to empty bowels) may cause physical effects including serum electrolytes imbalance and frequent recurring infections.

Treatment: Treatment of bulimics is likely to be prolonged. The initial treatment is to overcome the effects of weight loss and malnutrition. It is necessary to undertake the treatment in hospital under strict supervision.

Anorexia nervosa

It is the loss of appetite due to the fear of becoming obese. Such a feeling is common in human females between the ages of 12 and 21 years. Usually just after the onset of puberty.

Symptoms: It includes loss of appetite due to the fear of becoming obese. The anorexic girls over estimate the size of her own body and so insist that she is overweight, when in reality her weight has dropped to a dangerous level. These girls are often not matured psychologically and unable to cope with the challenges of puberty and their emerging sexuality. The losses of feminine characteristics enable the girls to retreat into a childlike state in which she feels safe.

Therapy: Psychiatric therapy is usually required to treat anorexic girls. Such patients are fed through any other route other than alimentary canal, i.e., intravenously. The recovery is very slow. It may take 2-4 years and in some cases longer.

Science Technology and Society Connections

- Relate ulcer, food poisoning and dyspepsia with eating habits of the society.

Activity

1. Tests to locate buds on tongue for detection of salt, sweet, sour and bitter taste
2. Microscopic observation of the villi, liver and pancreas from prepared slides

Exercise

MCQs

1. **Select the correct answer**

(i) Pepsinogen is activated to pepsin by
(A) active secretin (B) hydrochloric acid
(C) active pepsin and HCl (D) gastrin

(ii) Liver secretes bile into the
(A) duodenum (B) ileum (C) jejunum (D) peritoneum

(iii) Emulsification of fat will not occur in the absence of
(A) lipase (B) bile pigment (C) bile sat (D) pancreatic juice

(iv) Fatty acids and glycerol are first absorbed by
(A) lymph vessel (B) villi
(C) blood capillaries (D) hepatic portal vein

(v) The hormone responsible for stimulating secretion of hydrochloroic acid by stomach cells is
(A) pepsin (B) secretin (C) gastrin (D) insulin

(vi) Enzyme trypsinogen is changed to trypsin by
(A) gastrin (B) enterokinase (C) secretin (D) hydrochloric acid

Short Questions

2. Describe and write the function of each type of teeth.
3. What is mechanical digestion?
4. What is chemical digestion?
5. Explain peristalsis with diagram.
6. Name and write the function of epithelial cells of stomach of man.
7. Give one reason as to why some enzymes in stomach and intestine are secreted in inactive form?
8. Name the enzymes involved in protein digestion.
9. How could no secretion of HCl in our stomach affect food digestion?
10. How the stomach does protect itself from the damaging effect of HCl?
11. Why there are villi in the intestine and not in stomach?
12. Trypsin acts at alkaline pH. What provides the alkalinity?

13. What would happen to the activity of the intestinal enzymes if the pH in the small intestine remained at 2?
14. How does the absorption of fat differ from absorption of glucose?
15. Describe defaecation reflex in adults.
16. Describe defaecation reflex in infants.
17. Bile juice contains no digestive enzymes, yet it is important for digestion. Why?
18. What is the role of hormone gastrin in digestion?
19. What is the role of hormone secretin in digestion?
20. Describe the storage role of liver.
21. What is gall bladder? Write its function.
22. Write the differences between:
    (a) mechanical digestion and chemical digestion.
    (b) pharynx and larynx
    (c) pepsinogen and pepsin
    (d) bulimia nervosa and anorexia nervosa

Extensive Questions

23. Describe human oral cavity. What are the functions of oral cavity?
24. Describe the process of swallowing in man.
25. Describe the human stomach with diagram.
26. Describe the structure of human small intestine.
27. Explain the absorption of digested products from the small intestine lumen to the blood capillaries and lacteals of the villi.
28. Describe the large intestine of man. What are the functions of large intestine?
29. Describe the structure of liver.
30. What is bile? Describe the composition of bile. What is the role of constituents of bile? How secretion of bile is related to the secretion of hormone secretin?
31. Write the functions of liver of man.
32. What is the structure of pancreas? Explain the functions of pancreas as an exocrine gland.
33. Describe the aetiology, prevention and treatment of the following disorders:
    (a) Ulcer (b) Food poisoning (c) Dyspepsia.

12

CIRCULATION

After completing this lesson, you 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 the valves.
- State the phases of heartbeat.
- Explain the role of SA node, AV node and Purkinji fibers in controlling the heartbeat.
- 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 precapillary 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 circulation).
- Compare the rate of blood flow through arteries, arterioles, 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 the blood pressure.
- Define the term thrombus and differentiate between 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 principles of angiography.
- Outline the main principles of 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 problems.
- Describe the formation, composition and function of intercellular fluid.
- Compare 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 (lacteals) present in villi.
- Describe the functions of lymph nodes and state the role of spleen as containing lymphoid tissue.

Reading

Why do we need a transport system? You have read in the previous chapter that what is digestion? In chapter 1 you have read what are cells? All the cells of our body need food from small intestine and oxygen from the lungs. Carbon dioxide and waste chemicals have to be removed from the lungs and kidneys respectively. Our bodies are too large for materials to simple diffuse in and out. So we have a system of internal transport - a **circulatory system** that transports oxygen and carbon dioxide, distributes nutrients to the body cells and conveys the waste products of metabolism to specific site for disposal.

This chapter targets more detailed study of the circulatory system of man, the basic knowledge of which has been dealt with in biology IX-X course. Cardiovascular disorders and lymphatic system have been discussed in detail.

12.1 BLOOD CIRCULATORY SYSTEM OF MAN

The internal transport or blood circulatory system of man is divided into **cardiovascular system** and **lymphatic system**. The cardiovascular system consists of a strong muscular heart, three kinds of blood vessels: arteries, capillaries, veins and blood. The study of the diseases of cardiovascular system is called **angiology**.

12.1.1 Heart

The heart functions as a pump and is responsible for the circulation of the blood through the blood vessels. The human heart is a hollow, fibromuscular organ. The Greek name for the heart is *cardia* from which we have the adjective **cardiac**. The Latin name for the heart is *cor* from which we have adjective **coronary**. The adult heart has the shape of a cone. The blunt, rounded point of the cone is the apex and the larger flat part at the opposite end of the cone is the base.

12.1.2 Structure of Human Heart

The heart is located in the thoracic cavity between the lungs. The **pericardium** is a closed sac that surrounds heart. It consists of two parts; the outer part and inner part. The outer part consists of inelastic white fibrous tissue. The inner part is made up of two membranes. The inner membrane is attached to the heart and the outer one is attached to the fibrous tissue. Pericardial fluid is secreted between them and reduces the friction between the heart

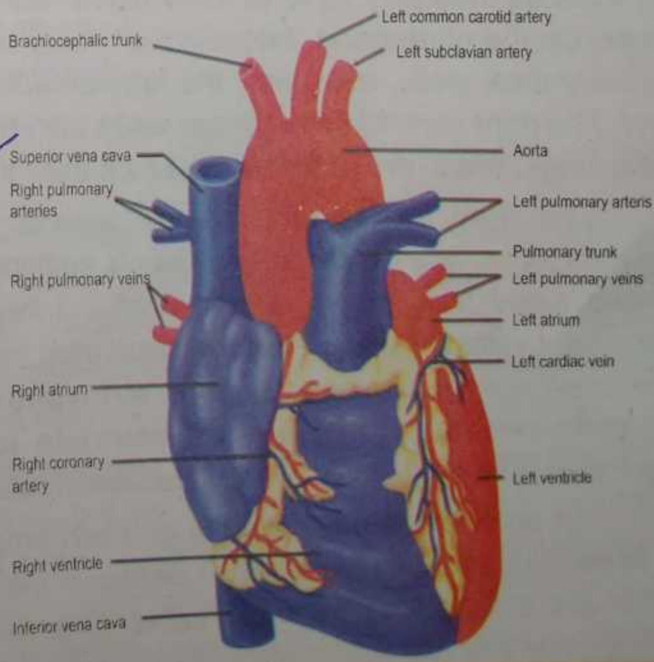


Fig. 12.1: Human heart, external view

wall and surrounding tissues when the heart is beating. The inelastic nature of the pericardium as whole prevents the heart from being overstretched or overfilled with blood.

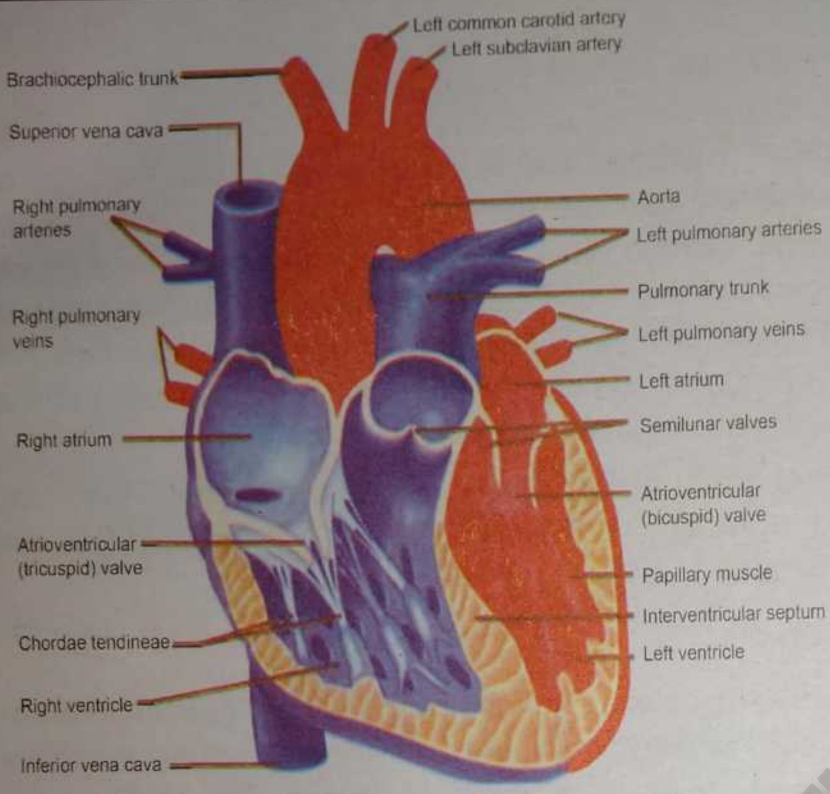


Fig. 12.2: Dissection of a human heart, as seen from the front, with the ventral part of both atria and both ventricles removed

The heart consists of four chambers: two **atria** (meaning, entrance chamber) and two **ventricles** (meaning, belly). The atria lie above the ventricles. The heart wall is composed of the three layers of tissue: The epicardium, the myocardium, and the endocardium. The **epicardium** is a thin **serous membrane** comprising of the smooth outer surface of the heart. The thick middle layer of the heart, the **myocardium**, is composed of cardiac muscle cells. The smooth inner surface of the heart chambers is the **endocardium**, which consists of simple squamous epithelium over a layer of connective tissue. The **heart valves** are formed by a fold of the endocardium, making a double layer of endocardium with connective tissue in between.

The thickness of the walls of each chamber is different: The atria have comparatively thin walls as they only have to force blood into the ventricles and this does not require much power. On the other hand, the ventricles have to force blood out of the heart hence they have relatively thick walls, especially the left ventricle which has to pump blood around the whole body. The right ventricle has thinner walls than the left ventricle in a ratio of 1:3, it pumps blood to the lungs, which are at a short distance from the heart.

The **right atrium** receives the superior vena cava, the inferior vena cava, and the coronary sinus (the coronary sinus is an additional opening into the right atrium that receives venous blood from the myocardium of the heart itself). The **left atrium** receives the four pulmonary veins. The two atria are separated from each other by the **interatrial septum**. The atria open into the ventricles through **atrioventricular canals**. The **right ventricle** opens into the pulmonary trunk, and the **left ventricle** opens into the aorta. The two ventricles are separated from each other by the **interventricular septum.**

An **atrioventricular valve** is on each atrioventricular canal and is composed of **cusps**, or flaps. The atrioventricular valve between the right atrium and the right ventricle has three cusps and is called the **tricuspid valve**. The atrioventricular valve between the left atrium and left ventricle has two cusps and is therefore called the **bicuspid** or **mitral valve**. Each ventricle contains cone-shaped muscular pillars called **papillary muscles**. These muscles are attached by thin, strong connective tissue strings called **chordae tendineae** to the cusps of the atrioventricular valves. The papillary muscles contract when the ventricles contract and prevent the valves from opening into the atria by pulling on the chordae tendineae attached to the valve cusps. The aorta and pulmonary trunk possess **aortic** and **pulmonary semilunar.**

12.1.3 Passage of Blood through Heart

The **superior vena cava** and the **inferior vena cava**, both carrying deoxygenated blood, enter the right atrium. The **right atrium** sends blood through the **tricuspid valve** to the right ventricle. The right ventricle sends blood through the **pulmonary semilunar valve** into the **pulmonary trunk** and the two **pulmonary arteries** to the lungs. Four **pulmonary veins**, carrying oxygenated blood from the lungs, enter the left atrium. The **left atrium** sends blood through the **bicuspid valve** to the **left ventricle**. The left ventricle sends blood through the **aortic semilunar valve** into the **aorta** to the body proper. The heart is a **double pump** because the right ventricle of the heart sends blood to the lungs, and the left ventricle sends blood throughout the body.

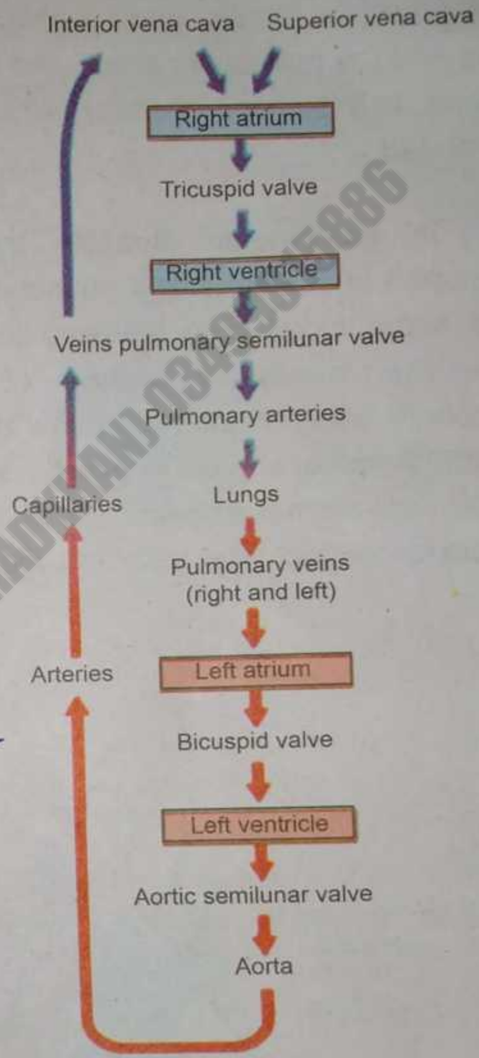


Fig. 12.3: Passage of blood through heart

12.1.4 Heartbeat and its Control

In a continuous, rhythmic cycle heart is passively filled with blood from the large veins and then the heart actively contracts, propelling the blood throughout the body. Its alternating relaxations and contractions make up the **cardiac cycle**. The cardiac cycle is a sequence of one heartbeat.

Phases of heartbeat

The term systole means to contract and diastole means to dilate. **Atrial systole** is contraction of the atrial myocardium and **atrial diastole** is relaxation of the atrial myocardium. Similarly **ventricular systole** is contraction of the ventricular myocardium and **ventricular diastole** is the relaxation of the ventricular myocardium. When the word "systole" and "diastole" are used without reference to specific chambers, they mean ventricular systole or diastole.

In **atrial diastole** blood enters the right atrium from the body through the vena cavae. At first the bicuspid and tricuspid valves are closed, but as the atria fill with blood, pressure in them rises. Eventually it becomes greater than that in the relaxed ventricles and the valves are pushed opens. In **atrial systole** the two atria contract simultaneously and blood is pushed through the **atrio-ventricular** valve into the still relaxed ventricles. At this phase semilunar valve is closed, tricuspid and bicuspid valves are open.

In **ventricular systole** almost immediately the **ventricles** contract. When this occurs the pressure in the ventricles rises and closes the atrioventricular valves, preventing blood from returning to the atria. This pressure forces, open semilunar valves of the aorta and the pulmonary artery and blood enters these vessels. In this phase the tricuspid and bicuspid valves are closed.

In **ventricular diastole** the high pressure developed in the aorta and pulmonary artery tends to force some blood back towards the **ventricles** and close the **semilunar valves** of the aorta and pulmonary artery. Hence back flow in the heart is prevented. In this phase **bicuspid valve** and **tricuspid valve** are open, **aortic semilunar valve**, and **pulmonary semilunar valve** are closed. The normal cardiac cycle is of 0.7 to 0.8 second depending on the capability of cardiac muscle to contract. The heart muscle rests 0.1 to 0.3 second between the beats.

Science Titbits

When a stethoscope is used to listen to the heart sounds, distinct sounds normally are heard. The **first heart sound** is a low-pitched sound, often described as a **"lub"** sound. It is caused by vibration of the atrioventricular valves which close near the beginning of ventricular systole. The **second heart sound** is a higher pitched sound often described as a **"dub"** sound. It results from closure of the aortic and pulmonary samilunar valves, near the end of systole. 'lub' is also written as 'lubb' and 'dub' as 'dupp'.

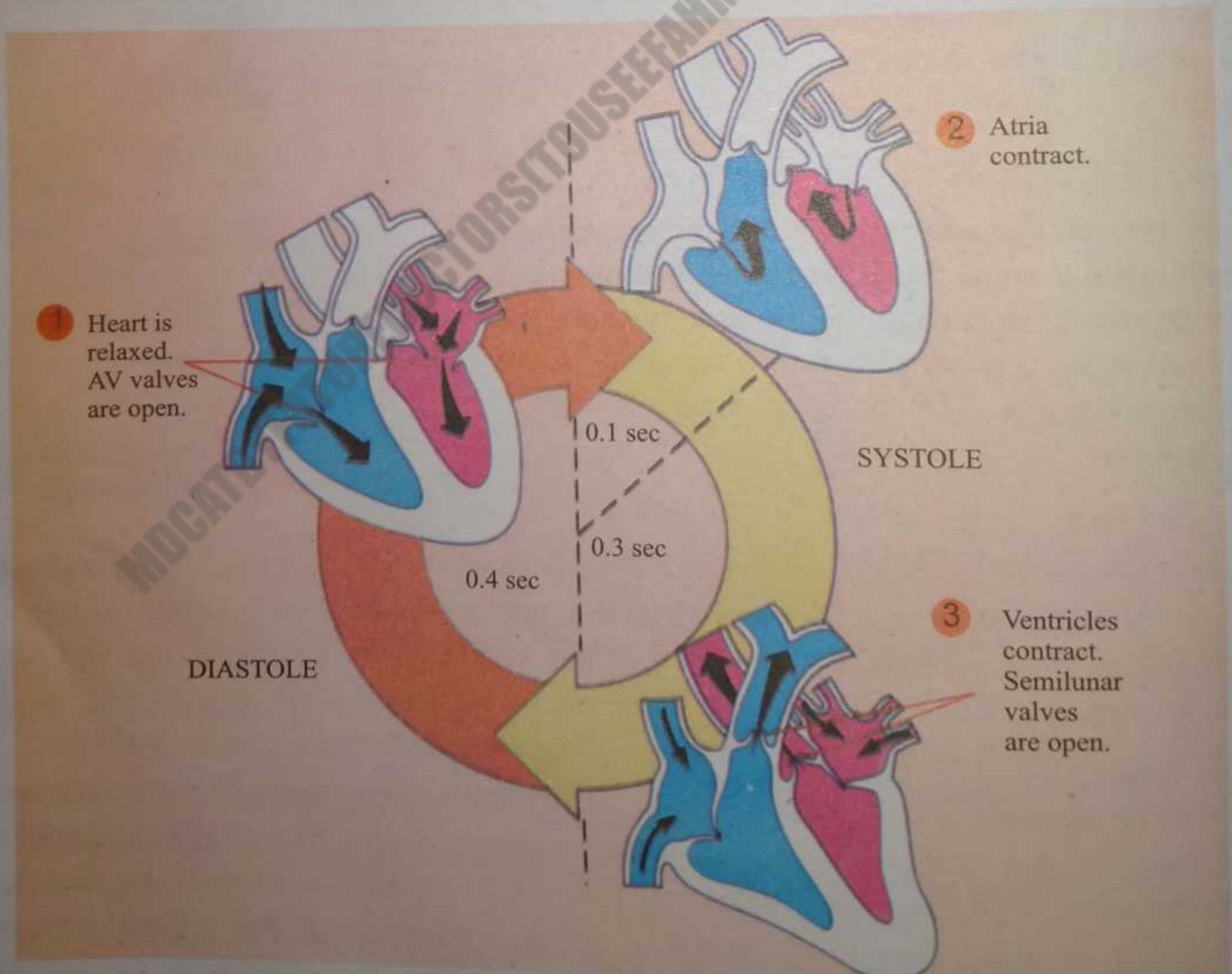


Fig. 12.4: Cardiac cycle

Conducting system of the heart

The heart will go on beating after it has been cut right out of the body. Cardiac muscles are **myogenic** i.e., its rhythmic contraction arise from within the muscle itself. Cardiac muscle has an intrinsic rhythmicity that allows the heartbeat to originate in and be conducted through the heart without extrinsic stimulation. Specialized strands of interconnecting cardiac muscle tissue that coordinate cardiac contraction constitute the **conduction system**. The conduction system constitutes the cardiac cycle. The components of the conduction system are the (a) Sinoatrial node, (b) Atrioventricular node, (c) Atrioventricular bundle (d) Conducting myofibrils.

Sinoatrial node in short is called **SA node**. It consists of specialized plexus of cardiac muscles embedded in the upper wall of the right atrium. It is close to where vena cavae enter the atrium. The SA node has been developed from the sinus venosus and has become a part of the atrium, so it is called sinoatrial node. There is another specialized group of cardiac muscle fibres called **atrioventricular node**. In short it is called **AV node**. It is present near the junction of right atrium and right ventricle.

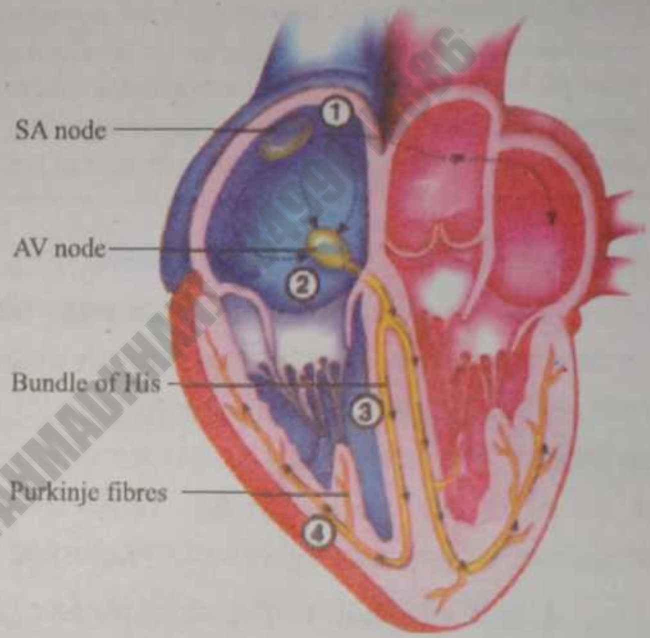


Fig. 12.5: Conducting system of the heart
1. Action potentials originate in the sinoatrial (SA) node and travel across the wall of the atrium (arrows) from the SA node to the atrioventricular (AV) node.
2. Action potentials pass through the AV node and along the atrioventricular (AV) bundle, which extends from the AV node, through the fibrous skeleton, into the interventricular septum.
3. The AV bundle divides into right and left bundle branches, and action potentials descend to the apex of each ventricle along the bundle branches.
4. Action potentials are carried by the Purkinje fibres from the bundle branches to the ventricular walls.

