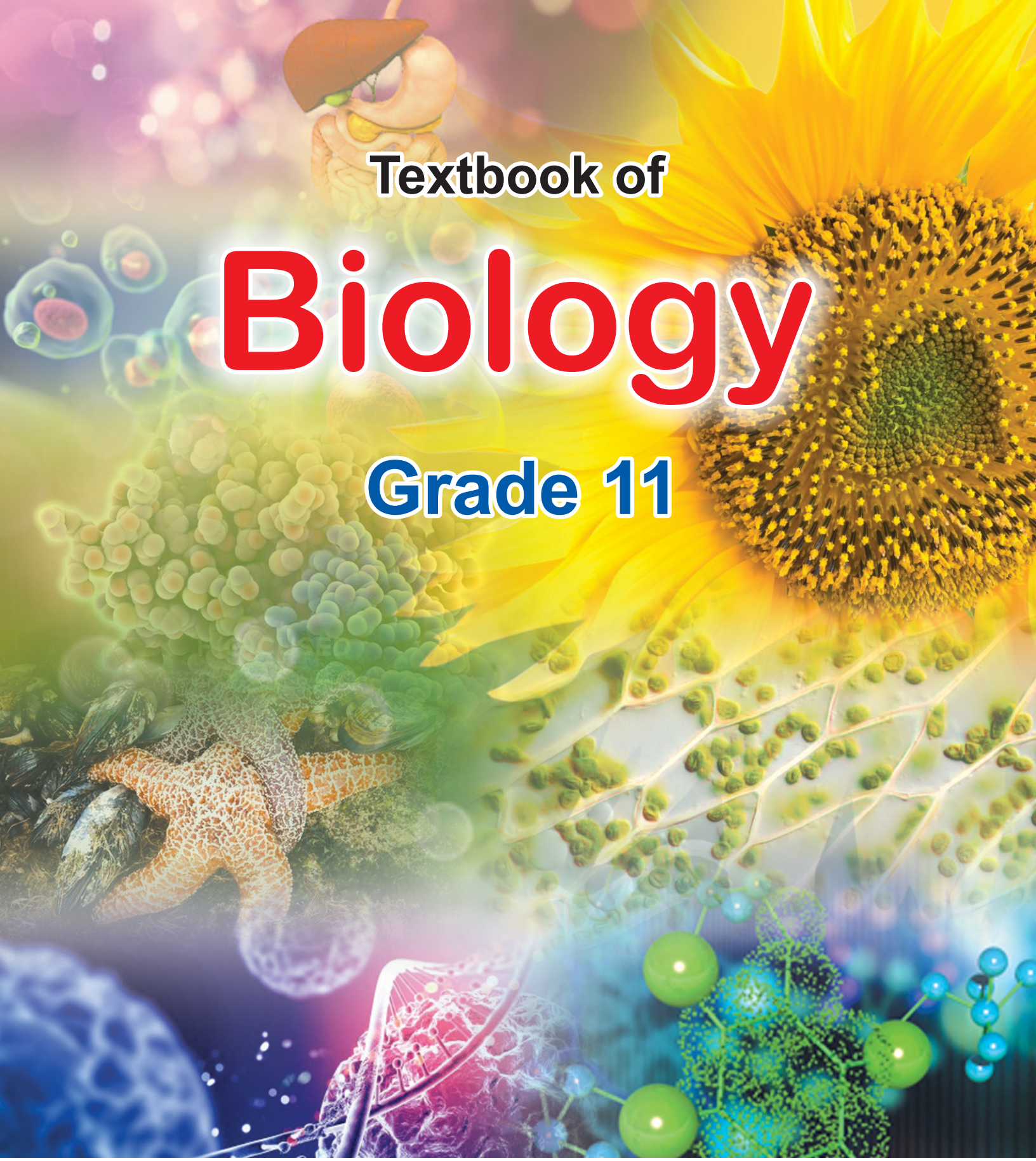

Textbook of

Biology

Grade 11

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OUR MOTTO

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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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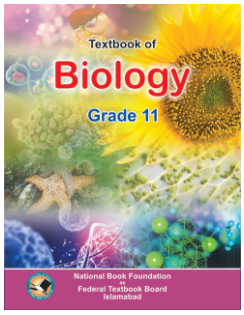

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Preface

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, Pedagogical Outcomes 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 and necessary changes, the book is being published again.