AV node is connected to a strand of specialized muscles (in the ventricular septum) known as **atrioventricular bundle** or **bundle of His.** This bundle passes through a small opening in the fibrous skeleton to reach the interventricular septum, where it divides to form right and left bundle branches, which extend beneath the endocardium on either side of the interventricular septum to the apices of the right and left ventricles respectively. The inferior, terminal branches of the bundle branches are called **Purkinje fibres**, which are large-diameter cardiac muscle fibres. They have fewer myofibrils than most cardiac muscle cells and do not contract forcefully. **Intercalated disks** are well developed between the Purkinje fibres and contain numerous gap junctions. As a result of these structural modifications, action potentials travel along the Purkinje fibres much more rapidly than through other cardiac muscle tissue. Cardiac muscle cells have the capacity to generate spontaneous action potentials, but cells of the SA node do so at a greater frequency. As a result, the SA node is called the **pacemaker** of the heart. When the heart beats under resting conditions, approximately 0.04 second is required for action potentials to travel from the SA node to the AV node. Within the AV node action potentials are propagated slowly compared with the remainder of the conducting system. As a consequence, there is a delay of 0.11 second from the time action potentials reach the AV node until they pass to the AV bundle. The total delay of 0.15 second allows completion of the atrial contraction before ventricular contraction begins.

Science, Technology and Society Connections

- **Rationalize the use of artificial pacemaker in patients of cardiac arrhythmias.**

A **cardiac arrythmia** is a disturbance in electrical rhythm of heart. It may be **bradycardia** (heart beat less than 40 beats per minute) or **tachycardia** (heart beat more than 100 beats per minute). Pacemaker supplies electrical initiation to myocardial contraction. The pacemaker is put surgically under the skin where it may be programmed. It generates electrical rhythm at a set rate, so in this way arrythmia are controlled.

12.1.5 Electrocardiogram

The electrical impulses that pass through the conduction system of the heart during the cardiac cycle can be recorded as an electrocardiogram (ECG). The electrical changes result from depolarization and repolarization of cardiac muscle fibres and can be detected on the surface of the skin using an instrument called the **electrocardiograph**. The principal aspects of an ECG are shown in fig. 12.6. The wave deflections, designated P, QRS, and T, are produced as specific events of the cardiac cycle occur.

Depolarization of the atrial fibres of the SA node produces the **P wave**. The ventricles of the heart are in diastole during the expression of the P wave. On the ECG recording, the **P-R interval** is the period of time from the start of the P wave to the beginning of the QRS complex. This interval indicates the amount of time required for the SA depolarization to reach the ventricles. The **QRS complex** begins as a short downward deflection (Q), continues as a sharp upward spike (R), and ends as a downward deflection (S). The QRS complex indicates the depolarization of the ventricles. During this interval, the ventricles are in systole and blood is being ejected from the heart. The time duration known as the **S-T segment** represents the period between the completion of ventricular depolarization and initiation of repolarization. The **T wave** is produced by ventricular repolarization. A normal ECG indicates that the heart is functioning properly. The P wave represents excitation and occurs just prior to contraction of the atria. The second wave, or the QRS complex, occurs just prior to ventricular contraction. The third, or T, wave occurs just before the ventricles relax.

Uses of electrocardiogram

An ECG is a painless test that measures heart electrical activity to show whether or not it is working normally. ECG can detect arrhythmias (irregular heartbeat), conduction defects, size and position of heart chambers, damage to heart muscle, impaired blood flow to heart muscle, the effect of cardiac medicines and function of artificial pacemakers.

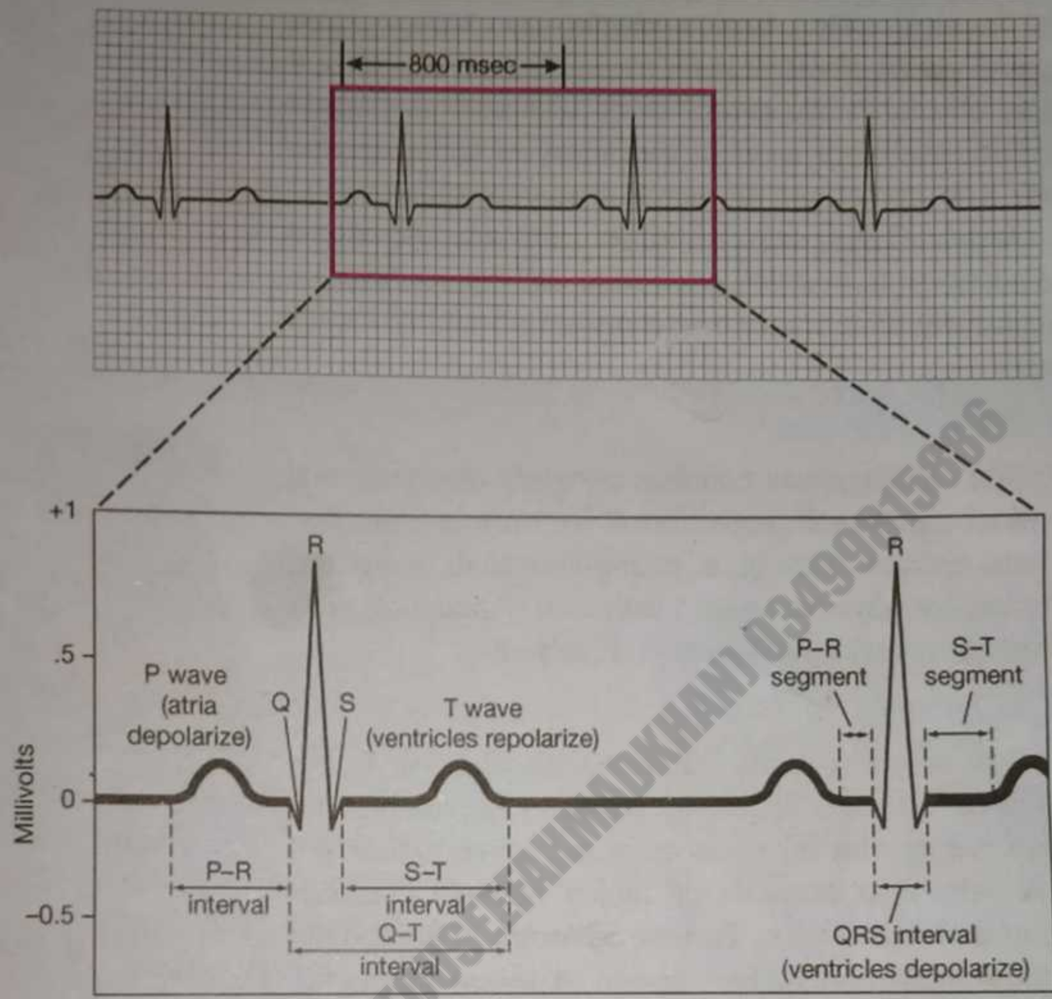


Fig. 12.6: Electrocardiogram (ECG)

12.2 BLOOD VESSELS

There are three types of blood vessels, the **arteries** (and arterioles), which carry blood away from the heart, the **veins**, which return blood to the heart, and **capillaries**, which permit exchange of materials with the tissues.

12.2.1 Arteries

- Arteries carry blood away from the heart. Arteries are pink in colour and are situated within the muscles. Arteries vary in size.

Arteries branch into **arterioles** and **capillaries**. The lumens of arteries have no valves. The wall of an artery consists of three coats or tunics: tunica adventitia, tunica media and tunica intima.

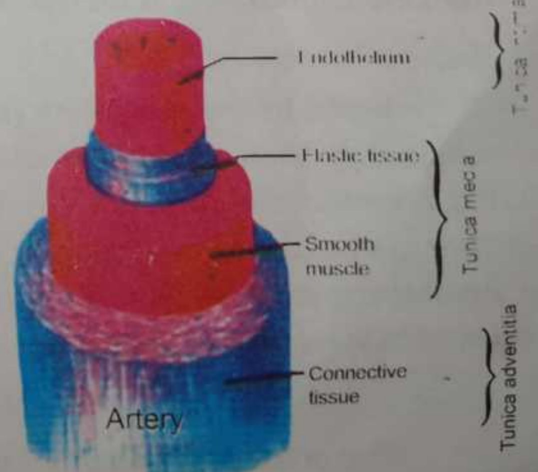


Fig. 12.7: Artery

The outermost layer is called **tunica adventitia**. It is composed of white fibrous connective tissue. The middle layer is called **tunica media**, and has variable amount of elastic fibres. It is many layered in thickness. It consists of one or two layers of circular smooth muscle cells. The innermost layer of the artery is called **tunica intima**. It is composed of simple squamous epithelium and elastic fibres composed of elastin. Arterioles transport blood from small arteries to capillaries. Aorta is approximately 23 mm and arterioles are about 0.2 mm in diameter.

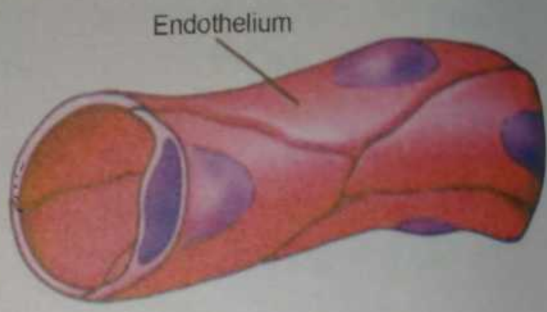


Fig. 12.8: Artery

12.2.2 Capillaries

The capillary wall consists primarily of endothelial cells. Most capillaries range from 7 to 9 µm in diameter, and thus branch without a change in their diameter. Capillaries are approximately 1 mm long. Red blood cells flow through most of capillaries in a single file.

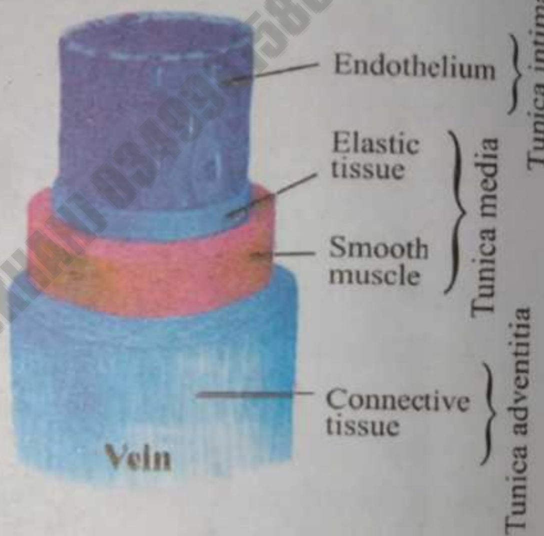


Fig. 12.9: Artery

12.2.3 Veins

The blood vessels that bring blood back to the heart are called veins. Veins are relatively not deep in the muscles. Veins can be seen as blue vessels under the skin. A vein also consists of tunica adventitia, tunica media and tunica intima. **Tunica adventia** is composed of collagenous connective tissue. **Tunica media** is composed of a thin layer of circularly arranged smooth muscle cells, collagen fibres and a few sparsely distributed elastic fibres. **Tunica intima** is a smooth muscle and consists of endothelial cells, thin layer of elastic fibres. **Venules** with a diameter of 40 to 50 µm are tubes composed of endothelium. The **venules** collect blood from the capillaries and transport it to the small veins.

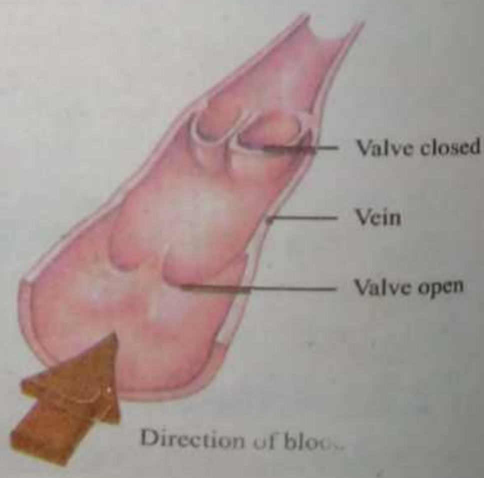


Fig. 12.10: Valves in veins

Valves in veins

Veins having diameters greater than 2mm contain valves that allow blood flow toward the heart but not in the opposite direction. Valves are present only in the lower part of the body especially in the abdomen and hind limbs. In the upper region above the heart there is no valve. As the blood pressure in the veins is comparatively low, so the flow of blood in the veins is helped by gravity, semilunar valve and muscular contraction.

12.2.4 Role of arterioles in vasodilatation and vaso-constriction

The amount of blood flowing through a blood vessel can be regulated by contraction or relaxation of smooth muscle in the tunica media. A decrease in blood flow results from vasoconstriction, a decrease in blood vessels diameter caused by smooth muscle contraction whereas an increase in blood flow is produced by vasodilation an increase in blood vessel diameter because of smooth muscle relaxation. Blood circulation is also controlled by hormones (vasoconstriction agents) acting on arterioles. Norepinephrine is an especially powerful vasoconstriction hormone, and epinephrine is less.

Several substance called **kinins** (vasodilator agents) can cause powerful vasodilation are formed in the blood and tissue fluids of some organs. e.g., histamine. Most of the prostaglandins are vasodilator agents though some of the prostaglandins are vasoconstrictor.

12.2.5 Role of precapillary sphincter in regulating the flow of blood through capillaries

Arterioles supply blood to each capillary network, blood then flows through the capillary network and into the venules. Blood flows from arterioles through **metarterioles**. From a metarteriole blood flows into a **thoroughfare channel**. Several capillaries branch from the thoroughfare channels. Flow in these capillaries is regulated by smooth muscle cells called **precapillary sphincter**, which are located at the origin of the branches. This sphincter can open and close the entrance to the capillary. Precapillary sphincters are normally either completely open or completely closed, and the degree of constriction of the metarteriole also varies. The precapillary sphincters and metarterioles often open and close cyclically several times per minute, with the duration of the open phases being about proportional to the metabolic needs of the tissue. The cyclic opening and closing is called **vasomotion**.

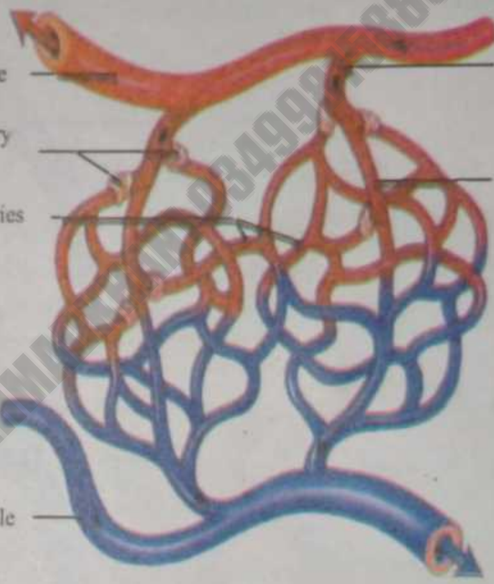


Fig. 12.11: Capillary network

12.2.6 Vascular Pathway

Cardiovascular system includes two circuits, the **pulmonary circuit** which circulates blood through lungs and **systemic circuit** which circulates blood to all other parts of the body.

Skills: Analyzing and Interpreting

- **Justify how Vasodilation and Vasoconstriction is Reflective of Emotions?**

During emotional rage such as apprehension and rage vasodilation occurs due to secretion of **epinephrine**. It is a hormone that is responsible for fear, flight and fright conditions. The sympathetic vasodilator fibres are part of a regulatory system that originates in cerebral cortex and ends at postganglionic neurons in blood vessels on skeletal muscles, activate them to release acetylcholine, and vasodilation occurs. Blood discharge through thoroughfare channels rather than capillaries so heat loss occurs and the skin becomes hot and red. While in vasoconstriction blood supply becomes less to skin, so heat is preserved and the skin becomes cold. Situations such as shock, hypotension and tachycardia occur by stimulation of arterial stretch receptors and production of hypertension and bradycardia (slowness of the heart) occur by increased intracranial pressure.

Pulmonary circulation

The left atrium receives oxygenated blood from the lungs through a pair of **pulmonary veins**, which open by common aperture into it. From left atrium the blood flows into the left ventricle. The superior and inferior vena cavae bring deoxygenated blood and open into the right atrium. From right atrium blood flows into the lungs for oxygenation by a **pulmonary arch** or **trunk** which divides into two **pulmonary arteries**, each going to the lung of its own side. This part of circulation is called **pulmonary circulation** or **circuit**. The pulmonary arteries carry deoxygenated blood and pulmonary veins carry oxygenated blood.

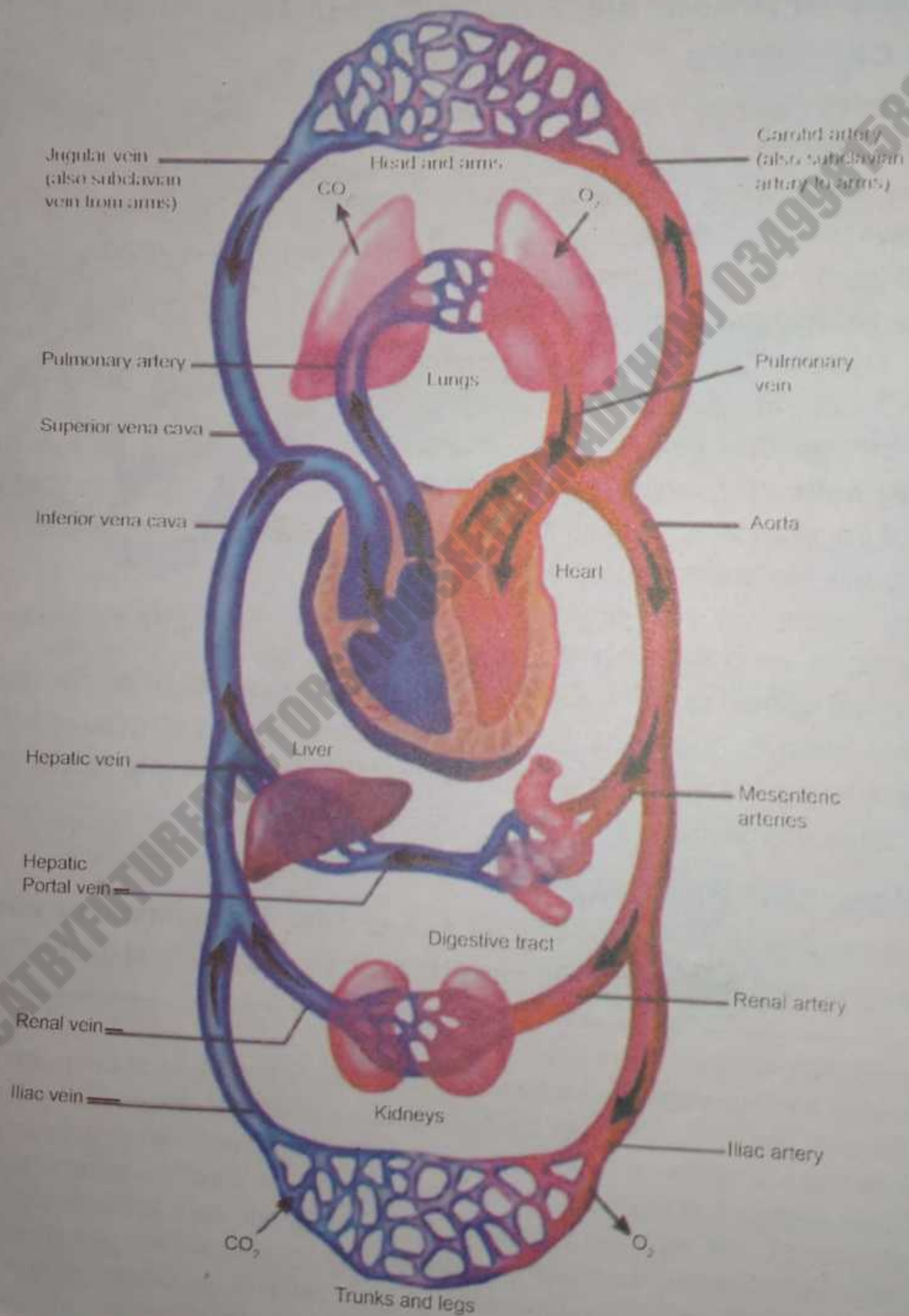


Fig. 12.12: Cardiovascular system

Systemic circulation

The systemic circuit includes all the **arteries** and **veins** other than involved in pulmonary circuit. The largest artery in the systemic circuit is the **aorta.** The largest veins are the **superior** and **inferior venae cavae**. The path of systemic blood to any organ in the body begins in the **left ventricle** which pumps blood in the aorta. Branches from **aorta** go to the organs and major body regions. The **superior vena cava** collects blood from the head, the chest and the arms. The **inferior vena cava** collects blood from the lower body regions. Both enter the right atrium. The aorta and the venae cavae are the major pathways in the systemic circuit. In most instances the artery and the vein that serve the same organ are given the same name.

Coronary circulation

The wall of the heart has its own supply of blood vessels to meet its vital needs. The myocardium is supplied with blood by the **right** and **left coronary arteries**. From the capillaries in the myocardium, the blood enters the **cardiac veins**. The course of these vessels parallels that of the coronary arteries. These cardiac veins converge to form the **coronary sinus channel** on the posterior surface of the heart. The coronary venous blood then enters the heart through an opening into the right atrium.

Hepatic portal system

A **portal** system is vascular system that begins and ends with capillary beds and has no pumping mechanism such as the heart. The **portal system** that begins with capillaries in the viscera and ends with the capillaries in the liver is the hepatic portal system. The **hepatic portal vein**, the largest vein of the system, is formed by the union of all the veins coming from digestive system. Within the liver the blood flows through a series of dilated capillaries which empty into **hepatic veins**. The hepatic veins join the inferior vena cava.

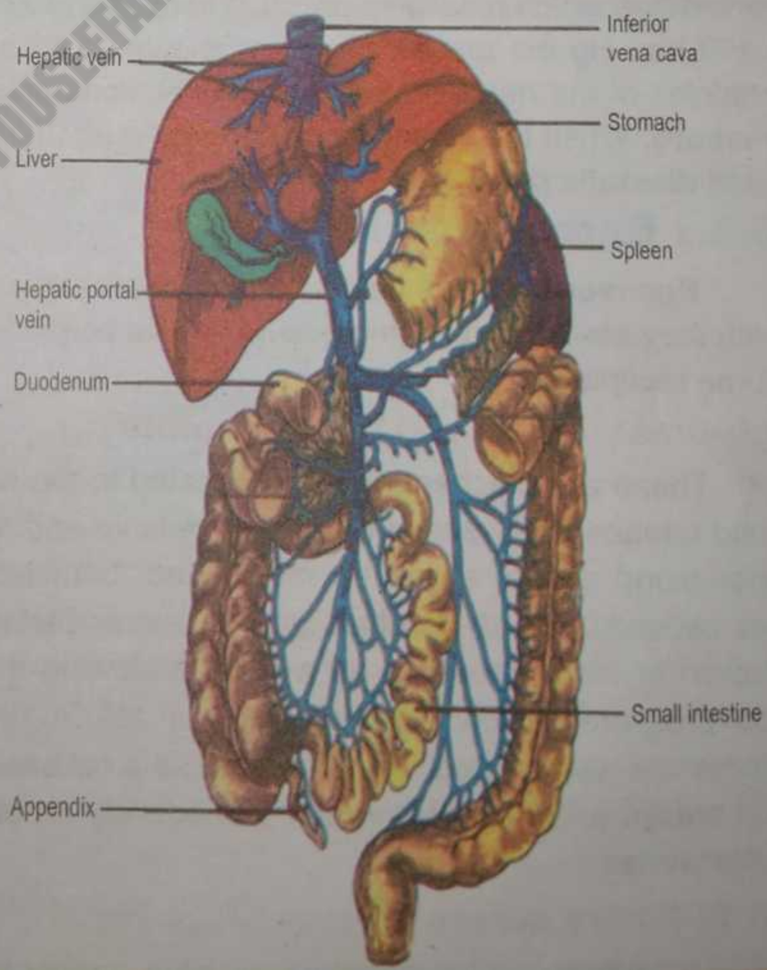


Fig. 12.13: Hepatic portal system

Renal circulation

Renal artery enters into kidney and gives branches which pass through medulla. In cortex they give rise to

afferent glomerular arterioles From here blood enters the **peritubular capillaries** and **vasa recta**. From these capillary networks the blood is drained through veins and leave the kidney as a single renal vein that empties into the inferior vena cava.

12.2.7 Rate of Blood Flow in Blood Vessels

Blood flow means simply the quantity of blood that passes through a given point in the circulation in a given period. The overall blood flow in the circulation of an adult at rest is about 5000 ml/min. This is called **cardiac output**. It is the amount of blood pumped by the heart in a unit period.

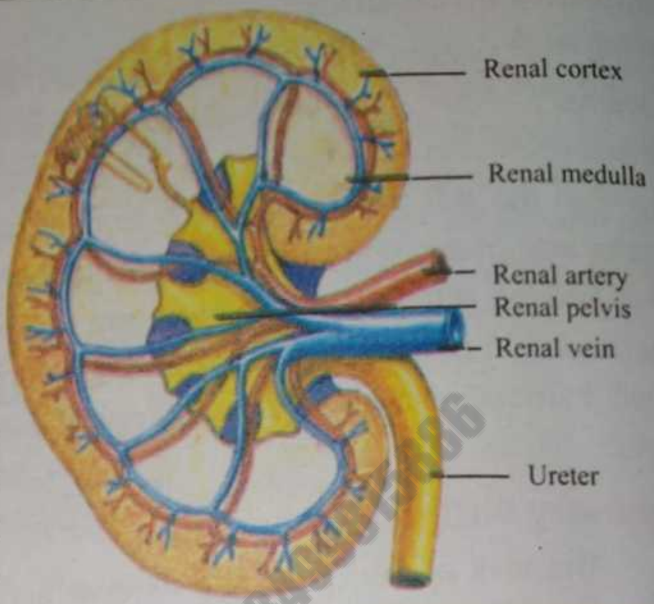


Fig. 12.14: Principal arteries and veins of kidney

12.3 BLOOD PRESSURE

Blood pressure is the force exerted by the blood against any unit area on the inner walls of the blood vessel. The standard reference for the blood pressure is the mercury (Hg) manometer, which measures pressure in millimetres of mercury (mm Hg). If the blood pressure is 100 mm Hg the pressure is great enough to lift a column of mercury 100 mm. When the ventricles of the heart contract the arterial blood pressure is the highest. It is called **systolic pressure**. When the ventricles of the heart relax, the arterial blood pressure is the lowest. It is called **diastolic pressure**.

13.3.1 Baroreceptors

Baroreceptors can be divided into two categories based on the type of blood vessel in which they are located: high-pressure arterial baroreceptors and low-pressure baroreceptors or volume receptors

High-pressure arterial baroreceptors

These are mechanoreceptors located in the walls of the aorta and carotid sinus in the carotid arteries. They sense the blood pressure and relay the information to the brain, so that a proper blood pressure can be maintained. Stimulation of parasympathetic nerves in these areas caused by cardiac output, produces vasodilatation throughout the body and consequent reduction in blood pressure as well as a slowing the heart rate. The opposite occurs when blood pressure is low. In this case, a fall in blood pressure increases nerve impulse transmission along sympathetic nerves. This causes body-wide vasoconstriction and a rise in blood pressure. Baroreceptors act immediately as part of a negative feedback system called the **baroreflex**.

Low-pressure baroreceptors

Low-pressure baroreceptors or volume receptors are found in the atria of the heart and carotid arteries. When these receptors detect a blood volume decrease in the atria, a signal is transmitted from the receptors to the hypothalamus in the brain. The hypothalamus, in turn, increases the production of antidiuretic hormone (ADH) which will cause water retention in kidney. This increases the blood volume, resulting in the increase of blood pressure.

13.3.2 Comparison of the rate of blood flow through arteries, arterioles, capillaries, venules and veins

Blood travels over a thousand times faster in the aorta, i.e., about 30cm/sec on average than in capillaries i.e., about 0.26 cm/sec. You might think that blood should travel faster through capillaries than through arteries, because the diameter of capillaries is very small.

However, it is the total cross-sectional area of capillaries that determines flow rate. Each artery conveys blood to such an enormous number of capillaries that the total cross-sectional area is much greater in capillary beds than in any other part of the circulatory system. For this reason the blood slows substantially as it enters the arterioles from arteries and slows further still in the capillary beds.

As blood leaves the capillaries and enters the venules and veins it speeds up again as a result of the reduction in total cross-sectional area. The carotid sinus and aortic arch baroreceptor reflexes are important in regulating blood pressure moment to moment.

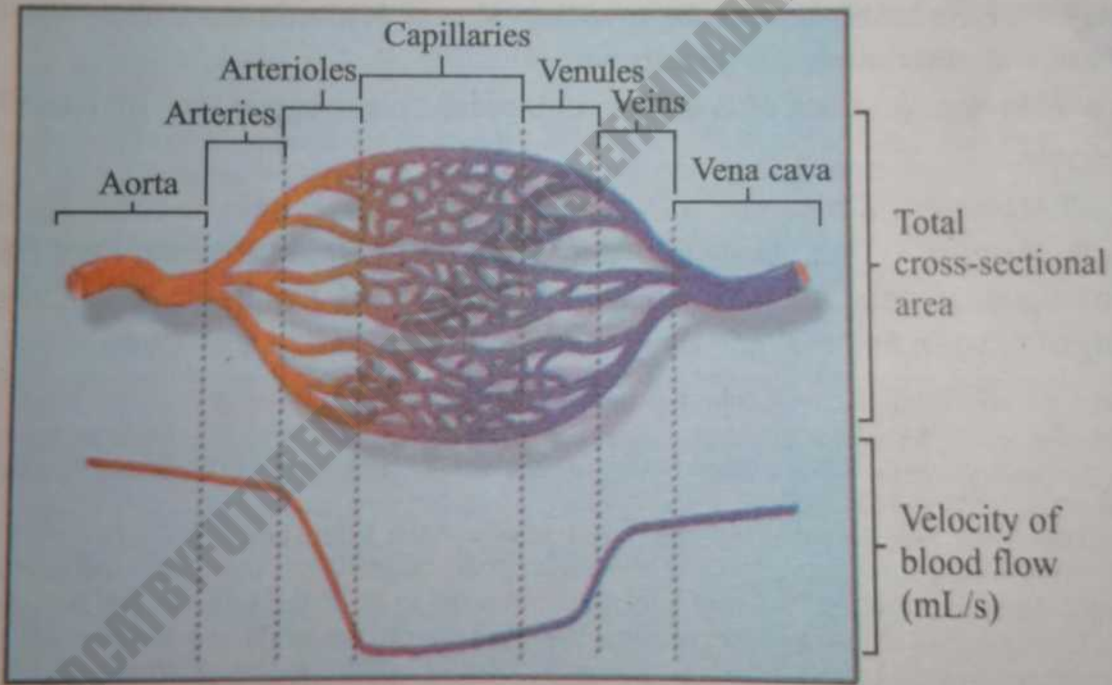


Fig. 12.15: Blood vessel types and velocity of blood flow: Total cross-sectional area for each of the major blood vessel types is the space through which blood flows, measured in square centimeters. The cross-sectional area of the aorta is about 2.5 cm^2. The crosssectional area of each capillary is much smaller, but there are so many that the total cross-sectional area is more than that of the aorta. The line at the bottom of the graph shows that blood velocity drops dramatically in arterioles, capillaries, and venules. As the total cross-sectional area increases the velocity of blood flow decreases

12.4 CARDIOVASCULAR DISORDERS

Cardiovascular disorders or diseases (CVD) are the diseases of the heart and blood vessels. The CVD are the leading cause of untimely death.

12.4.1 Thrombosis

The formation of a clotted mass of blood within a vessel or the heart during life is called **thrombosis**. The clotted mass of blood within a vessel or the heart during life is called **thrombus**. The occlusion (a closing of an opening) of some part of the cardiovascular system by any mass transported to the site through the blood stream is called **embolism**. **Embolus** is a detached intravascular solid, liquid or gaseous mass that is carried to a site distant from its point of origin. About 99% emboli arise from dislodgement of thrombi and are therefore called **thromboemboli**. Thrombus and embolus cause death.

12.4.2 Heart Problems

In this section we will discuss cardiovascular diseases, such as: atherosclerosis, angina pectoris, heart attack, heart failure.

Atherosclerosis

Atherosclerosis is the plaque deposition of cholesterol in the arteries resulting in the narrowing of the arteries lumen. Later, fibres are deposited in the cholesterol and these often start to calcify and become hard, a process known as **arteriosclerosis**. The plaque first forms thrombus and may detach to form embolus. The major factors that cause atherosclerosis and arteriosclerosis are: Hypercholesterolemia, (hyperlipidemia), Hypertension, Cigarette smoking, Diabetes mellitus, the other minor risk factors are:

(a) Increasing age, (b) Lack of exercise, (c) Stressful competitive life, (d) Obesity.

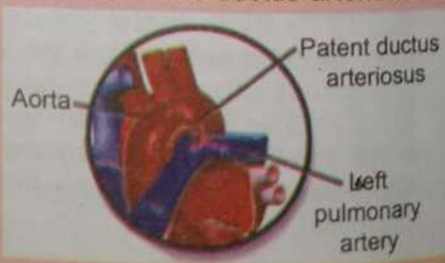
Angina pectoris

Due to atherosclerosis a person may feel occasional chest pain, a condition known as **angina pectoris**. **Angina** is most likely to occur when the heart is labouring hard because of physical or emotional stress. Angina is a signal that part of the heart is not receiving a sufficient supply of oxygen and that part of the heart attack could occur in future.

Patent ductus arteriosus (Extra reading material)

Heart diseases can be classified as congenital or acquired. Congenital heart problems result from abnormalities in the embryonic development and may be attributed to heredity, nutritional problems (poor diet) of the pregnant mother, or viral infection.

Patent ductus arteriosus: Before birth, the two major arteries—the aorta and the pulmonary artery—are connected by a blood vessel called the ductus arteriosus. This vessel is an essential part of foetal blood circulation. Before a baby is born, the foetus's blood does not need to go to the lungs to get oxygenated. The ductus arteriosus is a hole that allows the blood to skip the circulation to the lungs. However, when the baby is born, the blood must receive oxygen in the lungs. Within minutes or up to a few days after birth, the vessel is supposed to close as part of the normal changes occurring in the baby's circulation. If the ductus arteriosus is still open (or patent) the blood may skip this necessary step of circulation. The open hole is called the patent ductus arteriosus. This opening allows oxygen-rich blood from the aorta to mix with oxygen-poor blood from the pulmonary artery. This can put strain on the heart and increase blood pressure in the lung arteries. Treatment options for a patent ductus arteriosus include monitoring, medications and closure by cardiac catheterization or surgery.



Blue- baby syndrome or **blue baby** is usually caused by a heart defect which laymen often call "a hole in the heart". Normally, oxygenated blood from the lungs is separated from deoxygenated blood from other tissues. A defect in the heart **ventricle walls** can allow deoxygenated blood to mix with the blood from the lungs. The resulting blood going through the aorta has less oxygen than usual, and the baby looks blue. An operation is usually done to fix this.

Heart attack

Many heart attacks occur without warning. A blood clot may completely block a coronary artery, or atherosclerosis may reach a critical level causing massive damage to the heart muscle. All of a sudden, the person feels a heavy squeezing ache or discomfort in the centre of the chest. The pain may radiate to shoulder, arm neck or jaw. Other symptoms may include sweating, nausea, shortness of breath and dizziness or fainting. The whole process is called **myocardial** (heart muscle) **infarction** (death due to lack of oxygen). When heart muscles die, they are not replaced because cardiac muscles do not divide. When a person survives a heart attack scar tissue (a type of connective tissue) grows into the areas where the heart muscles have died. The scar tissue cannot contract as cardiac muscle. As a result the damaged heart is permanently weakened.

Heart failure

Congestive heart failure is inability of heart to pump all the blood coming to it. The cardiac output is unable to keep pace with the venous return.

Congenital heart problem

Congenital heart problems result from abnormalities in the embryonic development. It can be related to the malfunctioning of cardiac valves e.g., **Valvular stenosis.**

Atrial septal defect (Extra reading material)

Atrial septal defect is a congenital heart defect. If the interatrial septum is defective then oxygen-rich blood can flow directly from the left side of the heart to mix with the oxygen-poor blood in the right side of the heart, or vice versa. It results in cyanosis (blueness of the skin).During development of the foetus, the interatrial septum develops to separate the left and right atria. However, a hole in the septum called the foramen ovale, allows blood from the right atrium to enter the left atrium during foetal development. This opening allows blood to bypass the nonfunctional foetal lungs while the foetus obtains its oxygen from the placenta. After birth, the pressure in the right side of the heart drops as the lungs open and begin working, causing the foramen ovale to close entirely.

12.4.3 Diagnosis of Cardiovascular Disorders

Modern research efforts have resulted in improved diagnosis of CVD their treatment and prevention.

Principles of angiography

Cardiac catheterization is a technique in which specially designed catheter is inserted into a vein or artery and advanced into the heart under radiographic fluoroscopic guidance. This allows the operator to obtain angiograms by injecting contrast media into an area of interest. It is used to evaluate disease of the mitral valve, aortic valve and aorta, to determine the size and function of the left ventricle.

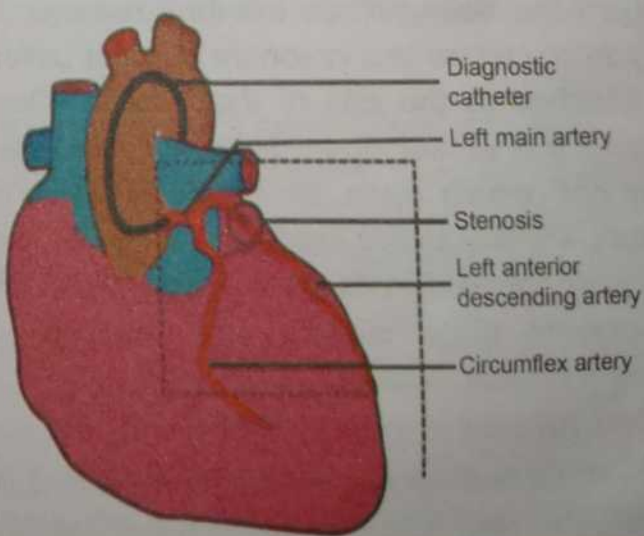


Fig.12.16: Coronary angiogram-schematic of the vessels and branches

Coronary angiography is used to detect **stenosis** (narrowing of a tube) and guide revascularisation procedures such as balloon angiography and stenting.

12.4.4 Treatment and Prevention of CVD

In this section we will discuss the range of advances that have been made for the treatment and prevention of CVD such as coronary bypass, angioplasty, open heart surgery.

Coronary bypass

A coronary bypass is a surgical procedure that relieves the effects of obstruction in the coronary arteries. The technique involves taking healthy segments of blood vessel from other parts of the patient's body usually a vein from the leg or an artery of thorax to bypass obstructions in the coronary arteries.

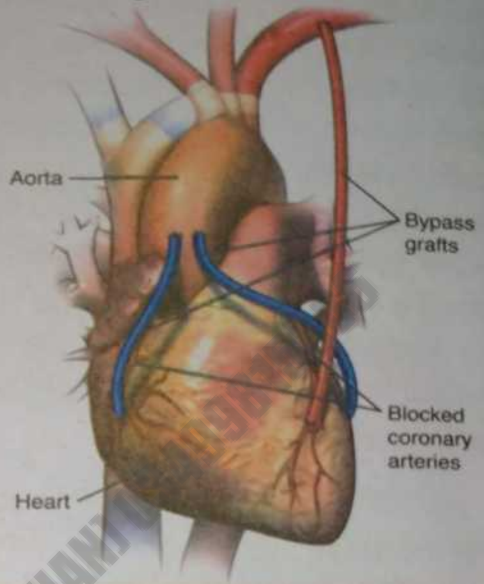


Fig.12.17: Coronary artery bypass graft.

Science, Technology and Society Connections

- **List the advantages and disadvantages of coronary bypass.**

The advantages of coronary artery bypass grafting are: (1) procedure is safe, (2) angina is abolished or greatly reduced in almost 90% of the patients, (3) it is used in the patients with: (a) 2 to 3 vessel diseases (b) disease of left main coronary artery (c) impaired left ventricular function (d) diabetic patients (e) lesion not suitable for angioplasty. The disadvantages of coronary artery bypass grafting are: (a) defused left ventricular damage, (b) peroperative (during operation), myocardial infarction. (c) infection (d) wound pain (e) longer hospital stay.

Angioplasty

In angioplasty a cardiologist threads a plastic tube into an artery of an arm or a leg and guides it through a major blood vessel toward the heart. When the tube reaches the region of plaque in a coronary artery a balloon is attached to the end of the tube is inflated forcing the vessel open. However, the artery may not remain open, so slotted tubes called **stents** are expanded inside the artery to keep the artery open. Stents are coated with heparin to prevent blood clotting and chemicals to prevent arterial closing.

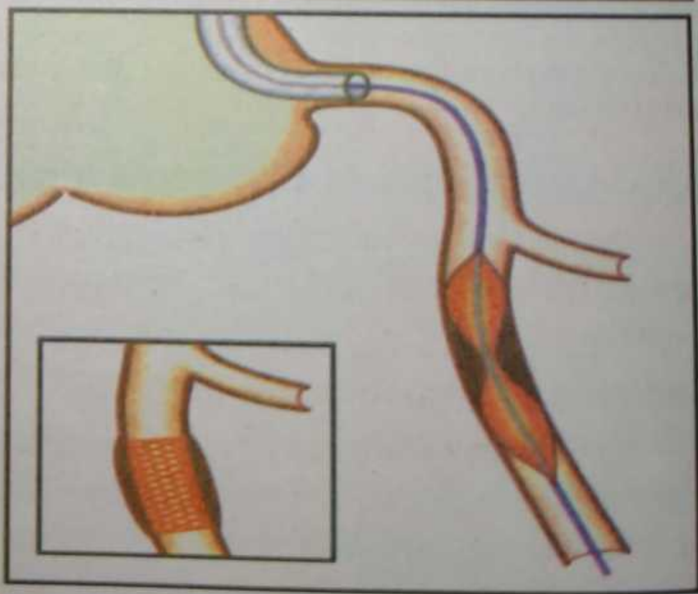


Fig: 12.18: Coronary angioplasty and Stenting

Open heart surgery

This is a surgery in which the patient's chest is opened. The surgery is performed on the heart. The term "open" refers to the chest, not to the heart itself. The heart may or may not be opened depending on the particular type of surgery. Heart surgery is used to correct heart problems in children and adults. An incision is made through the breastbone (sternum) while the patient is under general anesthesia. Tubes are used to re-route the blood through a special pump called a heart-lung bypass machine. This machine adds oxygen to the blood and keeps the blood warm and moving through the rest of the body while the surgeon is repairing the heart. Using the machine allows the heart to be stopped. Stopping the heart makes it possible to repair the heart muscle itself, the heart valves, or the blood vessels outside the heart. After the repair is done, the heart is started again, and the machine is removed. The breastbone and the skin incision are then closed.

DID YOU KNOW?

A new study suggests that one may have what doctors call "masked" hypertension, blood pressure that tends to be higher outside of the medical clinic environment. Masked hypertension was typically more common among males than females. Having diabetes raised the odds for the condition, and so did advancing age, the research showed. The findings were published Jan. 18, 2017 in the *American Journal of Epidemiology*.

12.4.5 Hypertension and Hypotension

Hypertension

Blood pressure is the force of blood against your blood vessels as it circulates. This force is necessary to make the blood flow, delivering nutrients and oxygen throughout your body. High blood pressure also called **"hypertension,"** is a serious medical condition. When the blood pushes harder against the walls of your arteries, your blood pressure goes up. Your blood pressure may be different at different times of the day. Hypertension is defined as blood pressure higher than 140/90 mmHg. A diagnosis of hypertension may be made when one or both readings are high. 120/80 mmHg is normal blood pressure. Modern lifestyle factors are responsible for a growing burden of hypertension: physical inactivity, stress, salt-rich diets with processed and fatty foods, alcohol, tobacco use, age and family history. Hypertension can strain the heart damage blood vessels, and increase the risk of heart attack, stroke, kidney problems and death.

Factors regulating blood pressure

Factors that regulate blood pressure are: heart rate, stroke volume, resistance to blood flow by the blood vessels, strength of the heartbeat, and vasomotor centre in the medulla.

Postural hypotension

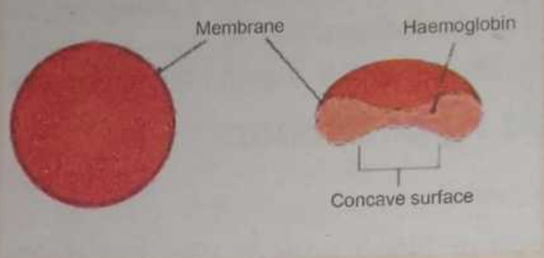
In some individuals, sudden standing or after eating causes a fall in blood pressure, dizziness, dimness of vision, and even fainting. Hypotension occurs primarily in adults older than 65. Other factors include: high blood pressure, some medications, some heart conditions, heat exposure can cause sweating, bed rest and pregnancy as woman's circulatory system expands rapidly during pregnancy.