May Allah Guides and helps us. (Ameen).

National Book Foundation

Contents

بِسۡمِ اللّٰہِ الرَّحۡمٰنِ الرَّحِیۡمِ ○

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.

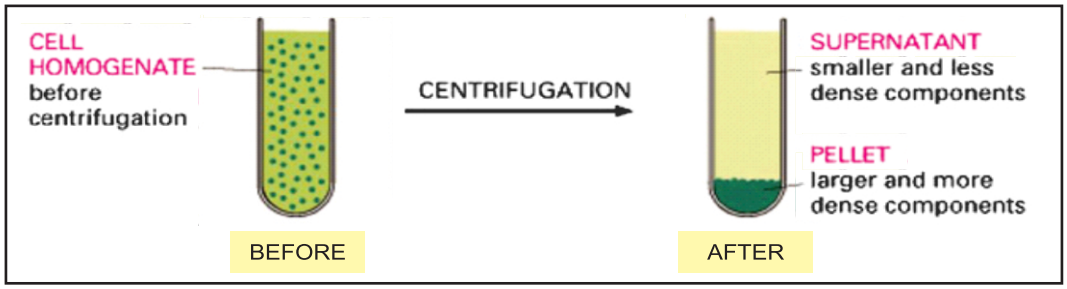


Fig 1.1: Centrifugation of cells

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.

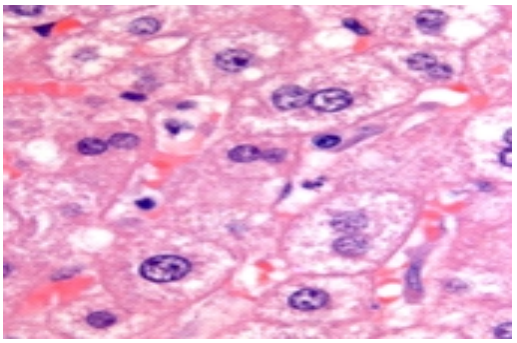


Fig. 1.2: Differential staining

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.

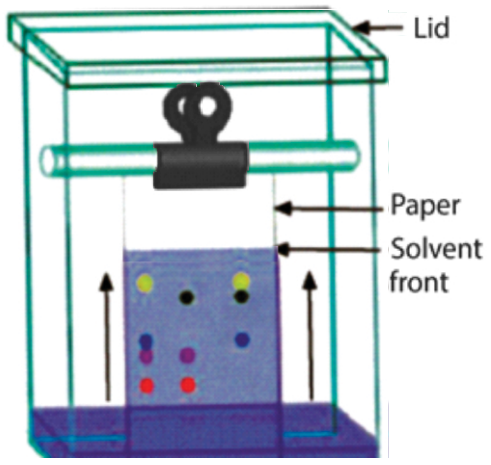


Fig. 1.3: Chromatography chamber

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.

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.