Prevention of cardio vascular diseases

All of us can take steps to prevent the occurrence of CVD. When a person **smokes**, the drug nicotine causes arterioles to constrict and blood pressure to rise. **Stimulants** such as cocaine and amphetamines can cause an irregular heart attack and stroke. Drinking alcohol and lack of exercise are also the factors that cause CVD. Some of the factors can obviously be avoided by changes in life style. One should try to maintain normal body weight. It is recommended that one should take diet having low cholesterol, low saturated fats and low salt. For calcium, magnesium and potassium one should take grains, fruits, green vegetables and vitamin D.

Human blood (Extra reading material)

Platelets are bits of cytoplasm pinched off from large cells in the bone marrow. The structure of red blood cells or **erythrocytes** suits its main function, which is to carry oxygen. Human erythrocytes are biconcave disk, thinner in the centre than at the sides. A biconcave disk has more surface area for gas exchange than a flat disk or a sphere has. Their smaller size also gives the erythrocytes greater total surface area for gas exchange. Erythrocytes are formed in bone marrow.



There are four kinds of white blood cells or leukocytes. Leukocytes fight infection by releasing chemicals e.g., histamine. Neutrophils and monocytes are phagocytes, eating bacteria and foreign proteins. Eosinophils are phagocytic. Lymphocytes are the key in immunity. Some lymphocytes produce antibodies.

12.5 Lymphatic System of Man

The lymphatic system includes lymph, lymphocytes, lymphatic vessels, lymph nodes, tonsils, spleen and thymus gland. About one sixth of the body consists of spaces between the cells, which collectively are called the **interstitium**. The fluid in these spaces is the **interstitial fluid** or **intercellular fluid**.

Formation: The fluid in the interstitium is derived by filtration and diffusion from the capillaries.

Composition: Interstitial fluid contains almost the same constituents as plasma except for much lower concentrations of proteins because proteins do not pass outward through the walls of the capillaries with ease.

Function: The interstitial fluid allows rapid transport of water molecules electrolytes, nutrients, cellular excreta, oxygen, carbon dioxide etc. Materials are exchanged between the blood and interstitial fluid and between the interstitial fluid and the body cells. In other words, to get from the blood to body cells or vice versa, materials must pass through the interstitial fluid.

12.5 LYMPHATIC SYSTEM OF MAN

The lymphatic system includes lymph, lymphocytes, lymphatic vessels, lymph nodes, tonsils, spleen and thymus gland. About one sixth of the body consists of spaces between the cells, which collectively are called the **interstitium**. The fluid in these spaces is the **interstitial fluid** or **intercellular fluid**.

12.5.1 Lymph, Composition and Function

Formation: The fluid in the interstitium is derived by filtration and diffusion from the capillaries.

Composition: Interstitial fluid contains almost the same constituents as plasma except for much lower concentrations of proteins because proteins do not pass outward through the walls of the capillaries with ease.

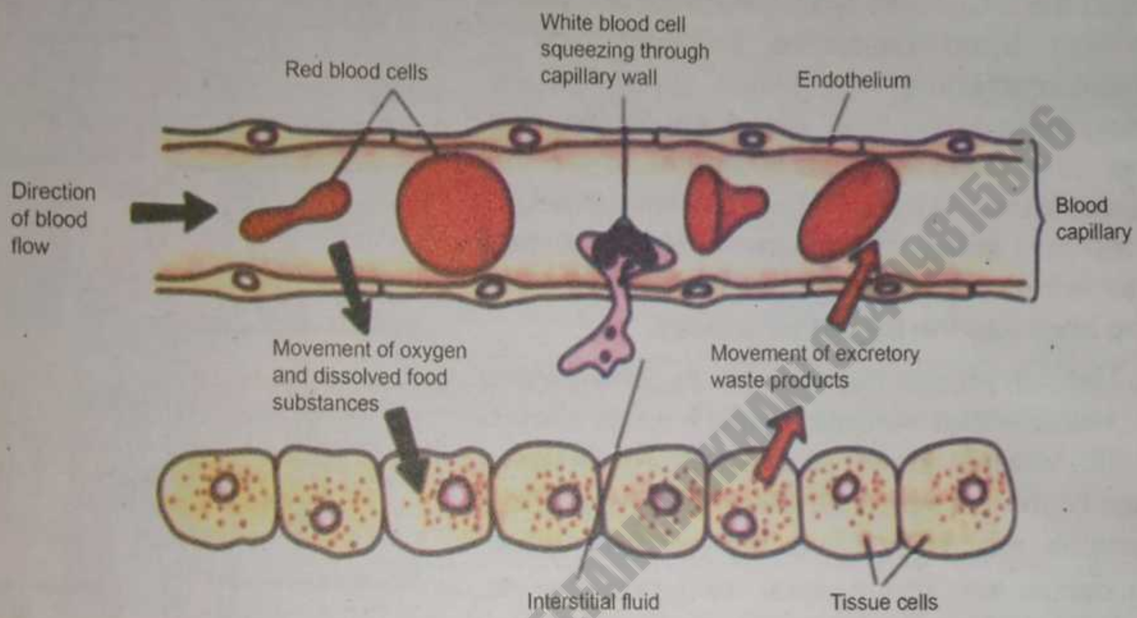


Fig. 12.19: Relationship between a blood capillary, interstitial fluid and tissue cells

Function: Interstitial fluid allows rapid transport of water molecules electrolytes, nutrients, cellular excreta, oxygen, carbon dioxide etc., through the interstitium. Materials are exchanged between the blood and interstitial fluid and between the interstitial fluid and the body cells. In other words, to get from the blood to body cells or vice versa, materials must pass through the interstitial fluid.

12.5.2 Comparison of the composition of interstitial fluid and lymph

Approximately 30 litres of fluid pass from the blood capillaries into the interstitial space each day, whereas only 27 litres pass from the interstitial space back into blood capillaries. The remaining 3 litres of fluid enters the lymphatic capillaries, where the fluid is called **lymph** (meaning clear spring water) and passes through the lymphatic vessels back to the blood. In addition to

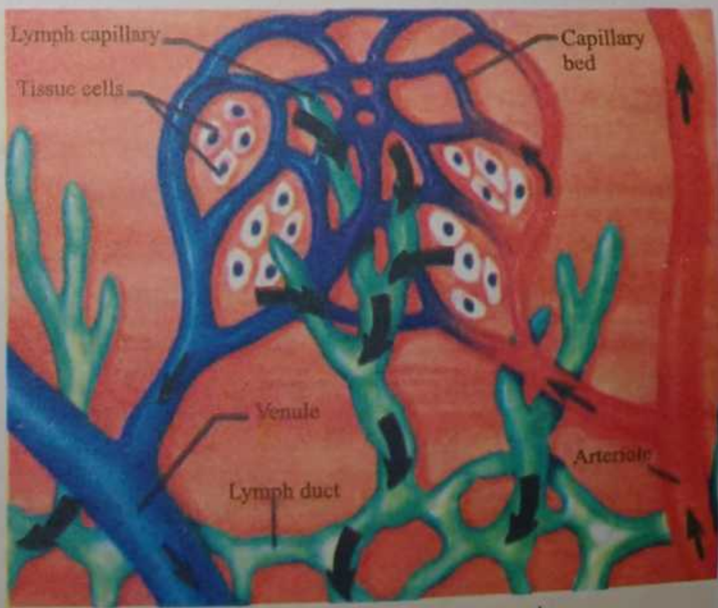


Fig. 12.20: Lymphatic vessels

water lymph contains solutes such as ions, nutrients, gases and some proteins, hormones, enzymes and waste products.

12.5.3 Lymphatic vessels

The lymphatic system as shown in figure 12.21 unlike the circulatory system only carries fluid away from tissue. The lymphatic system begins in the tissues as **lymph capillaries**, which differ from blood capillaries as they lack a basement membrane. The lymph capillaries are far more permeable than blood capillaries and nothing in the interstitial fluid is excluded from the lymph capillaries. The lymph capillary epithelium functions as a series of one-way valve that allows fluid to enter the capillary but prevent it from passing back into the interstitial spaces.

The lymph capillaries join to form larger lymph vessels that resemble small veins. Small lymphatic vessels have a beaded appearance because of the presence of one-way valves along their lengths that are similar to the valves of veins. Lymph nodes are round, oval, or bean–shaped bodies distributed along the various lymphatic vessels. The lymph nodes function to filter lymph.

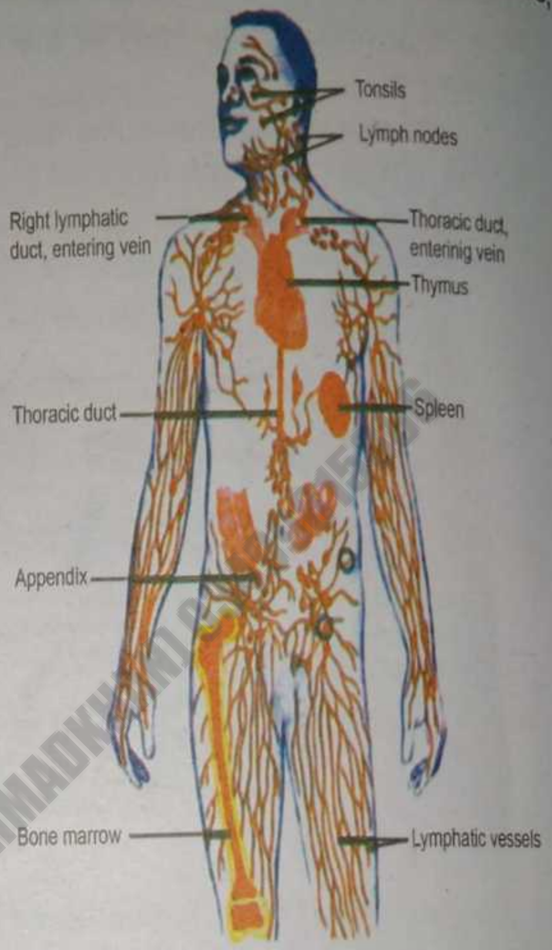


Fig. 12.21: Human lymphatic system

The thoracic duct drains the lower limbs, abdomen, the left thorax, the left upper extremity, and the left side of the head and neck. The duct ends by entering the left subclavian vein. The right lymphatic duct is much short and smaller in diameter than the thoracic duct. It drains the right thorax, right upper limb, and right side of the head and neck and opens into the right subclavian vein.

Role of lacteal present in the villi

Each villus contains a **lymph capillary** called **lacteal**. The lymphatic system absorbs fats and other substances from the digestive tract.

Lymph nodes are small, round or bran-shaped structures, ranging in size from 1 to 25 mm long, and are distributed along the course of the lymphatic vessels. They filter the lymph, remove bacteria and other materials. In addition, lymphocytes assemble, function and proliferate within lymph nodes.

Spleen

The spleen is located in the upper left abdominal cavity just beneath the diaphragm. It is a lymphoid organ. The spleen detects and responds to foreign substances in the blood, destroys worn-out erythrocytes, and acts as a blood reservoir, and to make blood available in times of low blood pressure or when the body needs extra oxygen-carrying capacity.

Skills: Initiating and Planning

- **Justify in what ways blood circulatory system is dependent on the lymphatic system.**

The lymphatic system represents an accessory route by which fluid can flow from the interstitial spaces into the blood. And, the most important, the lymphatic system can carry proteins and large particulate matter away from the tissue spaces, neither of which can be removed by absorption directly into the blood capillary. This removal of proteins from the interstitial spaces is an essential function, without which we would die within 24 hours. Thus blood circulatory system is dependent on lymphatic system.

- **Interpret why the swelling of the lymph nodes is a cause of concern.**

Lymphatic flow is determined by the interstitial fluid pressure and activity of lymphatic pump. Lymph node swelling is a cause of concern because lymph node swells in different diseases, e.g., in pyrexia (fever) of unknown origin enlarged lymph nodes appear. Enlargement of anterior and tonsillar nodes is usually associated with tonsillitis or pharyngitis, posterior lymphoadenopathy may suggest a glandular fever syndrome or HIV infection. The causes of lymphoadenopathy (swelling of lymph node) are bacterial (streptococcal, tuberculosis), viral, protozoan, fungal (histoplasmosis), leukeemias, lymphomas etc.

Activity

1. Correlating the *lub-dub* sounds of the closing of heart valves with the monitoring of the heartbeat
2. Identification of the phases of heartbeat on a printed ECG and comparison of the ECG of a cardiac patient with that of a healthy man
3. Dissection of the heart of sheep and describing its internal structure
4. Differentiation of an artery and a vein by observing prepared slides
5. Measuring blood pressure by using sphygmomanometer

Exercise

MCQs

1. **Select the correct answer**

(i) The rhythmic beating of cardiac muscle in the mammalian heart is initiated by the.

(A) atrio-ventricular node (B) parasympathetic nervous system

(C) Purkinje tissue (D) sino-atrial node

(ii) A red blood cell, entering the right side of the heart, passes by or through the following structures:

1. atrioventricular valve 2. semilunar valve 3.right atrium

4. right ventricle 5. Pulmonary trunk

In which order will the red blood cell passes the structures?

(A) 2 → 3 → 1 → 4 → 5

(B) 3 → 1 → 4 → 2 → 5

(C) 3 → 5 → 1 → 2 → 4

(D) 5 → 3 → 1 → 4 → 2

(iii) What produces systolic blood pressure?
(A) contraction of the right atrium (B) contraction of the right ventricle
(C) contraction of the left atrium (D) contraction of the left ventricle

(iv) Human heart is
(A) myogenic (B) neurogenic (C) cardiogenic (D) digenic

(v) Typical lub-dub sounds heard in heart in heartbeat are due to
(A) closing of bicuspid and tricuspid valves.
(B) closing of semilunar valves
(C) blood under pressure through aorta.
(D) closure of bicuspid –tricuspid valves followed by semilunar valves.

(vi) Bicuspid valve connects
(A) left atrium and left ventricle (B) left atrium and right ventricle
(C) right atrium and left ventricle (D) right atrium and right ventricle

(vii) Pacemaker is situated in heart
(A) in the wall of right atrium (B) on interauricular septum
(C) on interventricular septum (D) in the wall of left atrium

(viii) Lymph returns------------ to blood
(A) oxygen (B) carbon dioxide
(C) interstitial fluid (D) white blood cells

(ix) Lymph most closely resembles which of the following?
(A) blood (B) urine (C) water (D) interstitial fluid

(x) Which of these factors has little effect on blood flow in arteries?
(A) total cross sectional area of vessels (B) blood pressure
(C) skeletal muscle contraction (D) heartbeat

(xi) The Sino Atrial node (SA node)
(A) regulates the rhythm of contraction (B) is also called AV node
(C) regulates the rate of contraction (D) is also called bundle of His

Short Questions

2. Why do we have a circulatory system?
3. What are the contraction and relaxation of human heart called?
4. Where is SA node, AV node, Purkinje fibre, Bundle of His located?
5. Why action potentials travel along the Purkinje fibres more rapidly than through other muscle fibres?
6. Name the artery supplying blood to the heart.
7. What is blood pressure?
8. Why SA node is called pacemaker of the heart?

9. What is a cardiac cycle?
10. What is an arterial pulse? What is the normal human pulse rate?
11. Why is AV node essential for the conduction of cardiac impulse?
12. What are the risks associated with atherosclerosis?
13. Why can you feel your pulse in arteries but not in veins? If there is no pulse in your veins what pushes the blood in veins back to the heart?
14. Define the term thrombus and differentiate between thrombus and embolus.
15. Identify the factors causing atherosclerosis and arteriosclerosis.
16. List the advantages and disadvantages of coronary bypass.
17. List the changes in the life styles that can protect man from hypertension and cardiac problems.
18. What is the major feature of human lymphatic system?
19. Justify why blood circulatory system is dependent on the lymphatic system.
20. Interpret why the swelling of the lymph node is cause of conern.
21. Writ the differences between:
    (a) bicuspid valve and tricuspid valve
    (b) systole and diastole
    (c) SA node and AV node
    (d) P-wave and T-wave of ECG
    (e) blood capillaries and lymph capillaries
    (f) baroreceptor and volume receptor

Extensive Questions

28. Draw label and describe the external structure of human heart.
29. Describe the flow of blood through human heart as regulated by the valves.
30. State the phases of heartbeat in man.
31. Describe the conducting system of human heart.
32. Explain electrocardiogram with the help of diagram.
33. Describe the structure of blood vessels in man.
34. What is the role of precapillary sphincter?
35. Describe pulmonary circulation and systemic circulation.
36. Describe hepatic portal system
37. Give an account of blood pressure in man.
38. Compare the rate of blood flow through arteries, arterioles, capillaries, venules and veins.
39. Explain the following:
    (a) Principle of angiography
    (b) Coronary bypass
    (c) Angioplasty
    (d) Open heart surgery
40. Explain hypertension and hypotension. What are the factors that regulate blood pressure?
41. Describe the lymphatic system of man.

13

IMMUNITY

After completing this lesson, you 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 the Natural Killer (NK) cells kill the cells that are infected by microbes and also kill cancer cells.
- State how the proteins of the complement 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 acts as the most powerful means of resisting infection.
- Identify monocytes, T-cells and 8-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 T-cells in cell-mediated immunity.
- Describe the role of 8-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 diseases.
- Describe the role of T -cells and 8-cells in transplant rejections.

Reading

You have already learnt the composition of blood in grade IX-X biology course and lymphatic system in the previous chapter. In this chapter we will learn about the body's defence and more emphasis would be on the immune system. The body's response to foreign particles, such as the production of antibodies directed against a specific antigen, is called an **immune response**. **Immunity** is the ability to resist damage from foreign substances such as microorganisms and harmful chemicals, e.g., toxins released by microorganisms. **Immunology** is the study of foreign particles that can affect the living body and the defence mechanisms, which are taken by the body to eliminate these particles. The human body has three lines of defence against microbial attack. First line of defence comprises **external barriers** that keep microbes out of the body. Second line of defence consists of **nonspecific internal defence** (innate immunity) that combats all invading microbes. Third line of defence includes the **specific internal defence** (adaptive/ acquired immunity) also called **immune system**.

13.1 FIRST LINE OF DEFENCE

The first and obviously best, defence is to keep microbes out in the first place. The human body has two surfaces exposed to the environment: the skin and the mucous membranes of the digestive and respiratory tracts. These surfaces are external barriers to microbial invasion. Since these barriers inhibit generally all kind of microbial invasion thus, first line of defence is supposed to be a non-specific defence.

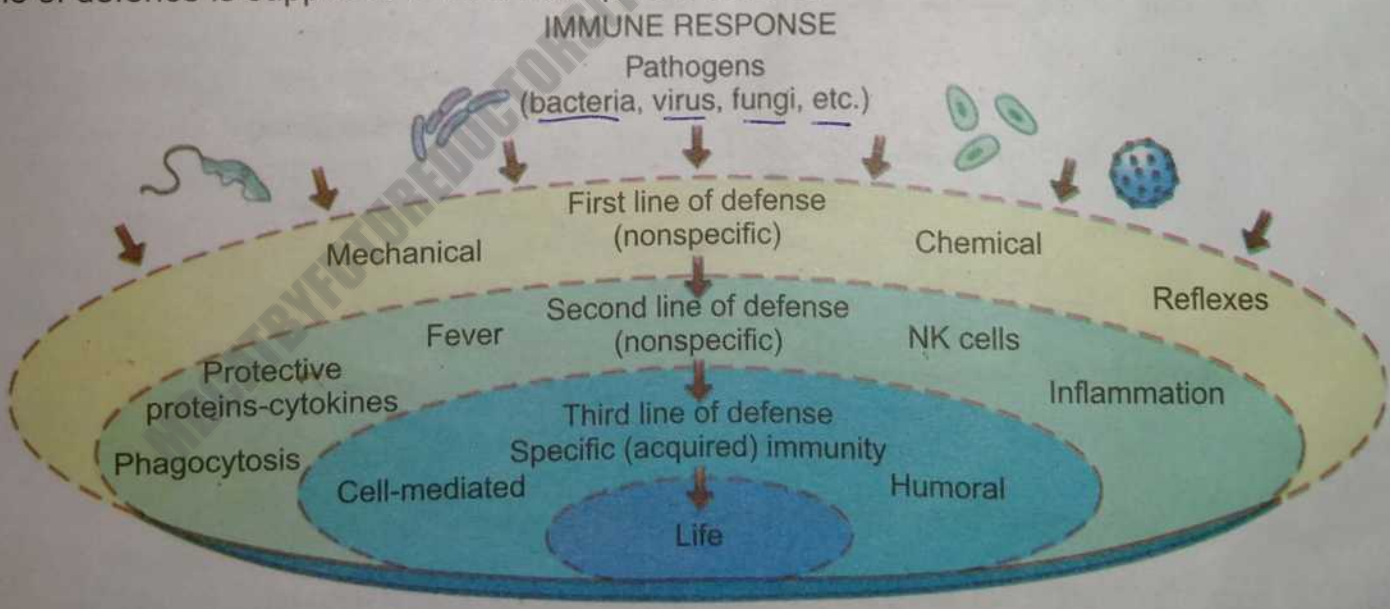


Fig. 13.1: Three lines of defence of the body

13.1.1 Skin: an impenetrable barrier against microbial invasion

The skin is made up of two layers i.e., epidermis and dermis. **Epidermis** is superficial multiple cell thickened layer while **dermis** is inner, comparatively thick layer containing glands, hair follicles, receptors, nerves and blood vessels. Most cells of epidermis have **keratin**. The outer surface of the skin also consists of dry dead cells. Consequently, most microbes that land on the skin cannot obtain the water and nutrients they need.

In addition, the dermis part of skin also contains the sebaceous glands and sweat glands. **Sebaceous glands** produce **sebum**, an oily substance whereas; **sweat glands** secrete **sweat**, a salty fluid that generally provides cooling effect to the body. Secretion from sweat glands and sebaceous glands usually cover the skin. These secretions contain natural antibiotics such as lactic acid that inhibit the growth of bacteria and fungi. These multiple defence make the unbroken skin an extremely effective barrier against microbial invasion.