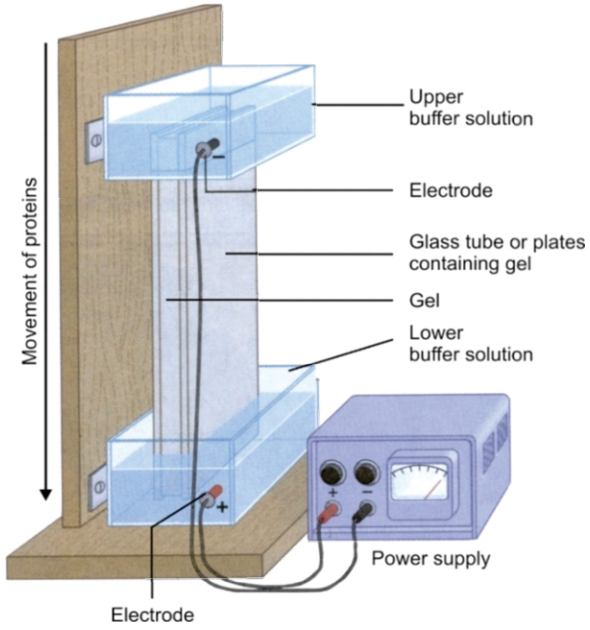


Fig. 1.4: Gel electrophoresis

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

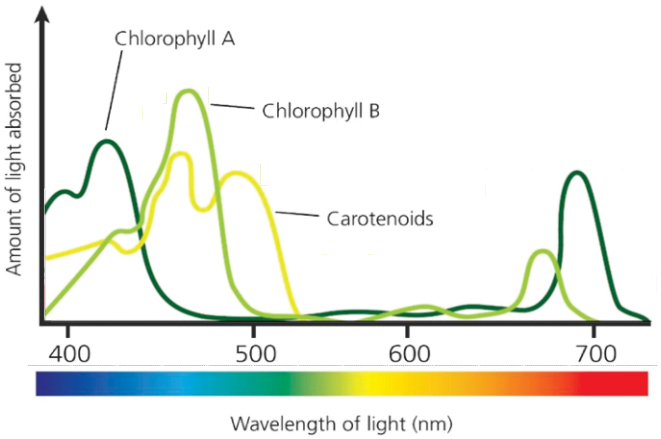


Fig. 1.6: Absorption spectrum

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.