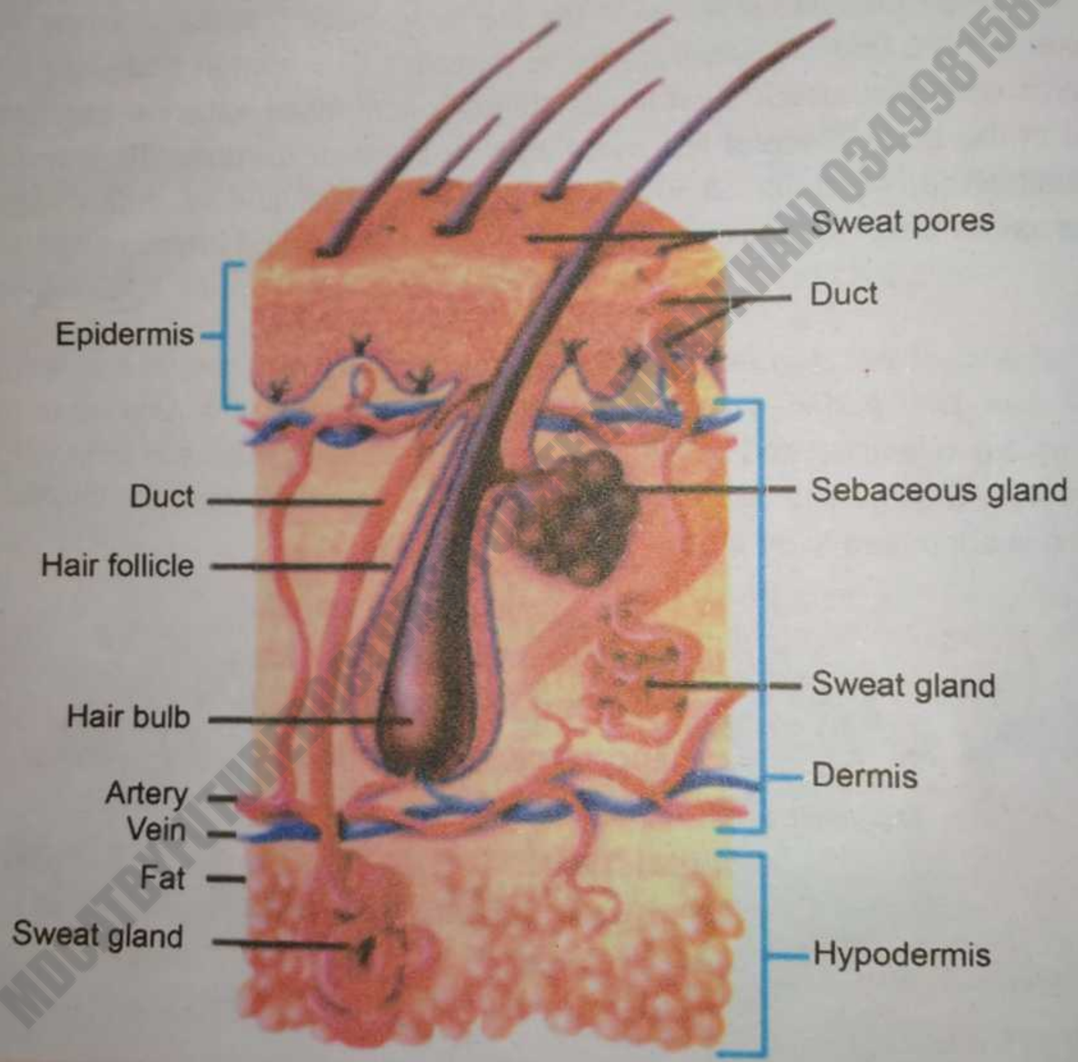


Fig. 13.2: Skin as an impenetrable barrier against microbial invasion

13.1.2 Epithelium of Digestive Tract: an impenetrable barrier against microbial invasion

The gastrointestinal tract (GIT), is covered by mucous membrane, which protects the G1T against microbial invasion by means of its various kind of secretions. Such as **hydrochloric acid** in the stomach is secreted by oxyntic or parietal cells that kills the bacteria present in food. In addition, various **digestive enzymes** present in gastric juice, intestinal juice and pancreatic juice also digest the bacteria present in food.

13.1.3 Epithelium of Respiratory Tract: an impenetrable barrier against microbial invasion

The anterior part of nasal cavities that contain hairs is called **vestibule**. These vestibular hairs filter the large dust particles of the inhaled air. The inner surface of nasal cavities is also lined by **ciliated mucous epithelium**. The **mucous** secreted by this epithelium is also involved in trapping of fine dust particles and microbes. The **cilia** of the epithelium sweep the trapped, fine dust particles and microbes posterior to the pharynx, where they are swallowed and are eliminated by the digestive system. The trachea and the air passageways within the lungs are also lined by ciliated mucous epithelium that is also involved in trapping of fine dust particles and microbes. The cilia in this region propel mucus and foreign particles towards the larynx, where they enter the pharynx and are swallowed.

Fig. 13.3: A diagrammatic view of the respiratory epithelium of trachea showing the direction of movement of mucous containing trapped particles towards pharynx

13.2 SECOND LINE OF DEFENCE - Nonspecific Defence

If microbes become successful to penetrate the skin or mucous membranes then a second line of defence takes action against these foreign invaders. The second line of defence comprises three nonspecific internal defence. First, the body has a standing army of phagocytic cells and **natural killer cells**. Second, invasion of microbes provokes an **inflammatory response**. Third, the body often produces **fever.** In addition, some protective proteins are also the part of second line of defence. These defence are nonspecific because they attack wide variety of microbes, rather than targeting specific invaders as the immune response does.

13.2.1 Killing Cells of Blood

There are white blood cells in the body called **phagocytes**. A phagocyte is a cell that destroys other abnormal body cells (cancerous cells) or invaded microorganisms by engulfing. This process is called **phagocytosis**. Two types of blood cells are phagocytes: macrophages and neutrophils.

Macrophages

Macrophages are derived from monocytes or the monocytes that leave the blood are called **macrophages**. Monocytes are formed in bone marrow. From bone marrow, through blood, macrophages are transported to the areas of the body where they are needed. Macrophages are generally found in the organs such as the lungs, liver, spleen, kidney and lymph nodes, rather than remaining in the blood. In these organs, they patrol within the free spaces among the cells and provide protection by trapping and destroying microorganisms entering the tissue. As macrophages interact with microbes, they not only engulf and destroy them; they also display some parts of microbes on their surface so that other body cells may also be informed. The macrophages also secrete many different proteins when they perform phagocytosis of the microbes. Some of these proteins trigger the maturation of monocytes into macrophages, thereby increasing their numbers. Another protein **interleukin-I** signals the brain to raise the body temperature, producing fever. Some other proteins also stimulate the specific immune response.

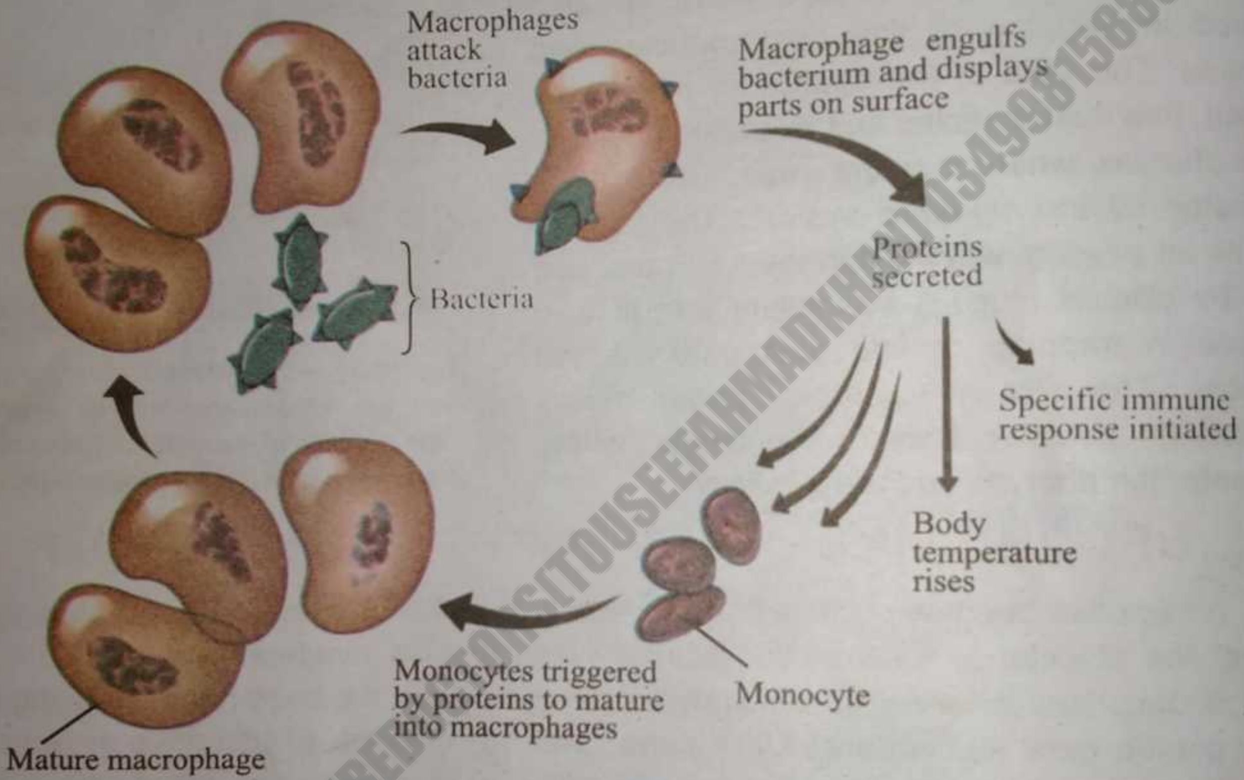


Fig. 13.4: Response of macrophages to foreign particles

Neutrophils

These belong to the granulocyte type of WBCs. They are highly short-lived and highly mobile as they squeeze between cells of capillary walls and can enter parts of tissue where other cells would not be able to enter otherwise. They move like *Amoeba* forming pseudopodia. They proceed rapidly to infected area to perform their duty and they often die after a single phagocytic event. Neutrophils also release lysosomal enzymes and certain chemicals that kill microorganisms and cause inflammation.

Natural killer cells

Natural killer (NK) cells are the type of T-lymphocytes. They are also called cytotoxic T-cells. In general, natural killer cells do not directly attack invading microbes. Instead, natural killer cells strike at the cancerous cells or body cells that have been invaded by viruses. NK cells kill their target by releasing proteins called **perforins**, which punch holes through the membranes of the infected cells. The pores formed by these proteins allow for the passive diffusion of certain apoptotic proteases, known as the **granzymes**, into the target cell. The cell dies by apostosis. NK cells also attack cancer cells at an early stage of tumor.

13.2.2 Protective Proteins of Complement System

The complement system consists over thirty types of small proteins found in the blood, in general synthesized by the liver, and normally circulating in inactive state. They are activated on the entry of foreign particles. Once a **complement protein** is activated, it activates another protein, which further activates other proteins of the system and so on. The result of this complement activation is stimulation of phagocytes to clear foreign and damaged material, development of inflammation to attract additional phagocytes at the site of infection and activation of the cell killing membrane attack complexes. The complement system is an important supporter of the immune system that enhances (complements) the ability of antibodies and phagocytic cells to clear microbes and damaged cells from the body, promotes inflammation, and attacks the pathogen's plasma membrane.

An example of protective proteins of complement system is **perforin**, a membrane attack complex that produces holes in the bacterial cell walls and plasma membranes of bacteria. The holes allow fluids and salts to enter the bacterial cell, thus, bacterial cell swells and eventually burst.

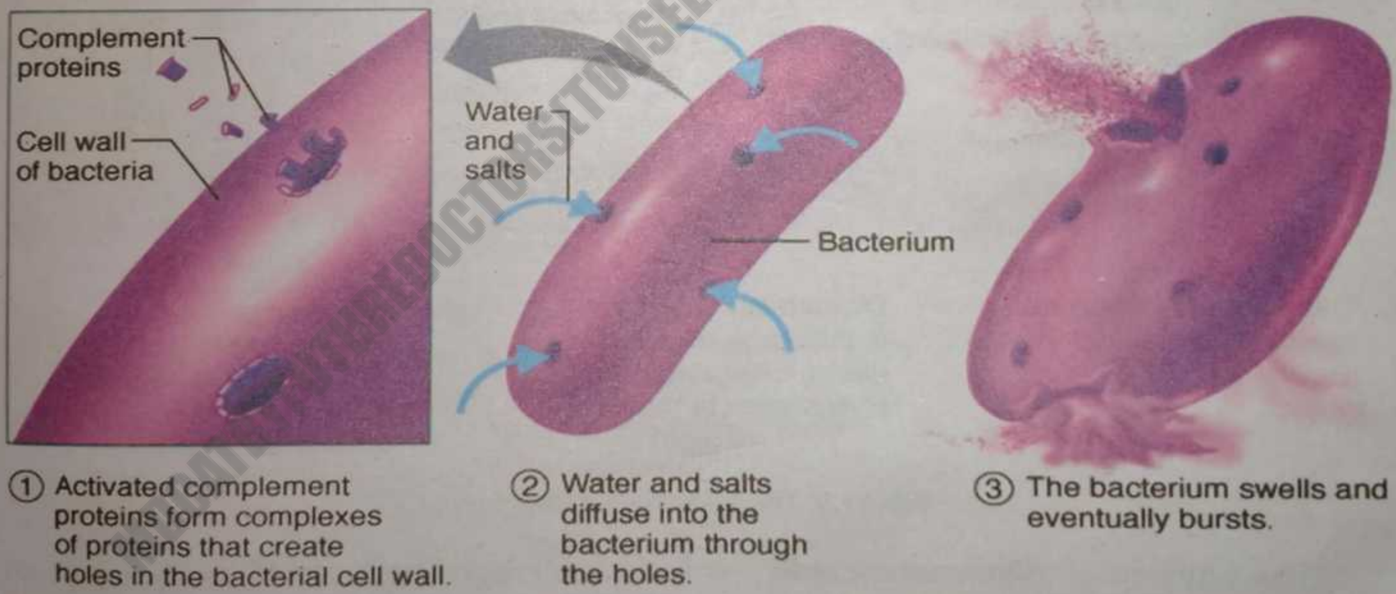


Fig. 13.5: Action of the complement system against a bacterium

Interferons

Interferons (IFNs) belong to the large class of proteins known as **cytokines**, molecules used for communication between cells during infection. They are released by host cells in response to the presence of several pathogens specially viruses. Interferons are named for their ability to "**interfere**" with viral replication. In this way, interferons limit cell-to-cell spread of viruses in the body. IFNs also activate immune cells, such as natural killer cells and macrophages that in turn destroy virally infected cells.

13.2.3 Inflammatory Response

The inflammatory response is a major component of the non-specific defence. Any damage to tissue, whether caused by an infectious microorganism or by physical injury, even just a scratch or an insect bite triggers this response. Inflammation can be localized or systemic (widespread). Local inflammation is an inflammatory response confined to a specific area of the body. The classical signs of inflammation are heat, pain, redness, swelling, and loss of function.

The figure 13.6 shows the chain of events that make up the inflammatory response, in case where a pin has broken the skin and infected it with bacteria. The first thing that happened when a tissue is injured is that the damaged cells release chemical alarm signals such as **histamine**. The chemical sparks the mobilization of various defence. Histamine for instance induces neighbouring blood vessels to dilate and blood vessels start leaking. Blood supply to the damaged area increases, and blood plasma passes out of the leaky vessels into the interstitial fluid of the affected tissues.

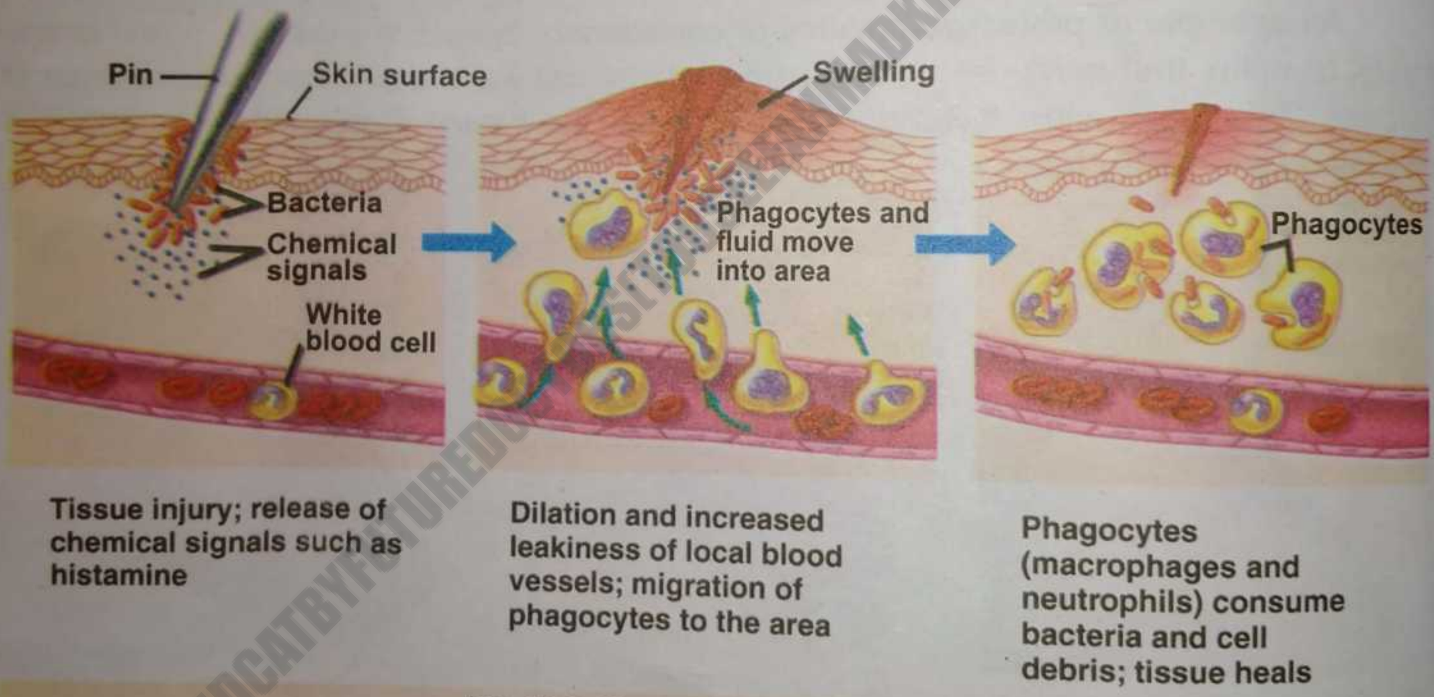


Fig. 13.6: The Inflammatory response

The function of inflammation is to eliminate the initial cause of cell injury, clear out necrotic cells and tissues damaged from the original insult (to attack physically) and the inflammatory process, and to initiate tissue repair. The inflammatory response also helps to prevent the spread of infection to the surrounding tissues.

Skills: Initiating and Planning

- **Justify the inflammatory response in arthritis as an example of a misdirected immune response.**

In this disease, autoantibodies are formed against IgG (antibody or immunoglobin of class G). These autoantibodies are called rheumatoid factors. The agent that induces these autoantibodies is unknown. Within the inflamed joints, the synovial membrane is infiltrated with T cells, plasma cells and macrophages and the synovial fluid contains high levels of macrophage- produced inflammatory cytokines.

13.2.4 Temperature Response

Fever or **pyrexia** is the raised body temperature than normal. The invaded microorganisms often release certain chemicals, which are generally termed as **pyrogens**. These pyrogens cause the temperature set point of the **hypothalamic thermostat** of the body to rise; as a result, all the mechanisms for raising the body temperature are brought into play, such as heat conservation and increased heat production. Since, higher body temperature than normal facilitate the microbial growth in the body, this is the reason why invaded microorganisms want to increase the host's body temperature.

On the other hand, certain white blood cells in response to the infection, also release hormones collectively called **endogenous pyrogens** that further increase the temperature set point of hypothalamus because higher body temperature than normal increases the activity of phagocytic white blood cells that attack upon bacteria. The endogenous pyrogens also cause other cells to reduce the concentration of iron in the blood because many bacteria require more iron to reproduce at temperature of 38°C or 39°C than at 37°C, so fever and reduced iron in the blood combine to slow down their rate of reproduction. Fever also increases the production of interferons that travel to other cells and increase their resistance to viral attack. The higher body temperature may directly inactivate the virus particles, particularly enveloped viruses, which are more heat-sensitive than non-enveloped viruses. Replication of some viruses is reduced at higher temperatures, therefore fever may inhibit replication.

Science Titbits

Several experiments have suggested that interleukin-1 causes fever by first inducing the formation of one of the prostaglandins. When drugs block prostaglandin formation, the fever is either completely abrogated or at least reduced. In fact, this may be the explanation for the manner in which aspirin reduces the degree of fever because aspirin impedes the formation of prostaglandins from arachidonic acid. It also would explain why aspirin does not lower the body temperature in a normal person because a normal person does not have any interleukin-1. Drugs such as aspirin that reduce the level of fever are called antipyretics.

Skills: Initiating and Planning

- **Justify why physician prescribe antihistamine therapy to the patients of runny nose or skin rashes.**

Runny nose or skin rashes are a type of hypersensitivity reaction in which histamine is released from the mast cells and basophils. Its release causes vasodilation, increased capillary permeability and smooth muscle contraction. Antihistamine drugs block histamine receptor sites so histamine action cannot take place. So in this way they are effective in allergic rhinitis i.e. runny nose and skin rashes

Science Technology and Society Connections

- **Justify why the physician prescribe antipyretic drugs, when fever is a nonspecific defence against microbial infections**

Antipyretic drugs create their effects by inhibiting prostaglandin production in the hypothalamus, which has the effect of blocking set point elevation and maintaining the set point at nearer normal levels.

However, fever is nonspecific defence against microbial infections, but often, high degree fever becomes destructive for body's own metabolic system and ultimately body is collapsed. Therefore, physicians use to prescribe antipyretic drugs to the patients of high degree fever.

13.3 THIRD LINE OF DEFENCE - The Specific Defences

If a pathogen is able to get past the body's nonspecific defence, the third line of defence interferes with a series of defence responses, often called immune responses that attack the particular pathogens having specific antigens. These antigens serve as the stimulus to produce an immune response. The term "antigen" comes from ANTI-body GENerating substances. Viruses, bacteria and other pathogen have specific antigens on their surface.

Since, the third line of defence respond against particular infections and acts as the most powerful means of resisting infections therefore, it is also called **specific defence**. Its response can be of two types: **Humoral immune response** and **cell-mediated immune response**. These immune responses are particularly carried out by two components:
B-lymphocytes or B cells and T-lymphocytes or T cells. However, third line of defence also involves role of monocytes (macrophages) that participate in activation of these lymphocytes.

13.3.1 Role of Monocytes in Third Line of Defence

As already described in second line of defence that monocytes are kind of WBCs, which are produced by lymphoid tissues. The monocytes circulate in blood for 10 to 20 hours and ultimately they leave the blood and come into the intercellular space of tissues. In the tissues, they swell and attain a larger size to become tissue **macrophages**. When macrophages perform phagocytosis of invaded microorganisms, after digesting them they not only display microbial antigens on their surfaces but also begin to secrete about 100 different compounds including various enzymes, interferons and a protein called **interleukin-1.** The interleukin-1 secreted by macrophages activates the T cells that in turn begin to secrete **interleukin-2**, which then activates the B cells. Interleukin-1 also promotes a general response to injury, causing fever and activating other mechanisms that defend the body against invasion.

Science Titbits

Early investigators of the immune system found that, when plasma from an immune animal was injected into the blood of a non-immune animal, the non-immune animal became immune. Because the process involved body fluids (humors), it was called humoral immune response. As in this response antibodies are responsible, hence, it is also called antibody mediated immune response. It was also discovered that blood cells transferred from an immune animal could be responsible for immunity and this process was called cell-mediated immunity.

13.3.2 Role of T Cells in Third Line of Defence (Cell mediated immune response)

T cells originate from stem cells in the bone marrow. After early embryonic development, the newly forming T cells migrate to **thymus gland** for processing. The thymus makes T cells immunocompetent that is capable of immunological response. The immune response provided by T cells is called **cell mediated immune response**.