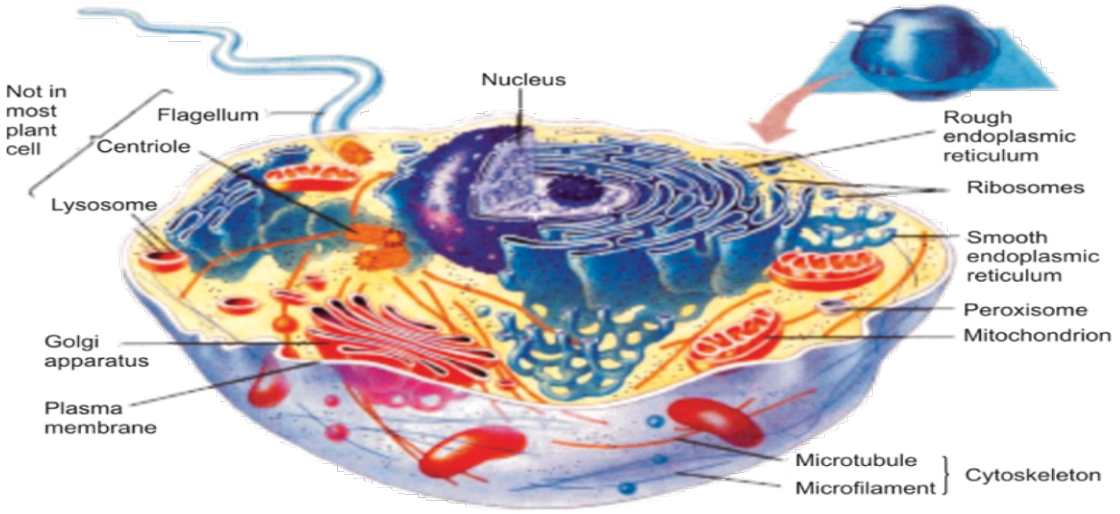


Fig. 1.7: Electron microscopic structure of an animal cell

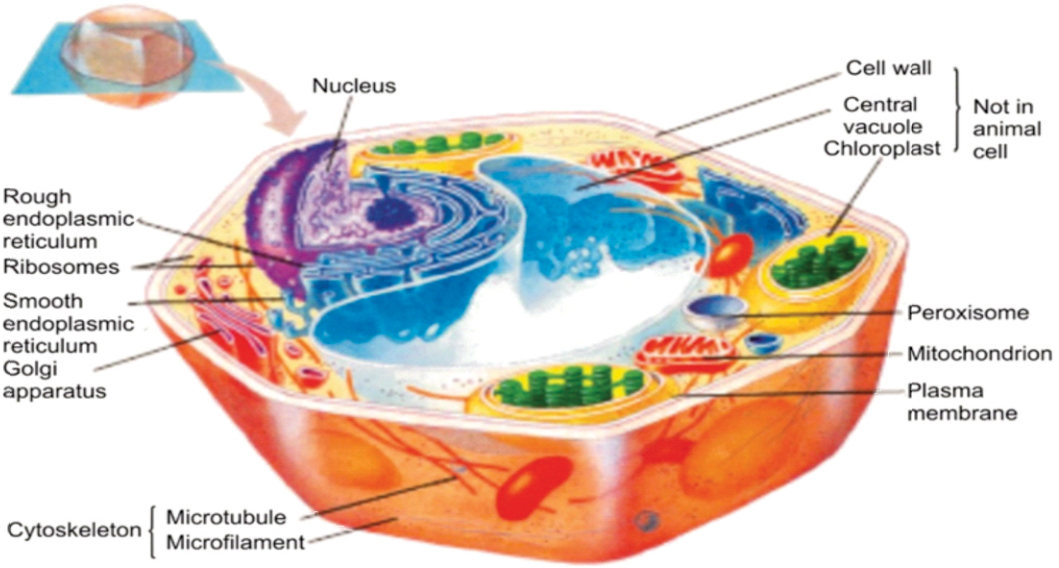


Fig. 1.8: Electron microscopic structure of a plant cell

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.

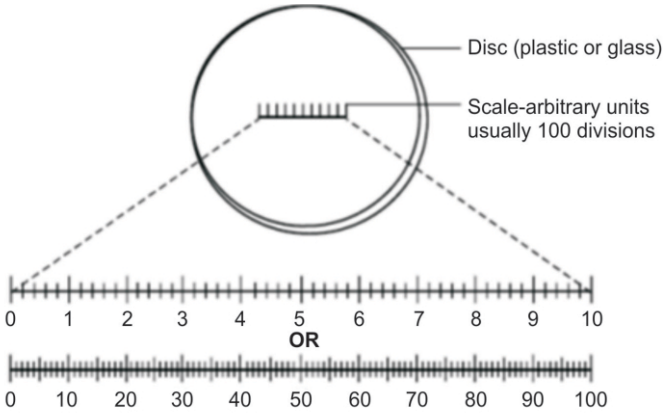


Fig. 1.9: Ocular micrometre

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.

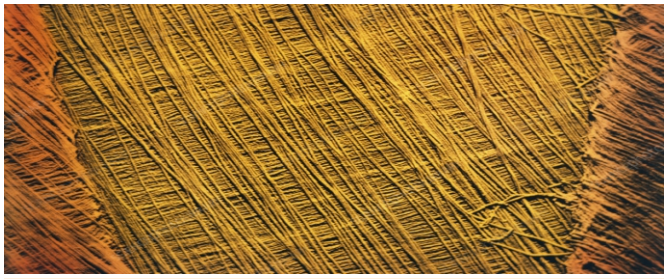


Fig. 1.10 : Crisscross arrangement of cellulose

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.