Activations of T cells

In case of infection, macrophages perform phagocytosis of invaded microorganism and detect particular **antigens (nonself molecules)** of the organism. Macrophages isolate and display these antigens on their surface with the help of their own proteins (self-protein) called **major histocompatibility complex (MHC)**. In this way, macrophages become **antigen-presenting cells (APCs).** Macrophages also secrete **interleukin-1** that stimulates and attracts helper T cells towards the displayed antigen. Helper T cells have specific receptor on their surface called **T cell receptor (TCR)** by which they bind with a particular antigen displayed on APC. Interleukin-1 also stimulates the helper T cells to secrete another protein, the interleukin-2 that not only compel the helper T cells to divide but also causes the proliferation of certain cytotoxic T cells and B cells. The activation of T-cells by a specific antigen is called **cell-mediated immunity**. The body contains millions of different T-cells, each able to respond to one specific antigen.

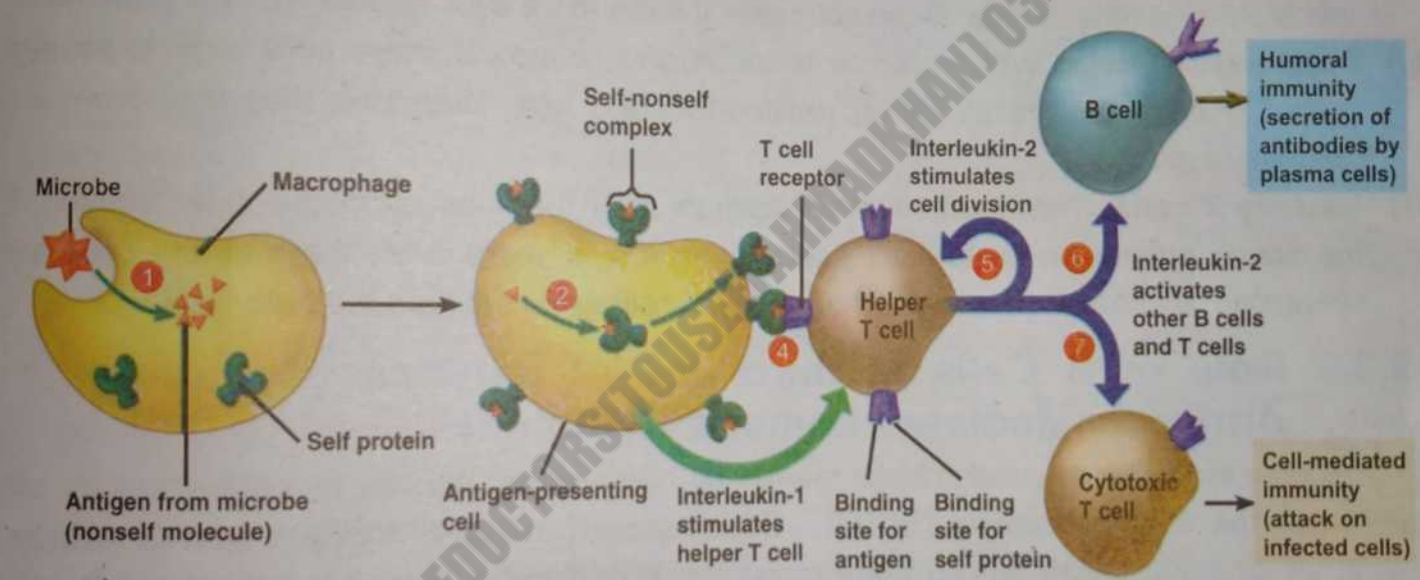


Fig. 13.7: Activation of cell mediated immune response

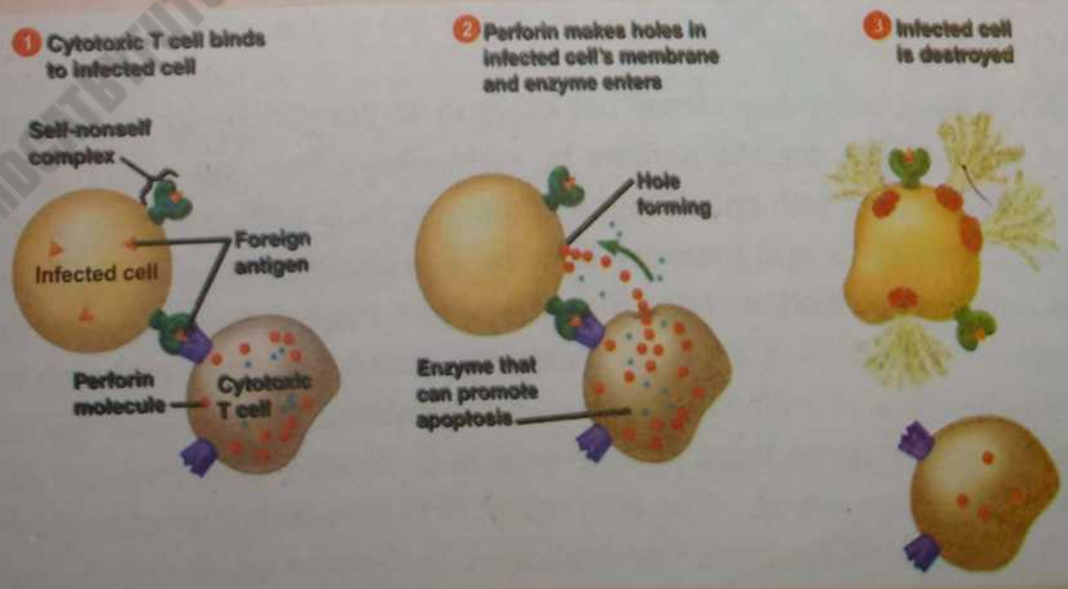


Fig. 13.8: Mode of action of cytotoxic T cells

Types of T cells

Two main categories of T cells have been identified. The first group, known as **CD8** cells because they have surface marker designated **CD8**, include cytotoxic T cells and suppressor T cells. The second group i.e., **helper T cells** also known as **CD4** cells because they have a surface marker designated **CD4**.

When T cells are activated, they divide and produce four types of cells which have specific role in cell-mediated immune response.

(i) **Cytotoxic T cells:** These cells secrete **cytotoxin** which triggers destruction of the pathogen's DNA or **perforin** which is a protein that creates holes in the pathogens plasma membrane. The holes cause the pathogen to lyse (rupture).

(ii) **Helper T cells:** These cells secrete i**nterleukin 2** which stimulates cell division of T cells and B cells. In other words, these cells recruit even more cells to help fight the pathogen.

(iii) **Suppressor T cells:** When infection is successfully removed, these cells begin to secrete certain proteins that inhibit further proliferation of T cell. Therefore, they shut down the immune response.

(iv) **Memory T cells:** These cells remain dormant after the initial exposure to an antigen. If the same antigen presents itself again, even if it is years later, the memory cells are stimulated to convert themselves into helper T cells and help fight the pathogen.

13.3.3 Role of B Cells in third line of defence: Humoral/ Antibody Mediated Immune Response

B cells are differentiated in bone marrow. B cells express specific receptors on their cell membrane, the B cell receptors (BCRs). BCRs allow the B cell to bind a specific antigen, against which it will initiate an antibody response. Like T cells, there are millions of B cells types, found in the body; each is specific for one particular antigen.

Activation of B cells

B cell activation begins when the B cell binds to an antigen via its BCR. Actually, B cells are stimulated to bind with specific antigen by interleukin-2 proteins, which are secreted by helper T cells. After binding with specific type of antigen the B cells divide to produce two type of cells: **plasma clone cells** and **memory B cells**. The plasma clone cells are specialized to secrete bulk quantity of antibodies. After B cells become plasma cells they live only for a few days but secrete a great deal of antibody during the time. A **plasma cell** can produce more than 10 million molecules of antibody per hour. If the same antigen enters the body later, the memory B cells divide to make more plasma cells and memory cells that can protect against future attacks by the same antigen. The stimulation of B cells to divide into plasma clone cells and memory B cells and the secretion of antibodies by plasma clone cells is called **humoral and cell mediated immune response**.

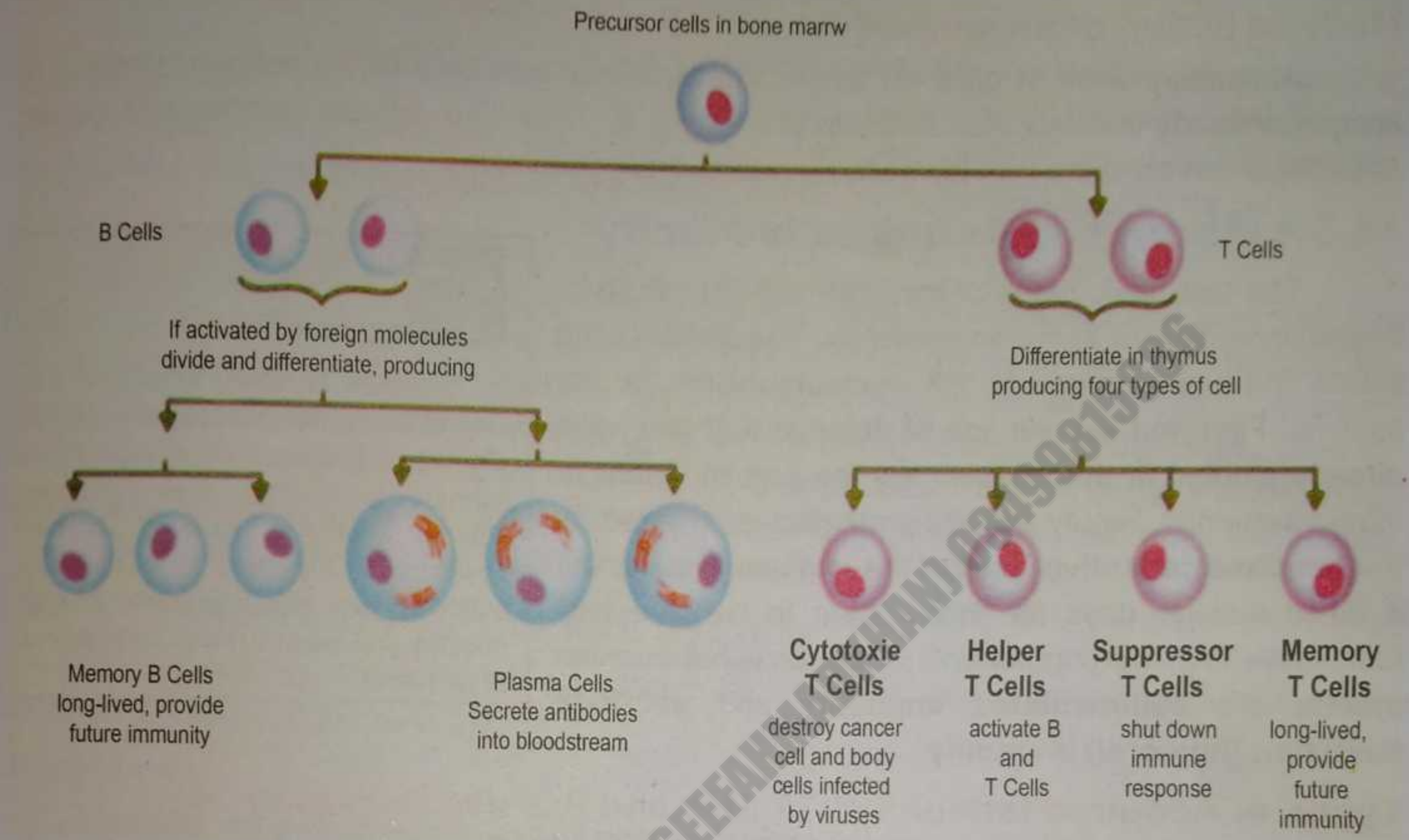


Fig. 13.9: The major cells of Immune system and their roles in the immune system

Structure of an antibody

Antibodies (also called immunoglobulins or Ig's) are Y-shaped proteins that circulate through the blood stream and bind to specific antigens, thereby attacking microbes. The antibodies are transported through the blood and the lymph to the pathogen invasion site.

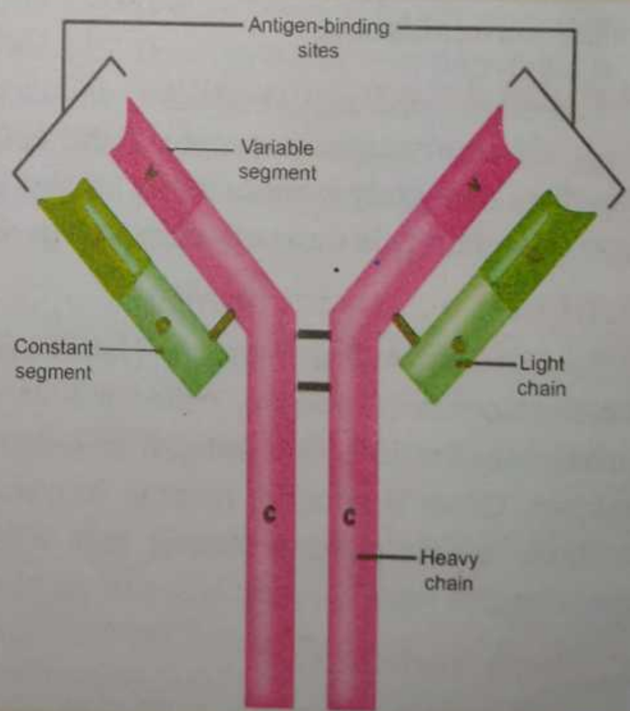


Fig. 13.10: Structure of an antibody

A typical antibody is a Y-shaped molecule, which consists of four polypeptide chains: two identical long chains called **heavy chains**, and two identical short chains called **light chains**. Each chain has a **constant segment**, a functional segment, and a **variable segment**. In the constant segment, (C) of the heavy chains, the amino acid sequence is constant within a particular immunoglobulin class. On the other hand, the variable segments (V) consist of different amino acid sequences in every antibody. Therefore, they act as antigen-binding site. Each antibody has two antigen-binding sites.

Mode of action of an antibody

Antibodies work in different ways: The antibody can bind to an antigen, forming an antigen-antibody complex thus promote phagocytosis. They also activate complement system. Antibodies can combine with toxins to neutralize them (Antitoxin).

13.3.4 Inborn and Acquired Immunity

The two basic types of immunity are (a) inborn or innate immunity (b) acquired immunity. The ability of the innate immune system to kill microorganisms is not specific. First and second line of defence that you have already studied in this chapter are the part of innate or inborn immunity. Highly specific protection is provided by the **acquired** (**adaptive**) **part** of the immune system, but it takes several days for this system to become fully functional. The two components of the acquired immune system are **cell-mediated immunity** and **antibody mediated** (**humoral**) **immunity**.

Science Titbits

In 1717 Mary Montagu, the wife of an English ambassador to the Ottoman Empire, observed local women inoculating their children against smallpox. **Edward Jenner** observed and studied Miss Sarah a milkmaid who had previously caught cowpox and was found to be immune to smallpox.

Types of Acquired Immunity ---Active and Passive Immunity

There are two ways to acquire adaptive immunity: (a) Active Immunity (b) Passive Immunity. Both types may be acquired naturally or artificially. Providing immunity artificially is called **immunization**.

Natural Active Immunity

Natural active Immunity is the kind of immunity, which is obtained as a result of an infection. The body manufactures its own antibodies when exposed to an infectious agent. This type of immunity is most effective and generally persists for a long time, sometimes even for life.

Artificial active immunity

Artificial Active Immunity (vaccination) is achieved by injecting (or administering orally) small amounts of antigen, called the vaccine, into the body of an individual. The process is called **vaccination**. The antigen stimulates the body to manufacture antibodies against other antigen. Often a second, booster is given and this stimulates a much quicker production of antibody which is long lasting and which protects the individual from the disease for a considerable time. Several types of vaccine are currently in use.

Passive immunity

In passive immunity antibodies from one individual are passed into another individual. They give immediate protection, unlike active immunity, which takes a few days or weeks to build up. However, it only provides protection against infection for a few weeks, for the antibodies are broken down by the body's natural processes, so their number slowly fall and protection is lost.

Natural passive immunity

It may be gained naturally. For example, antibodies from a mother can cross the placenta and enter her foetus. In this way they provide protection for the baby until its own immune system is fully functional. Passive immunity may also be provided by **colostrum**, the first secretion of the mammary glands. The baby absorbs the antibodies through its gut.

Artificial passive immunity

Antibodies which have been formed in one individual are extracted and then injected into the blood of another individual which may or may not be of the same species. They can be used for immediate protection if a person has been; or is likely to be, exposed to a particular disease. For example, specific antibodies used for combating tetanus and diphtheria used to be cultured in horses and injected into humans. Only antibodies of human origin are now used for humans. Antibodies against rabies and some snake venoms are also available. Antibodies against the human rhesus blood group antigen are used.

13.3.5 Disorders of Immune System

Some conditions that stimulate a defective immune response or destroy immune system are called disorders of immune system.

Allergies

Allergies are defective immune responses leading to chronic health conditions like Hay fever, eczema, asthma and food allergy. The immune system of allergy patients overreacts when allergens (like pollen, dust or mold) are inhaled or ingested or enter through skin. The body starts producing large quantity of special antibodies IgE. This IgE binds with basophils to release inflammatory chemicals like histamine. Histamine increases capillary leakiness, swelling, mucus secretion, inflammation and other allergic responses. Antihistamine drugs block some of the effects of histamine, relieving the symptoms of allergies. Vaccination can be effective treatment of allergy specially for asthma.

Autoimmune disease

Sometimes, a person's immune system does not normally respond to the antigens (self-molecules) borne on the body's own cells and the antibodies are going to produce against bodies own components and begin to destroy them. This problem is called an **autoimmune disease**. For example:

a) Some types of anemias are caused by antibodies that destroy a person's red blood cells.

b) Many cases of insulin-dependent (juvenile-onset) diabetes occur because the insulin-secreting cells of the pancreas are the victims of a misdirected immune response.

Unfortunately, at present there is no way to cure autoimmune diseases. The autoimmune response can be suppressed with drugs.

Transplant rejections

It is occasionally desirable to transplant some tissue or an organ such as the skin, kidney, heart, or liver, from one person to another to replace a non-functional damaged or lost body part. In such cases, there is a danger that the recipient cells may recognize the donor's organ or tissue as being foreign. This triggers the recipient's immune mechanisms, which may act to destroy the donor tissue. Such a response is called **transplant rejection**.

Role of T cells in transplant rejection

Although the mechanism of rejection probably varies with the nature of the tissue and the degree of incompatibility, all the mechanisms require that the host helper T cells come into contact with the graft tissue's major histocompatibility complex (MHC) antigens. This contact is probably mediated by the dendritic cells of the graft tissue itself. At this point, three different possibilities exist. In the first, **antigen-specific TH cells** stimulate the activation and proliferation of appropriate T cells, which then mount a focused attack on the transplant tissue. In the second, **responsive** antigen-specific TH cells move to the graft site, where they release **lymphokines**. These recruit monocyte/macrophages and T cells to the graft site and maintain them at the scene while they destroy the tissue.

Role of B cells in transplant rejection

There is a third mechanism in which antibodies plays a role. The responsive helper T cell interacts with the appropriate B cell clone, producing a shower of antibodies to the implanted tissue's MHC antigens. These can trigger either complement-mediated graft damage or facilitating the phagocytosis of the grafted tissue by macrophages.

Science, Technology and Society Connections

- **Describe malignant melanoma as due to the inability of tumour-infiltrating lymphocyte (TIL) to control the tumour of skin cancer and correlate it with the scientific advancements of inserting a gene of tumour necrosis factor in the lymphocyte.**

Most dangerous form of skin cancer

Cancer starts when cells in the body begin to grow out of control. Melanoma is a cancer that usually starts in the melanocytes a type of skin cell. Melanomas can develop anywhere on the skin, but they are more likely to start on the trunk (chest and back) in men and on the legs in women. The neck and face are other common sites. The cancerous growths develop when unrepaired DNA damage to skin cells (most often caused by ultraviolet radiation from sunshine or tanning beds) triggers mutations (genetic defects) that lead the skin cells to multiply rapidly and form malignant tumours. These tumours originate in the pigment-producing melanocytes in the basal layer of the epidermis. Tumour-infiltrating lymphocytes are believed to represent the immune reaction/response to melanoma cells. Tumour (tumor)-infiltrating lymphocytes (TIL), are white blood cells that have left the bloodstream and migrated into a tumour. They are mononuclear immune cells, a mix of different types of cells (i.e., T cells, B cells, NK cells, macrophages) in variable proportions, T cells being the most abundant cells. They can often be found in the stroma and within the tumour itself.

TILs are not strong enough to control certain types of tumors e.g., malignant melanoma. For the gene therapy of malignant melanoma first the TIL cell are removed from the patient and reinserted a gene that codes for the protein tumour necrosis factor (TNF). The protein kills tumour cells by preventing them from establishing a blood supply. The engineered TIL cells were then returned to the patient blood stream to seek out and invade the malignant melanoma tumours.

Skills: Initiating and Planning

- **Justify why physician prescribe antihistamine therapy to the patients of runny nose or skin rashes.**

Runny nose or skin rashes are a type of hypersensitivity reaction in which histamine is released from the mast cells and basophils. Its release causes vasodilation, increased capillary permeability and smooth muscle contraction. Antihistamine drugs block histamine receptor sites so histamine action cannot take place. So in this way they are effective in allergic rhinitis i.e. runny nose and skin rashes.

Skills: Initiating and Planning

- **Explain why a transplant recipient is given immune suppressant drugs and determine what implications does this has on his life.**

Organ transplantation has become a routine procedure due to improvement of surgical techniques, better tissue typing and the availability of drugs that more selectively inhibit rejection of transplanted tissues and prevent the patient from becoming immunologically compromised. Transplant rejection occurs as a delayed hypersensitivity reaction as a function of lymphocytes and not due to antibodies. Administration of immunosuppressive drugs enhances tolerance. People receiving immunosuppressive drugs have side effects like pain, diarrhoea, leukopenia, sepsis, lymphoma, thrombocytopenia, skin rashes, anaphylactic reaction, hypertension, hyperkalemia and neurotoxicity (tremors, seizures, hallucination). Hence, each system is affected, so the person starts to feel weakness and gets fatigue easily.

Science, Technology and Society Connections

- **Describe the discovery of monoclonal antibodies and justify how this accomplishment revolution many aspects of biological research.**

In 1970 Cesar Milstein and Georges Kohler working in Cambridge solve the problem of developing a technique for producing monoclonal antibodies, for which they were awarded Nobel Prize in 1984. Monoclonal means belonging to one clone. Each type of antibody is made by one type of B cells which cloned itself, in other words multiplies to make many identical copies of itself in response to a particular antigen. Milstein and Kohlar fused B cells with cancer cells, which are immortal to form hybridoma cells. The hybridoma cells continue to multiply and can be cloned so that large quantities of antibodies can be produced. Monoclonal antibodies are harvested from cell cultures rather than animals. The ability to make monoclonal antibodies has been spawned a new industry. A common area of application is medical diagnosis. Monoclonal antibodies are used for determining pregnancy and for diagnosing diseases such as, hepatitis, rabies, cancer, streptococcal throat infections, herpes viruses, leukaemias (cancers of white blood cells) and lymphomas etc. A monoclonal antibody has been developed which is very effective at preventing rejection of transplanted kidneys. Monoclonal antibodies can be used to find out the types of antigens present in the donor and increase the accuracy of matching.

Science Titbits

A group of antimicrobial proteins called **defensins** are secreted by activated macrophages. These small proteins damage broad groups of pathogens, by various mechanisms without harming the body cells.

Activity

1. Recognizing phagocytes and lymphocytes while observing prepared slides

Exercise

MCQs

1. **Select the correct answer**

(i) Plasma cells are
(A) the same as memory cells
(B) formed from blood plasma
(C) B cells that are actively secreting antibody
(D) inactive T cells carried in the plasma

(ii) Antibodies combine with antigens
(A) at variable regions
(B) at constant region
(C) only if macrophages are present
(D) both A and C are correct

(iii) In addition to the immune system, we are protected from disease by
(A) normal body temperature
(B) hormones
(C) antigens
(D) mucous membrane and cilia

(iv) Fever
(A) decrease interferon production
(B) decrease the concentration of iron in the blood
(C) decrease the activity of phagocytes
(D) decrease the inflammation

(v) T and B cells are
(A) lymphocytes
(B) macrophages
(C) natural killer cells
(D) red blood cells

(vi) When B-cells are presented with antigen they differentiate into
(A) T-cells
(B) helper T-cells
(C) plasma cells
(D) bursa cells

(vii) When one receives a booster shot for polio which type of cell is most directly stimulated?
(A) killer T-cells
(B) memory cells
(C) phagocytes
(D) suppressor cells

Short Questions

2. What is immune response?
3. Name the three lines of defence against microbial attack.
4. How oil and sweat glands take part in defence against microorganisms?
5. Name the parts of antibody molecule.
6. What are the memory cells?
7. How does an antibody differ from an antigen?
8. Why does each antibody bind only to a specific antigen?
9. Why is passive immunity temporary?
10. Name the disorders of immune system.
11. What are the autoimmune diseases?
12. Write the differences between:
    (a) sebaceous gland and sweat gland
    (b) macrophages and neutrophils
    (c) antibody-mediated immune response and a cell-mediated immune response.
    (d) cytotoxic T cells and suppressor T cell
    (e) plasma cells and memory cells
    (f) antibody and antigen
    (g) inborn immunity and acquired immunity

Extensive Questions

13. Describe the human skin as an impenetrable barrier against invasion by microbes.
14. What is the role of macrophages and neutrophils in killing bacteria?
15. Explain the protective proteins of complementary system with diagram.
16. Explain in detail inflammatory response with diagram.
17. Explain temperature response against infection.
18. What are the ways fever kills microbes?
19. Describe the role of monocytes in immune system.
20. What is the role of T cells in cell mediated response.
21. Describe the role of B cells in humoral antibody mediated immune response.
22. Describe the types of acquired immunity.
23. Describe the role of T cells and B cells in transplant rejection.
24. Explain why a transplant recipient is given immune suppressant drugs and determine what implications this has on his life.

Glossary

A

acidosis: an increase in hydrogen ion concentration.

allantois: One of the extraembryonic membranes of the embryo, in amniotes. Forms a ventral outgrowth of the gut, enlarges during development, and functions in waste (uric acid) storage and gas exchange.

anaerobic (an"air-oh'bik): growing or metabolizing only in the absence of molecular oxygen.

antibody (an-tih-bod'ee): protein compound (immunoglobulin) produced by plasma cells in response to specific antigens and having the capacity to react against the antigens.

anticodon: a sequence of three bases in transfer RNA that is complementary to the three bases of a codon of messenger RNA.

antidiuretic hormone: (ADH) (an"ty-dy-uh-ret'ik) a hormone secreted by the posterior lobe of the pituitary that controls the rate of water reabsorption by the kidney.

antigen (an'tih-jen): any substance capable of stimulating an immune response; usually a protein or large carbohydrate that is foreign to the body.

apical dominance (ape'ih-kl): the inhibition lateral buds by a shoot up.

apical meristem (mehr'ih-stem): an area of dividing tissue located at the tip of a shoot or root; apical meristems cause an increase in the length of the plant body.

apoenzyme (ap"oh-en'zime): protein portion of an enzyme that requires the presence of a specific coenzyme to become a complete functional enzyme.

apoplast: a continuum consisting of the interconnected, porous plant cell walls.

atherosclerosis: a disease characterize by obstruction of arteries by cholesterol deposits and thickening of arterial walls.

autoimmune disease: a disorder in which the immune system produces antibodies against the body's own cells.

autotomy: The casting off by an animal of a part of its body, to facilitate escape when attacked

auxin (awk'sin): a plant hormone involved in various aspects of growth and development, such as stem elongation, apical dominance and root formation on cuttings.

B

B cells: a type of lymphocytes that participates in humoral immunity, gives rise to plasma cells that secrete antibodies into the circulatory system and to become memory cells.

basal body (bay'sl): structure involved in the organization and anchorage of a cilium or flagellum.

base pair: a complementory pair of nucleolides, containing a purine, pyrimidine.

basidiocarp (ba-sid'e-o-karp): the fruiting body of a basidiomycete, e.g., mushroom.

basidiomycete (ba-sid"e-o-my'seat): member of a phylum of fungi characterized by the production of sexual basidiospores.

basidiospores (ba-sid"e-o-spor): one of a set of sexual spores,usually four, borne on a basidium of a basidiomycete.

basidium (ba-sid"ee-um): the club-like spore-producing organ of basidiomycetes that bears sexual spores called basidiospores.

bilateral symmetry: a body shape with right and left halves that are approximately mirror images of one another.

bile: a liquid secretion of the liver stored in the gall bladder and released into the small intestine during digestion. Bile is a complex mixture of bile salts, water, other salts, and cholesterol.

binary fission: the process by which a single bacterium divides in half, producing two identical offspring.

biodiversity: all living things within a given geographical area and the interrelationships among them.

biotechnology: the use of biological processes from microorganisms to make substance or to provide service to man.

bipinnaria: free swimming, ciliated, bilateral larva of the asteroid echinoderms; develops into the brachiolaria larva.

blastopore (blas'toh-pore): primitive opening into the body cavity of an early embryo that may become the mouth (in protostomes) or anus (in deuterostomes) of the adult organism.

blood pressure: the force exerted by blood against the inner walls of the blood vessels.

brachiolaria: It is the second stage of larval development in many starfishes it follows the bipinnaria. Brachiolaria have bilateral symmetry, unlike the adult starfish, which have pentaradial symmetry.

budding: asexual reproduction in which a small part of the parent's body separates form the rest and develops into a new individual; Characteristic of yeasts and certain other organisms. e.g. *Hydra*

C

C_3 cycle: the cyclic series of reactions whereby carbon dioxide is fixed into carbohydrates during the light-independent reactions of photosynthesis also called Calvin cycle.

C4 pathway: the series of reactions in certain plants that fixes carbon dioxide into oxaloacetic acid, which is later broken down for use in the C3 cycle of photosynthesis.

carbon fixation: the initial steps in the C3 cycle in which carbon dioxide reacts with the ribulose bisphosphate to form a stable organic molecule.

cardiac (kar'dee-ak): pertaining to the heart.

cardiac cycle: one complete heart beat.

carrier proteins: a membrane proteins that facilitates diffusion of specific substances across the membrane. The molecule to be transported binds to the outer surface of the carrier proteins, the protein than changes shape, allowing the molecule to move across the membrane through the protein.

carrier-mediated active transport: transport across a membrane of a substance from a region of low concentration to a region of high concentration; requires both a transport protein with a binding site for the specific substance and an energy source (often ATP).

casparian strip: a waxy, water proof band in the cell walls between endodermal cells in a root, which prevents the movement of water and minerals in and out of the vascular cylinder through the extracellular space.

cell-mediated immunity: the immune response in which foreign cells or substances are destroyed by contact with T cells.

cellular slime mold: a phylum of fungus-like protists whose feeding stage consists of unicellular, amoeboid organisms that aggregate to from a pseudoplasmodium during reproduction.

centrifuge device: used to separate cells or their components by subjecting them to centrifugal force.

centromere (sen'tro-meer): specialized constricted region of a chromatid; contains the kinetochore. In cells at prophase and metaphase, sister chromatids are joined in the vicinity of their centromeres.

channel protein: a membrane protein that forms a channel or pore completely through the membrane and that is usually permeable to one or a few water-soluble molecules specially ions.

chemiosmosis: a process of ATP generation in chloroplasts and mitochondria. The movement of electron transport system is used to pump hydrogen ions across membrane, thereby building up a concentration gradient of hydrogen ions across the membrane. The hydrogen ions diffuse back across the membrane through the pores of ATP-synthesizing enzymes. The energy of their movement down their concentration gradient drives ATP synthesis.

chitin (ky'tin): a nitrogen-containing structural polysaccharide that forms the exoskeleton of insects and the cell walls of many fungi.

choanocyte (koh-an'oh-sight): a unique cell having a flagellum surrounded by a thin cytoplasmic collar; characteristic of sponges and group of protists.

chorion: the outermost extra embryonic membrane of the embryo of an amniote. Becomes highly vascular and aids in gas exchange.

chromatin (kro' mah-tin): the complex of DNA, protein, and RNA that makes up eukayotic chromosomes.

chromosomes (kro'moh-soms): structures in the cell nucleus, composed of chromatin and containing the genes.

ciliate (sil'e-ate): a unicellular protozoon covered by many short cilia.

citrate (citric acid): a 6-carbon organic acid.

citric acid cycle: series of chemical reactions in aerobic cellular respiration in which acetyl coenzyme A is completely degraded to carbon dioxide and water with the release of metabolic energy which is used to produce ATP; also known as the Krebs cycle and the tricarboxylic acid (TCA) cycle.

clone: a population of cells descended by mitotic division from a single ancestral cell, or a population of genetically identical organisms asexually propagated from a single individual.

club mosses: a phylum of seedless vascular plants with a life cycle similar to ferns.

cnidocytes: stinging cells characteristic of cnidarians.

codon (koh'don): a triplet of mRNA bases that specifies an amino acid, a start signal, or a signal to terminate the polypeptide.

coelom (see'lum): the main body cavity of most animals; a true coeloms is lined with mesoderm.

coenocyte (see'no-site): an orgainsim consisting of a multinucleated cell; an organism in which the nuclei are not separated form one another by septa.

coenzyme A (CoA): organic cofactor responsible for transferring groups derived form organic acids.

cofactor: a non-protein substance needed by an enzyme for normal activity; some cofactors are inorganic (usually metal ions;) others are organic cofactors, known as coenzymes.

conenzyme (koh-en'zime): an organic cofactor for an enzyme; generally participates in the reaction by transferring some component.

conidiophore (kah-nid'e-o-for"): a specialized hypha that bears conidia.

conjugation: (kon"jew-gay'shun) (1) a sexual phenomenon in certain protists that involves exchange or fusion of a cell with another cell; (2) a mechanism for DNA exchange in bacteria that involves cell to cell contact.

coupled reactions: a pair of reactions, one exergonic and one endergonic, that are linked together so that the energy produced by the exergonic reaction provides the energy needed to derive the endergonic reaction.

cristae (kris'tee) (sin. crista): shelf-like or finger-like inward projections of the inner membrane of a mitochondrion.

cycad (sih'kad): a phylum of gymnosperms that live mainly in tropical and semitropical regions and have stout stems and fern-like leaves.

cycloid scale: Thin overlapping dermal scales of fish posterior margins are smooth.

cytokinin (sy"toh-kih'nin): a plant hormone involved in various aspects of plant growth and development, such as cell division and delay of senescence.

cytosine: a nitrogenous pyrimidine base that is a component of nucleic acids.

cytoskeleton: internal network of protein fibres; includes microfilaments, intermediate filaments, and microtubules.

cytosol fluid: *component of the cytoplasm in which the organelles are suspended.*

cytotoxic T cells: a type of T cells that directly destroy foreign cells upon contacting them.

D

deamination (dee-am-ih-nay'shun): removal of an amino group ($-NH_2$) from an amino acid or other organic compound.

decomposers: microbial heterotrophs that breakdown dead organic material and use the decomposition products as a source of energy. Also called saprotrophs or saprobes.

deoxyribonucleic acid (**DNA**): double stranded nucleic acid; contains genetic information coded in specific sequences of its constituent nucleotides.

deoxyribose pentose: sugar lacking a hydroxyl (--OH) group on carbon-2'; a constituent of DNA.

diastole (di-as'toh-lee): phase of the cardiac cycle in which the heart is relaxed.

diatom (die'eh-tom"): a usually unicellular alga that is covered by an ornate, siliceous shell consisting of two overlapping halves; an important component of plankton in both marine and fresh waters.

dikaryotic (dy-kare-ee-ot'ik): condition of having two nuclei per cell (i.e, n + n), characteristic of certain fungal hyphae.

dioecious (dy-ee'shus): having male and female reproductive structures on separate plants.

dipeptide: a compound consisting of two amino acids linked by a peptide bond.

disaccharide (dy-sak'ah-ride): a sugar produced by covalently linking two monosaccharides.

dorsal (dor'sl): toward the uppermost surface or back of an animal.

double fertilization: a process in the flowering plant life cycle in which there are two fertilizations; one fertilization results in the formation of a zygote that develops into a young plant, while the second results in the formation of endosperm (nutritive tissue).

E

electron microscope: microscope capable of producing high resolution, highly magnified images through the use of an electron beam (rather than light).Transmission electron microscopes (TEM) produce images of thin sections; scanning electron microscopes (SEM) produce images of surfaces.

electron transport system: a series of chemical reactions during which hydrogens or their electrons are passed along from one acceptor molecule to another (the electron transport chain), with the release of energy.

electrophoresis: a biochemical technique that separates molecules according to their electrical charge and molecular weight.

encephalitis: it is characterized by necrotic lesion in one temporal lobe, fever, vomiting, seizures and altered mental status.

endoderm (en'doh-derm): the inner germ layer of the early embryo; becomes the lining of the digestive tract and the structures that develop from the digestive tract liver, lungs, and pancreas.

endoplasmic reticulum (ER) (en'doh-plaz"mik reh-tik'yoo-lum): interconnected network of internal membranes in eukaryotic cells enclosing a compartment, the ER lumen. Rough ER has ribosomes attached to the cytosolic surface; somooth ER, a site of lipid biosynthesis, lacks ribosomes.

epiglottis: a thin, flexible structure that guards the entrance to the larynx, preventing food from entering the airway during swallowing.

epinephrine: a hormone secreted by adrenal medulla.

ester linkage: covalent linkage formed by the reaction of a carboxyl group and a hydroxyl group, with the removal of the equivalent of a water molecule; the linkage includes an oxygen atom bonded to a carbonyl group.

ethene: a plant hormone that promotes the ripening of fruits and dropping of leaves and fruits .

exocytosis (ex"oh-sy-toh'sis): the active transport of materials out of the cell by fusion of cytoplasmic vesicles with the plasma membrane.

euchromatin: chromosome material which does not stain strongly except during cell division. It represents the major genes and is involved in transcription.

F

facilitated diffusion: the passive transport of ions or molecules by a specific carrier .protein in a membrane. As in simple diffusion, net transport is down a concentration gradient, and no additional energy has to be supplied.

facultative anaerobe: organism capable of carrying out aerobic respiration, but able to switch to fermentation when oxygen is not available; e.g., yeast.

feedback inhibition: in enzyme mediated chemical reactions the condition in which the product of a reaction inhibits one or more of the enzymes involved in synthesizing the product.

fermentation: anaerobic process by which ATP is produced by a series of redox reactions in which organic compounds serve as electron donors and as electron acceptors.

fibre: (1) in plants a type of sclerenchyma. Fibres are long, tapered cells with thick walls. (2) in animals, an elongated cell such as a muscle or nerve cell.

florigen (flor'uh-jen): a hypothetical plant hormone that promotes flowering.

fluid-mosaic model: the modern picture of the plasma membrane and other cellular membranes in which protein molecules float in phospholipids bilayer.

G

gametophyte generation (gam-ee;'toh-fite): the *n*. gamete producing stage in the life cycle of a plant.

ganoid scale: thick, bony rhombic scales of bony fish, not overlapping.

gastrin (gas'trin): a hormone released by the stomach mucosa; stimulates the gastric glands to secrete pepsinogen.

gastrovascular cavity: a central digestive cavity with a single opening that functions as both mouth and anus; characteristic of cnidarians and flatworms.

gene therapy: any one of a variety of methods designed to correct a disease or alleviate its symptoms through the introduction of genes into the affected person's cells.

genetic engineering: manipulation of genes, often through recombinant DNA technology.

genital herpes: it is characterized by painful vesicular lesions of the male and female genitals and anal areas.

genome (jee'nome): all the genetic material in a cell or organism.

genomic DNA library: a collection of recombinant plasmids in which all the DNA in the genome is represented.

geotropism: growth with respect to the direction of gravity.

germ layers: primitive embryonic tissue layers; endoderm, mesoderm, or ectoderm.

germ line: in animals, the line of cells that will ultimately undergo meiosis to form gametes.

gibberellin (jib"ur-el'lin): a plant hormone involved in many aspects of plant growth and development, such as stem elongation, flowering, and seed germination.

gingivostomatitis: occurs primarily in children and is characterized by fever, irritability and vesicular lesions in mouth.

globulin (glob'yoo-lin): one of a class of proteins in blood plasma, some of which (gamma globulins) function as anti-bodies.

glycerol: a three-carbon alcohol, with a hydroxyl group on each carbon; a component of neutral fats and phospholipids.

glycolysis (gly-kol'ih-sis): the first stage of cellular respiration, literally the "splitting of sugar." The metabolic conversion of glucose into pyruvate, accompanied by the production of ATP.

glycosidic linkage: covalent linkage joining two sugars; includes an oxygen atom bonded to a carbon of each sugar,

goblet cells: unicellular glands that secrete mucus.

granum (pl. grana): a stacks of thylakoids within a chloroplast.

guanine (gwan'een): a nitrogenous purine base that is component of nucleic acids.

guard cell: one of a pair of epidermal cells that adjust their shape to form a stomatal pore for gas exchange.

H

haemocoel: blood cavity characteristic of animals with an open circulatory system.

haemoglobin (hee'moh-gloh"bin): the red, iron-containing protein pigment of erythrocytes that transports oxygen and carbon dioxide and aids in regulation of pH.

haploid (hap'loyd): the condition of having one set of chromosomes per nucleus.

haustorium (hah-stor'e-um) (pl. haustoria): a specialized hypha of a parasitic fungus that penetrates a host cells to absorb food and other materials.

hemicelluloses: (also known as polyose) is any of several heteropolymers (matrix polysaccharides), such as arabinoxylans, present along with cellulose in almost all plant cell walls.[1] While cellulose is crystalline, strong, and resistant to hydrolysis, hemicellulose has a random, amorphous structure with little strength. It is easily hydrolyzed by dilute acid or base as well as myriad hemicellulase enzymes.

helper T cell: T lymphocyte that facilitates the ability of B lymphocytes to form an antibody-producing clone in response to an antigen.

hepatic (heh-pak'ik): pertaining to the liver.

herpes labialis: fever, blister and cold sore and crops of vesicles usually at the junction of lips of nose.

heterocercal: in some fishes, a tail with the upper lobe larger than the lower, and end of the vertebral column somewhat upturned in the upper lobe, as in sharks.

hetrochromatin: chromosome material of different density from normal (usually greater), in which the activity of the genes is modified or suppressed

heterospory (het" ur-os'pur-ee): production of two types of n spores, microspores (male) and megaspores (female).

histones (his"tones): small, positively charged (basic) proteins in the cell nucleus that bind to the negatively charged DNA.

homocercal: a tail with the upper and lower lobes symmetrical and the vertebral column ending near the middle of the base, as in most teleost fishes.

homospory (hoh" mos'pure-ee): production of one type of n spore that gives rise to a bisexual gametophyte.

hormone: an organic chemical messenger in multicellular organisms produced in one part of the body and transported to another part where it affects some aspect of metabolism.

hydrolysis: reaction in which a covalent bond between two subunits is broken through the addition of equivalent of a water molecule; a hydrogen atom is added to one subunit and a hydroxyl group to the other.

hydrophilic: attracted to water.

hydrophobic: repelled by water.

hydroponics (hy"dra-paun'iks): growing plants in an aerated solution of dissolved inorganic minerals (that is, without soil).

hypertonic: term referring to a solution having an osmotic pressure (or solute concentration) greater than that of the solution with which it is compared, also called hyperosmotic.

hypha (hu'fah) (pl. hyphae): one of the thread-like filaments composing the mycelium of a water mold or fungus.

hypokalemia: abnormally small concentration of potassium ions in the blood

hypothalamus (hy-poh-thal'uh-mus): part of the mammalian brain that regulate the pituitary gland, the autonomic system, emotional responses, body temperature, water balance, and appetite, located below the thalamus.

hypotonic: term referring to a solution having an osmotic pressure (or solute concentration) less than that of the solution with which it is compared.

I

immune response: a specific response by the immune system to invasion of the body by particular foreign substance or microorganism, characterized by recognition of the foreign material by immune cells and its subsequent destruction by antibodies or cellular attack.

in *vitro*: occurring outside a living organism (literally "in glass").

in *vivo*: occurring in a living organism.

inflammatory response: a non-specific, local response to injury to the body, characterized by phagocytosis of foreign substances and tissue debris by white blood cells and "walling off" of injury site by clotting of fluids escaping from near by blood vessels.

interferon (in"tur-feer'on): a protein (cytokine) produced by animal cells when challenged by a virus. Important in immune responses, it prevents viral reproduction and enables cells to resist a variety of viruses.

intrinsic factor (IF): also known as gastric intrinsic factor (GIF), is a glycoprotein produced by the parietal cells of the stomach. It is necessary for the absorption of vitamin B_{12} (cobalamin) later on in the small intestine.

intron: In eukaryotes, a non expressed (noncoding) portion of a gene, that is excised from the RNA transcript. The coding portion of a gene is called exon.

isoprene units: five-carbon hydrocarbon monomers that make up certain lipids such as carotenoids and steroids.

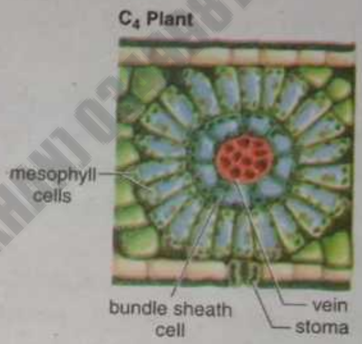
isotonic (eye'soh-ton'ik): term applied to solutions that have identical concentrations of solute molecules and hence the same osmotic pressure also called isosmotic.

K

karatconjunctivities: corneal ulcer and lesion at the conjunctival epithelium. Recurrent can lead to blindness.

kinetochore (kin-eh'toh-kore): portion of the chromosomes centromere to which the mitotic spindle fibres attach.

Kranz anatomy: the special structure of leaves in C_4plants (e.g. maize) where the tissue equivalent to the spongy mesophyll cells is clustered in a ring



around the leaf veins, outside the bundle-sheath cells. (The term **'Kranz' means** wreath or ring in German).

Kuru (koo roo) a progressive and fatal brain disease, found only in certain parts of Papua New Guinea and thought to be transmissible by a slow virus.