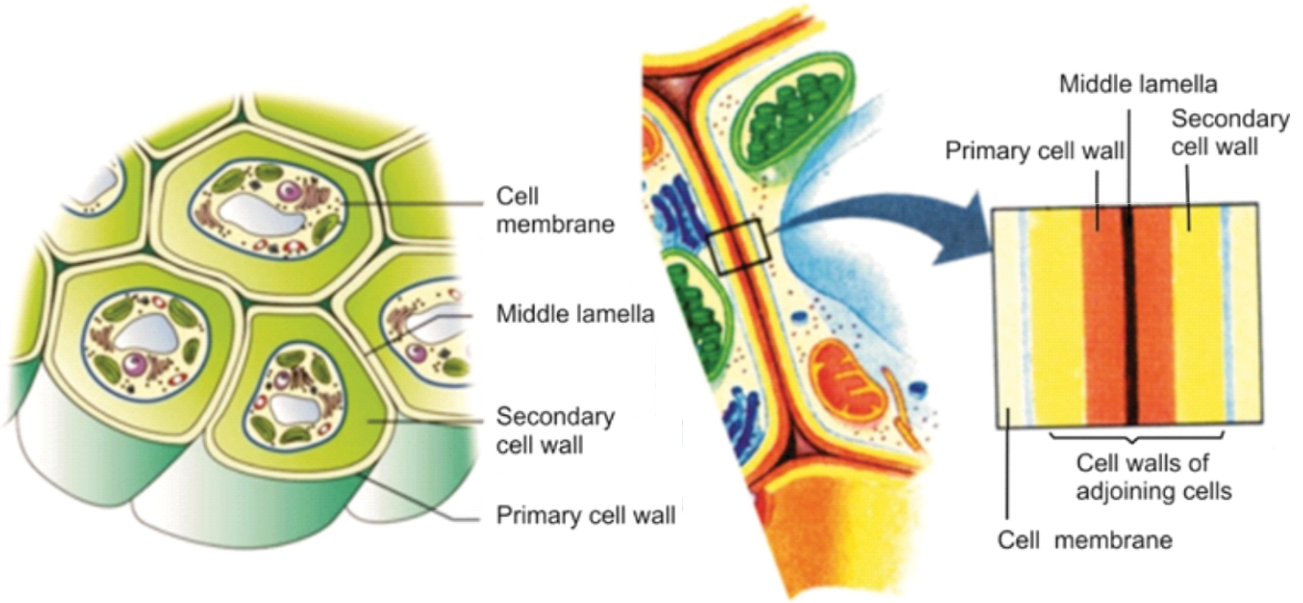


Fig. 1.11: Plant cell wall

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.

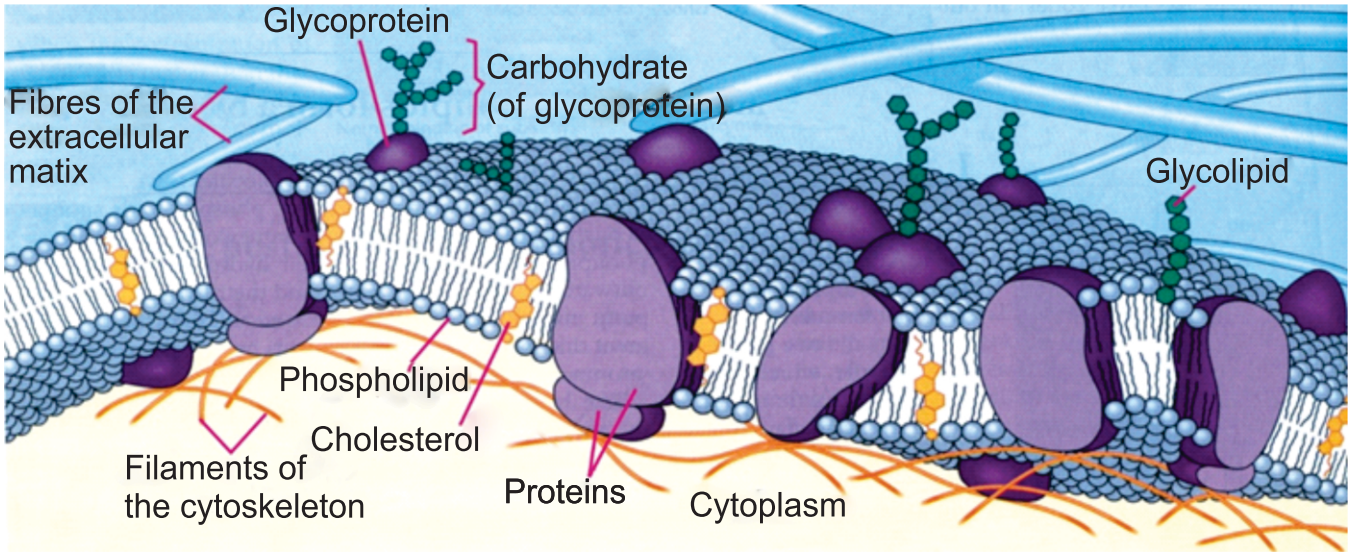


Fig. 1.12: Fluid mosaic model of plasma membrane

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**.

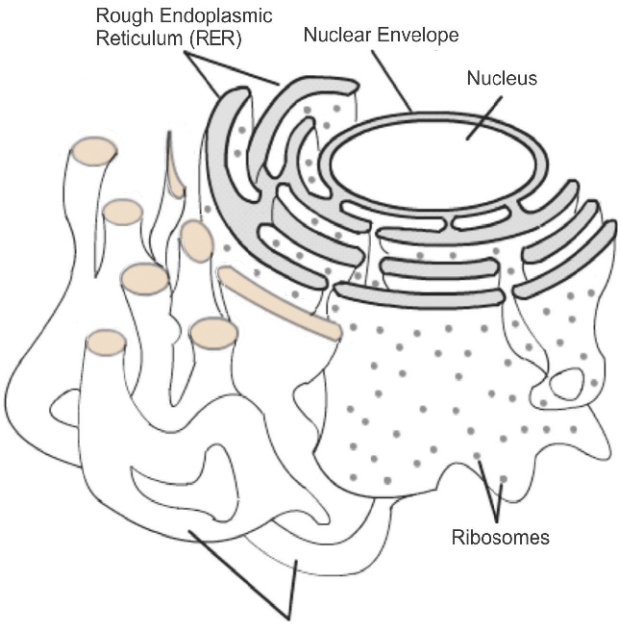


Fig.1.13: Endoplasmic reticulum

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.

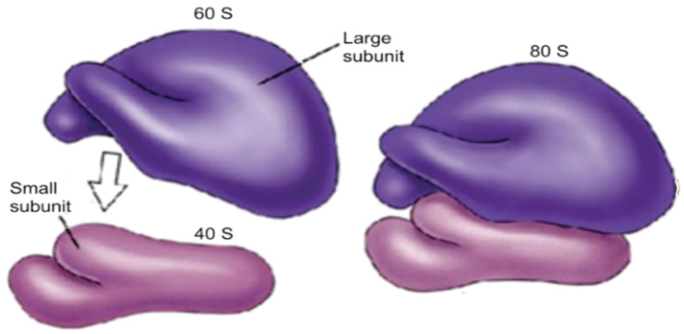


Fig.1.14: Eukaryotic 80S ribosome

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.

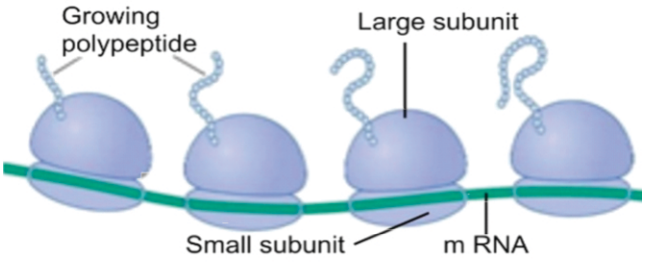


Fig.1.15: Polysome

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.

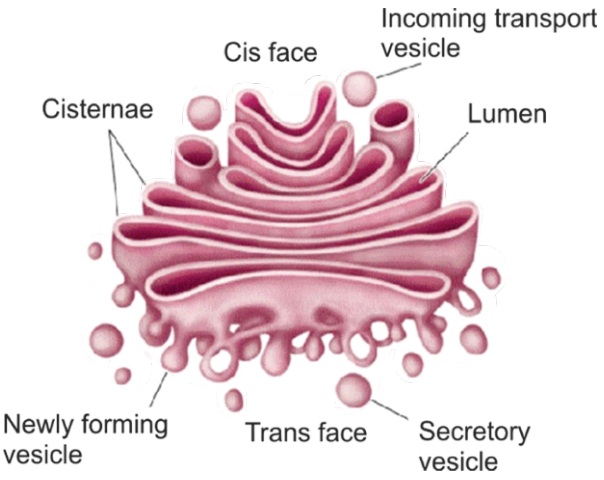


Fig. 1.16: Golgi complex

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.