L

lacteal (lak'tee-al): one of the many lymphatic vessels in the intestinal villi that absorb fat.

lactic acid: a 3-carbon organic acid; also known also lactate.

large intestine: the portion of the digestive tract of humans (and other vertebrates) consisting of the cecum, colon, rectum, and anus.

larva (pl. larvae): an immature form in the life history of some animals; may be unlike the parent.

lateral meristems: areas of localized cell division on the side of a plant that give rise to secondary tissues. Lateral meristems, including the vascular cambium and the cork cambium; cause an increase in the girth of the plant body.

leeukopenia: It is a disease in number of white blood cells (leukocyte) found in blood, which places individuals at risk of infection.

lignin (lig'nin): the substance found in many plant cell walls that confers rigidity and strength, particularly in woody tissues.

lipase (lip'ase): fat-digesting: enzyme.

lithotrophs are a diverse group of organisms using inorganic substrate (usually of mineral origin) to obtain reducing equivalents for use in biosynthesis (e.g., carbon dioxide fixation) or energy conservation (i.e., ATP production) via aerobic or anaerobic respiration.

lumen (loo'men): (1) the space enclosed by a membrane, such as the lumen of the endoplasmic reticulum;

lymph (limf): the colourless fluid within the lymphatic vessels that is derived from blood plasma and resembles it closely in composition; contains white cells; ultimately, returns to the blood.

lymph nodes: a mass of lymph tissue surrounded by a connective tissue capsule; manufactures lymphocytes and filters lymph.

lymphatic system: a subsystem of the cardiovascular system; returns excess interstitial fluid to the circulation; defends the body against disease organisms.

lymphocyte (limf'oh-site): white blood cell with nongranular cytoplasm that is responsible for immune responses.

lymphoma: It is a cancer that begins in the lymphocytes of immune system and presents as a solid of tumor of lymphoid cells. They often originate like balls in lymph node.

lysosomes (ly'soh-somes): interacellular organelles present in many animal cells; contain a variety of hydrolytic enzymes.

M

macrophage: a type of white blood cell that engulfs microbes. Macrophages destroy microbes by phagocytosis and also present microbial antigens to T cells, helping to stimulate the immune response

major histocomatibility complex (MHC): proteins usually located on the surface of body cell that identify the cell as "self". MHC proteins are also important in stimulating and regulating the immune response.

malignant: term used to describe cancer cells (tumor cells that are able to invade tissue and metastasize).

medusa: a jellyfish-like animal; a free-swimming, umbrella shaped stage in the life cycle of certain cnidarians.

megaspore (meg'uh-spor): the n spore in heterosporous plants that gives rise to a female gametophyte.

memory cell: B or T lymphocyte that permits rapid mobilization of immune response on second or subsequent exposure to a particular antigen.

mesonephrons: the middle of the three pairs of embryonic renal organs in vertebrates. The functional kidney of fish and amphibians.

messenger RNA (mRNA): RNA that specifies the amino acid sequence of a protein; transcribed from DNA.

metastasis (met-tas'tuh-ssis): the spreading of cancer cells from one organ or part of the body to another.

microbodies: membrane-bounded structures in eukaryotic cells that contain enzymes; include peroxisomes and glyoxisomes.

microfilaments: thin fibres composed of actin protein subunits; form part of the cytoskeleton.

micronutrient: an essential element that is required in traceamounts for normal plant growth.

microphyll (mi'kro-fil): type of leaf found in club mosses; contains one vascular strand (i.e., simple venation).

molting: the shedding and replacement of an outer covering such as an exoskeleton.

monoacylglycerol (mono"o-as"-il-glis'er-ol): a neutral fat consisting of glycerol combined chemically with a single fatty acid, also called monoglyceride.

monocyte (mon'oh-site): a type of white blood cell, a large phagocytic, nongranular leukocyte that enters the tissues and differentiates into a macrophage.

monoecious (mon-ee'shus): having male and female reproductive parts in separate flowers on the same plant;

monomer (mon'oh-mer): A molecule of a compound that can be linked with other similar molecules to form a polymer.

monophyletic group (mon"oh-fye-let'ik): a group made up of organisms that evolve from a common ancestor.

mucosa (mew-koh'suh): a mucous membrane, especially in the lining of the digestive and respiratory tracts.

mucus (mew'cus): a sticky secretion composed of covalently linked protein and carbohydrate; serves to lubricate body parts and trap particles of dirt and other contaminants. (the adjectival form is spelled mucous.)

mycelium (my-seel'ee-um) (pl. mycelia): the vegetative body of fungi and certain protists (water molds); consists of a branched network of hyphae.

mycorrhizea (my"kor-rye'zee): mutualistic associations of fungi and plant roots that aid in the plant's absorption of essential minerals from the soil.

myoglobin (my'oh-gloh"bin): a haemoglobin-like oxygen transferring protein found in muscle.

myxoviruses: these are enveloped, have single stranded negative polarity RNA, e.g., influenza virus. The term myxo refers to the affinity of the viruses for mucin and "ortho" (orthomyxoviruses) is added to distinguish them from paramyxo viruses.

N

NAD+/NADH: oxidized and reduced forms, respectively, of nicotinamide adenine dinucleotide; coenzyme that transfers electrons (as hydrogen), particularly in catabolic pathways, including cellular respiration.

NADP+/NADPH: oxidized and reduced forms, respectively, of nicotinamide adenine dinucleotide phosphate; coenzyme that acts as an electron (hydrogen) transfer agent, particularly in anabolic pathways, including photosynthesis.

nematocyst (nem-at'oh-sist): a stinging structure found within cnidocytes (stinging cells) in cnidarians; used for anchorage, defence, and capturing prey.

neonatal herpes: originates chiefly from contact with vesicular lesions within the birth canal.

nuclear mitosis: In it the nuclear envelope remains intact from prophase to anaphase. Spindle fibres form in the nucleus rather than within the cytoplasm. When completed the nuclear envelope pinches in two.

neutral fat: a lipid used for energy storage, consisting of a glycerol covalently bonded to one, two or three fatty acids.

nucleoside (new'klee-oh-side): molecule consisting of a nitrogenous base (purine or pyrimidine) and a pentose sugar.

nucleosomes (new'k-lee-oh-somz): repeating units of chromatin structure, each consisting of a length of DNA wound around a complex of eight histone molecules (two of four different types) plus a DNA linker region associated with a fifth histone protein.

nucleotide (noo'klee-oh-tide): a molecule composed of one or more phosphate groups, a 5-carbon sugar (ribose or deoxyribose) and nitrogenous base (purine or pyrimidine).

O

oogamous: (adj) related to reproduction by the union of mobile male gamete and immobile female gamate.

organotroph is an organism that obtains hydrogen or electrons from organic substrates. This term is used in microbiology to classify and describe organisms based on how they obtain electrons for their respiration processes. Some**organotrophs** such as animals and many bacteria, are also heterotrophs.

osmoregulation (oz"moh-reg-yoo-lay'shun): the active regulation of the osmotic pressure of body fluids so that they do not become excessively dilute or excessively concentrated.

osmosis (oz-moh'sis): net movement of water (the principal solvent in biological systems) by diffusion through a selectively permeable membrane from a region of higher concentration of water (a hypotonic solution) to a region of lower concentration of water (a hypertonic solution).

osmotic pressure: the pressure that must be exerted on the hypertonic side of a selectively permeable membrane to prevent diffusion of water (by osmosis) from the side containing pure water.

ovoviviparous (oh'voh-vih-vip"ur-us): a type of development in which the young hatch from eggs incubated inside the mother's body.

oxidative phosphorylation (fos"for-ih-lay'shun): the production of ATP using energy derived from the transfer of electrons in the electron transport system of mitochondria; occurs by chemiosmosis.

oxyhaemoglobin: haemoglobin that has combined with oxygen.

P

P680: chlorophyll a molecules that serve as the reaction centre of Photosystem II, transferring photoexcited electrons to a primary acceptor; named by their absorption peak at 680 nm.

P700: chlorophyll a molecules that serve as the reaction centre of Photosystem I, transferring photoexcited electrons to a primary acceptor; named by their absorption peak at 700 nm.

pacemaker (of the heart): the sinoatrial (SA) node of the heart; specialized cardiac muscle where each heartbeat begins.

passive immunity: temporary immunity that depends on the presence of immunoglobulins produce by another organism.

pathogen (path'oh-gen): an organism, usually a microorganism, capable of producing disease.

pentose: a sugar molecule containing five carbons.

pepsin (pep'sin): an enzyme produced in the stomach that initiates digestion of proteion.

peptide (pep'tide): a compound consisting of a chain of amino acid groups. A dipeptide consists of two amino acids, a polypeptide of many amino acids.

peptide bond: a distinctive covalent carbon-to-nitrogen bond that links amino acids in peptides and proteins.

peptidoglycan (pep"tid-oh-gly'kan): a modified protein or peptide possessing an attached carbohydrate; component of the bacterial cell wall.

period: an interval of geological time that is a subdivision of an era. Each period is divided into epochs.

peristalsis (pehr"ih-stal'sis): rhythmic waves of muscular contraction and relaxation in the walls of hollow tubular organs, such as the ureter or parts of the digestive tract, that serve to move the contents through the tube.

peroxisomes (pehr-ox'ih-somz): membrane-bounded organelles in eukaryotic cells containing enzymes that produce or degrade hydrogen peroxide.

phagocytosis (fag"oh-sy-toh'sis): literally," cell eating"; a type of endocytosis by which certain cells engulf food particles, microorganisms, foreign matter, or other cells.

phosphodiester linkage: covalent linkage between two nucleotides in a strand of DNA or RNA; includes a phosphate group bonded to the sugars of two adjacent nucleotides.

phosphoenolpyruvate (**PEP**): 3-carbon phosphorylated compound that is an important intermediate in glycolysis and is a reactant in the initial carbon fixation step in the C4 and CAM pathways of carbon fixation in photosynthesis.

phosphoglycerate (PGA): phosphorylated 3-carbon compound that is an important metabolic intermediate.

phospholipids (fos"foh-lip"idz): fatlike substances in which there are two fatty acids and a phosphorus-containing group attached to glycerol; major components of cellular membranes.

phosphorylatiohn (fos"for-ih-lay'shun): the introduction of a phosphate group into an organic molecule. Kinases are enzymes that catalyze certain phosphorylation reactions.

photolysis (foh-tol'uh-sis): the photochemical splitting of water in the light-dependent reactions of photosynthesis, catalyzed by a specific enzyme.

photon (foh'ton): a particle of electromagnetic radiation; one quantum of radiant energy.

photoperiodism (foh"toh-peer'ee-od-izm): the physiological response (such as flowering) of plants to variations in the length of daylight and darkness.

photophosphorylation (foh"toh-fos-for-ih-lay'shun): the production of ATP in photosynthesis.

photosystem: a group of chlorophyll molecules, accesory pigments, and associated electron acceptors that emits electrons in response to light; located in the thylakoid membrane (in photoautorophic eukaryotes).

phototrophs : are the organisms that carry out photon capture to acquire energy. They use the energy from light to carry out various cellular metabolic processes. It is a common misconception that phototrophs are obligatorily photosynthetic.

phototropism (foh"toh-troh'pizm): the growth of a plant in response to the direction of light.

phytochrome (fy'toh-krome): a blue-green, proteinaceous pigment involved in a wide variety of physiological responses to light; occurs in two interchangeable forms depending on the ratio of red to far-red light.

pinocytosis (pin"oh-sy-toh'sis): cell drinking a type of endocytosis by which cells engulf and absorb droplets of liquids.

plankton: the small and microscopic organisms drifting or floating in the sea or fresh water, consisting chiefly of diatoms, protozoan, small crustaceans, and the eggs and larval stages of larger animals. Many animals are adapted to feed on plankton, especially by filtering the water.

plasma cell: cell that secretes antibodies; differentiated B lymphocyte.

plasmids (plaz'midz): small circular DNA molecules that carry genes separate from the main bacterial and yeast DNA.

plasmodesmata (sing. plasmodesma): cytoplasmic channels connecting adjacent plant cells.

plasmodial slime mold (plaz-moh'dee-uhl): a fungus-like protist whose feeding stage consists of a plasmodium.

plasmolysis (plaz-mol"ih-sis): the shrinkage of cytoplasm and the pulling away of the plasma membrane from the cell wall when a plant cell (or other walled cell) loses water, usually in a hypertonic environment.

platelets (play'lets): cell fragments in the blood that function in clotting; also called thrombocytes.

polymer (pol'ih-mer): a molecule built up from repeating monomers, such as a protein, nucleic acid, or polysaccharide.

polyp (pol'ip): Hydra-like animal; the sessile stage of the life cycle of certain cnidarians e.g., *Obelia*.

polypeptide: a compound consisting of many amino acids linked by peptide bonds.

polysaccharide (pol-ee-sak'ah-ride): a carbohydrate consisting of many monosaccharide subunits; examples are starch, glycogen, and cellulose.

porins: these are beta barrel proteins that cross a cellular membrane and act as a pore, through which molecules can diffuse.[1] Unlike other membrane transport proteins, porins are large enough to allow passive diffusion, i.e., they act as channels that are specific to different types of molecules. They are present in the outer membrane of gram-negative bacteria and some gram-positive bacteria of the group Mycolata (mycolic acid-containing actinomycetes), the mitochondria, and the chloroplast.

positive polarity: it is defined as an RNA with the same base sequence as the mRNA with negative polarity has a base sequence that is complementary to the mRNA. For example, if the mRNA sequence is an A-C-U-G, and RNA with negative polarity would be U-G.A-C and an RNA with positive polarity would be A-C-U-G.

potassium (k^+) ion mechanism: mechanism by which plants open and close their stomata. The influx of potassium ions into guard cells causes water to move in by osmosis, changing the shape of the guard cells and opening the pore.

poxviruses: these are largest DNA viruses, with bricklike shape, an envelope with an unusual appearance and a complex capsid symmetry. They are named for the skin lesions or 'pocks' they cause. Small pox virus and vaccinia virus are the two important member. The later virus is used in the small pox vaccine.

precambrian time: all of geological time before the Paleozoic era, encompassing approximately the first 4 billion years of Earth's history.

pressure-flow: hypothesis the mechanism by which dissolved sugar is thought to be transported in phloem.

prokaryote (pro-kar'ee-ote): cell that lacks a nucleus and other membrae-bounded organelles; include the bacteria, members of Kingdom Prokaryotae.

prophage (pro'faj): a latent state of a bacteriophage in which the viral genome is inserted into the bacterial host chromosome.

protist (proh'tist): one of a vast kingdom of eukaryotic organisms, primarily single-celled or simple multicellular; mostly aquatic.

pseudocoelom (soo"doh-see'lom): a body cavity between the mesoderm and endoderm; derived form the blastocoel.

pseudocoelomate (soo"doh-seel'oh-mate): animal possessing a pseudocoelom.

pulse: alternate expansion and recoil of an artery.

purines (pure'eenz): nitrogenous bases with carbon and nitrogen atoms in two attached rings; components of nucleic acids, ATP, NAD^+, and certain other biologically active substances. Examples are adenine and guanine.

R

radial cleavage: pattern of blastomere production in which the cells are located directly above or below one another; characteristic of early deuterostome embryos.

radial symmetry: a body plan in which any section through the mouth and down the length of the body divides the body into similar halves. Jellyfish and other cnidarians have radial symmetry.

radula (rad'yoo-lah): a rasplike structure in the digestive tract of chitons, snails, squids, and certain other mollusks.

recombinant DNA: any DNA molecule made by combining genes from different organisms.

redox reaction (ree'dox): chemical reaction in which one or more electrons are transferred from one substance (the substance that becomes oxidized) to another (the substance that becomes reduced).

rennin: an enzyme found in gastric juice which cause coagulation.

renin: a protein enzyme secreted by the kidneys into the blood stream, where it helps to maintain blood pressure.

reoviruses: these are naked, i.e., nonenveloped viruses with two icosahedral capsid coats. Have double-stranded linear RNA. The main pathogen is rotavirus which causes diarrhoea mainly in infants.

retrovirus (ret'roh-vy"rus): an RNA virus that uses reverse transcriptase to produce a DNA intermediate in the host cell. These are enveloped viruses with icosadehedral and identical strands of single stranded, linear, plus RNA. The term "retro" pertains to the reverse transcription of RNA genome into two DNA. There are two medically important groups. (1) The oncovirus group, which contains the sarcoma and leukemia virus.(2) The lentivirus ("slow virus") group , which includes HIV and certain animal pathogen.

rhabdoviruses: these are bullet shaped enveloped viruses, single stranded linear, negative polarity RNA. The term "rabdo" refers to the bullet shape e.g., rabies virus.

ribonucleic acid (RNA): a family of single-stranded nucleic acids that function mainly in protein synthesis.

ribulose bisphosphate (**RuBP**): a 5-carbon phosphorylated compund with a high energy potential reacts with carbon dioxide in the initial step of the Calvin cycle.

rubisco: common name of ribulose bisphosphate carboxylase, the enzymes the reaction of carbon dioxide with ribulose bisphosphate in the Calvin cycle.

rugae (roo'jee): folds, such as those in the lining of the stomach.

S

sclereid (skler'id): in plants, a sclerenchyma cell that is variable in shape but typically not long and tapered.

sclerenchyma (skler-en'kim-uh): cells that provide strength and support in the plant body, are often dead at maturity, and have extremely thick walls; include fibres and sclereids.

scrapie: it is a disease of sheep, characterized by tremors, ataxia and itching, in which sheep scrap off their wool against fence post.

secondary growth: an increase in the girth of a plant due to the activity of the vascular cambium and cork cambium, secondary growth results in the production of secondary tissues, i.e., wood and bark.

second messenger: molecule inside cells that acts to transmit signals from a receptor to a target. The term second messenger was coined upon the discovery of these substances in order to distinguish them from hormones and other molecules that function outside the cell as "first messengers" in the transmission of biological information. Many second messenger molecules are small and therefore diffuse rapidly through the cytoplasm, enabling information to move quickly throughout the cell. Examples of second messenger molecules include cyclic AMP, cyclic GMP, inositol trisphosphate, diacylglycerol, and calcium.

semilunar valves: valves between the ventricles of the heart and the arteries that carry blood away from the heart.

sepsis: It is characterized by a whole-body inflammatory state and the presence of a known or suspected infection. The body may develop this inflammatory response to microbes in the blood, urine, lungs, skin or other tissue.

septum (pl. septa): a cross-wall or partition; for example, the walls that divide a hypha into cells. Permanently attached to sessile (ses'sile) one location. Coral animals, for example, are sessile.

small intestine: portion of the vertebrate digestive tract that extends from the stomach to the large intestine.

sodium potassium pump: a set of active transport molecules in nerve cell membranes that use the energy of ATP to pump sodium ions out of the cell and potassium ions in maintaining the concentration gradients of these ions across the membrane.

spongy mesophyll (mez'oh-fil): the loosely arranged mesophyll cells near the lower epidermis in certain leaves.

sporophyte generation (spor'oh-fite): the 2n spore-producing stage in the life cycle of a plant.

starch: a polysaccharide composed of alpha glucose subunits; made by plants for energy storage.

steroids (steer'oids): complex molecules containing carbon atoms arranged in four attached rings, three of which contain six carbon atoms each and the fourth of which contains five. Cholesterol and certain hormones, including the male and female sex hormones of vertebrates, are examples.

stomach: muscular region of the vertebrate digestive tract extending from the oesophagus to the small intestine.

stomata (sing. stoma): small pores located in the epidermis of plants that provide for gas exchange for photosynthesis, each stoma is flanked by two guard cells, which are responsible for its opening and closing.

storbilus (stroh'bil-us) (pl. strobili): in certain plants, a cone-like structure that bears spore-producing sporangia.

stroma: a fluid space of the chloroplast, enclosed by the chloroplast inner membrane and surrounding the thylakoids; site of the reactions of the Calvin cycle.

substrate: a substance on which an enzyme acts; a reactant in an enzymatically catalyzed reaction.

suppressor T cell: T lymphoctye that suppresses the immune respones.

systole: the part of the cardiac cycle when the heart is contracting.

T

T cell (**T lymphocyte**): lymphocyte that is processed in the thymus. T cells have a wide variety of immune function but are primarily responsible for cell-mediated immunity.

T-cell receptor: a protein receptor located on the surface of a T cell which binds a specific antigen and triggers the immune response of the cell.

thrombus (throm'bus): a blood clot formed within a blood vessel or within the heart.

thromcytopenia: When the number of blood platelets is lower than the normal i.e. 150,000 to 450,000.

thylakoids (thy'lah-koidz): interconnected system of flattened, sac-like membranous structures inside the chloroplast; the thylakoids membranes contain chlorophyll and the electron transport chain, and enclose a compartment, the thylakoids space.

thyroid gland: an endocrine gland that lies anterior to the trachea and releases hormones that regulate the rate of metabolism.

tonoplast: The cytoplasmic membrane surrounding the vacuole, separating the vacuolar contents from the cytoplasm in a cell. As a membrane, it is mainly involved in regulating the movements of ions around the cell, and isolating materials that might be harmful or a threat to the cell.

trace element: an element required by an organism, but in very small amounts.

tracheid (tray'kee-id): a type of water-conducting and supporting cell in the xylem of vascular plants.

transfer RNA (tRNA): RNA molecules that bind to specific amino acids and serve as adapter molecules in protein synthesis. The tRNA anticodons bind to complementary mRNA codons.

transposon: A transposable element is a DNA sequence that can change its position within a genome, sometimes creating or reversing mutations and altering the cell's genetic identity and genome size. These mobile segments of DNA are sometimes called "jumping genes"

trichome (try'kohm): a hair or other appendage growing out from the epidermis of a plant.

tricylglycerol (try-as"il-glis'er-oil): a neutral fat consisting of a glycerol combined chemically with three fatty acids; also called triglyceride.

triose: a sugar molecule containing three carbons.

tube feet: structures characteristic of echinoderms; function in locomotion.

V

vaccine (vak-seen'): a commercially produced weakened or killed antigen of a particular disease that stimulates the body to make antibodies

vertebral column: backbone of vertebrates through which the spinal cord passes.

vesicle (ves'ih-kl)" any small sac, especially a small spherical membrane-bounded compartment, within the cytoplasm.

viroid (vy'roid): tiny, naked virus consisting only of nucleic acid.

viscera (vis'ur-uh): the internal body organs, especially those located in the abdominal or thoracic cavities.

visna: it is a disease of sheep, characterized by pneumonia and lesions in brain.

W

water potential: free energy of water; the water potential of pure water is zero, and that of solutions is a negative value.

water vascular system: The starfish's water vascular system provides the water pressure that operates the animal's tube feet. From madreporite, water moves into the ring canal, then into the rays through radial canal and finally into the tube feet. The canals are like a network of water pipes attached to the tube feet.

wavelength: the distance from one wave peak to the next; the energy of electromagnetic radiation is inversely proportional to its wavelength.

X

xylem (zy'lem): the vascular tissue that conducts water and dissolved minerals in plants.

Xanthomonas oryzae: Causes blight disease in rice.

Y

yeast: a unicellular fungus (ascomycote) that reproduces asexually by budding or fission and sexually by ascospores.

Z

zoospore (zoh'oh-spore): a flagellated motile spore produced asexually by certain algae, water molds, and other protists.

zygomycotes: fungi characterized by the production of nonmotile asexual spores and sexual zygspores.

zygospore (zy'gah-spor): a thick-walled sexual spore produced by a zygomycote.

zygote: the *2n* cell that results from the union of n gametes in sexual reproduction. Species that are not polyploid have haploid gametes and diploid zygotes.

(1) What are the different model that explain the mode of action of enzymes?

Q4 a) Compare and contrast light and dark reaction with diagram?

b) Lymphatic system is different from circulatory system, justify the statement.

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