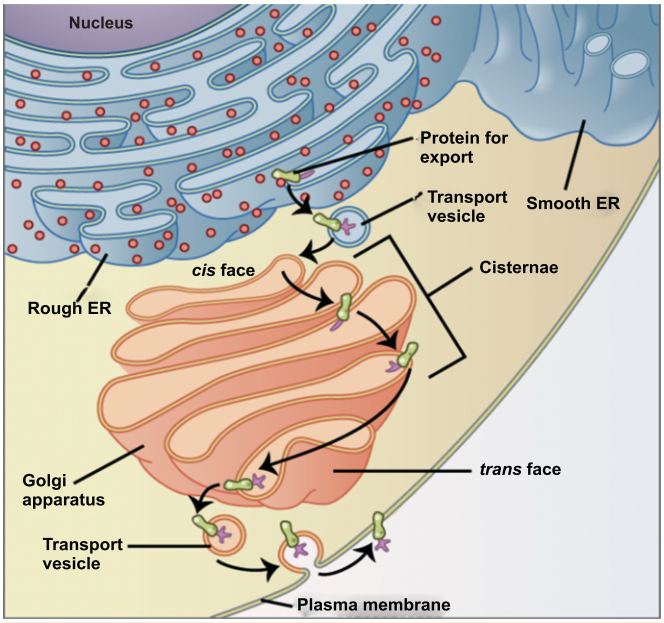


Fig. 1.17: Role of Golgi complex in a glandular cell

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.

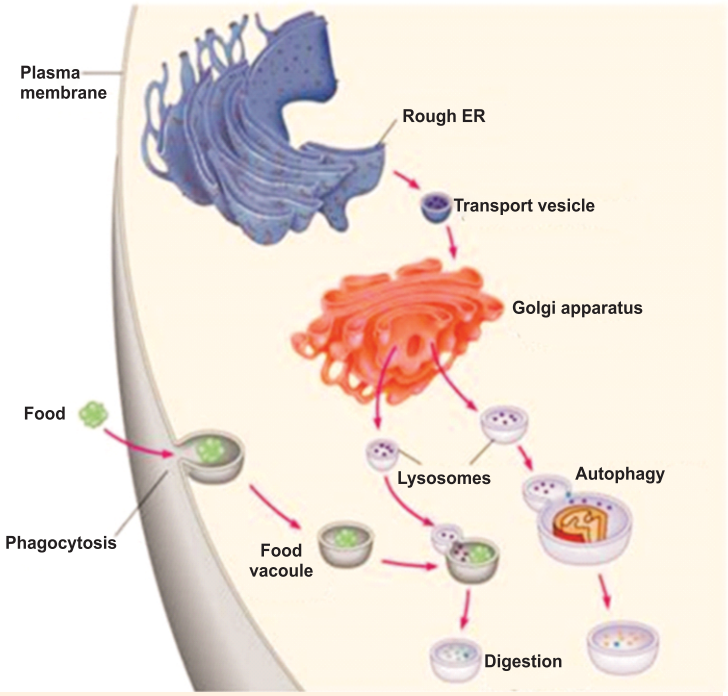


Fig. 1.18: Formation and functions of Lysosomes

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.**

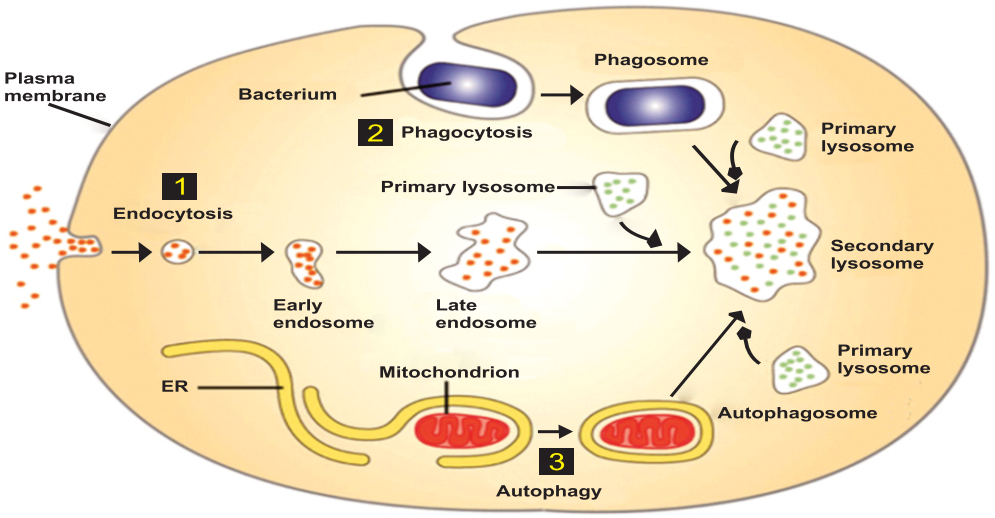


Fig. 1.19: Functions of Lysosomes

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.

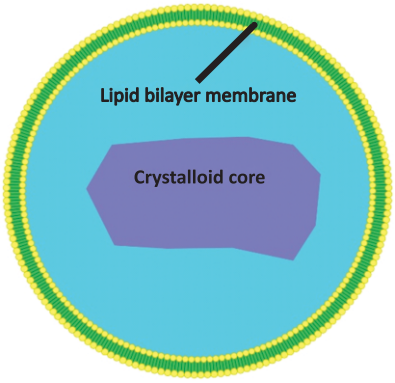


Fig. 1.20: Peroxisomes

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.

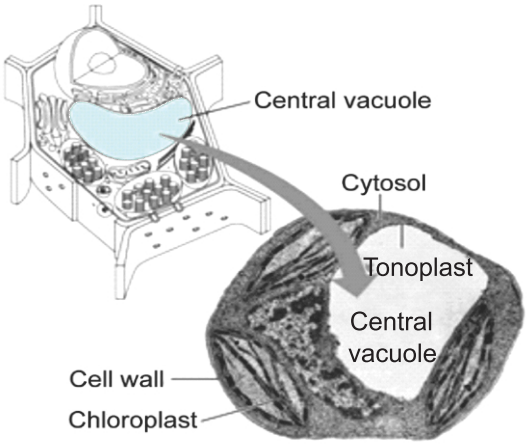


Fig. 1.21: Vacuole of a mature plant cell

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.

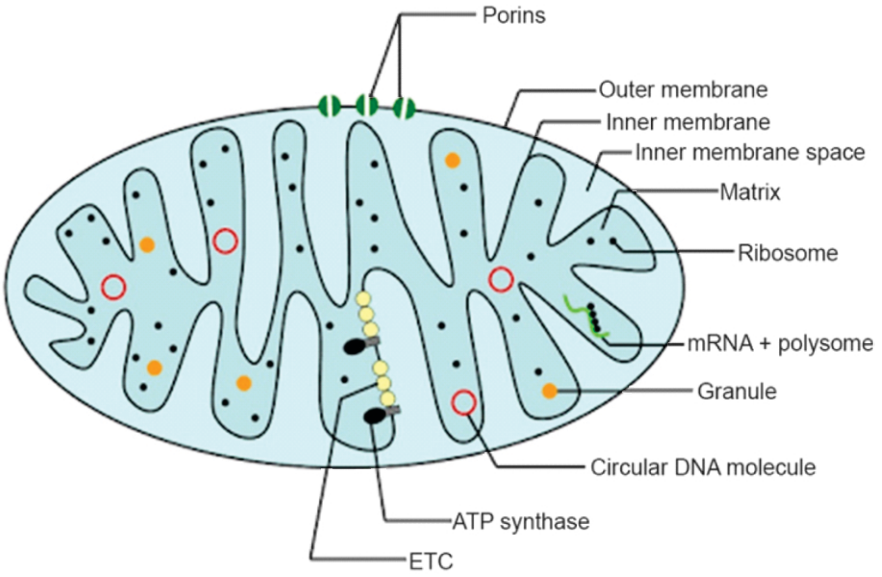


Fig. 1.22: Mitochondrion structure

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.

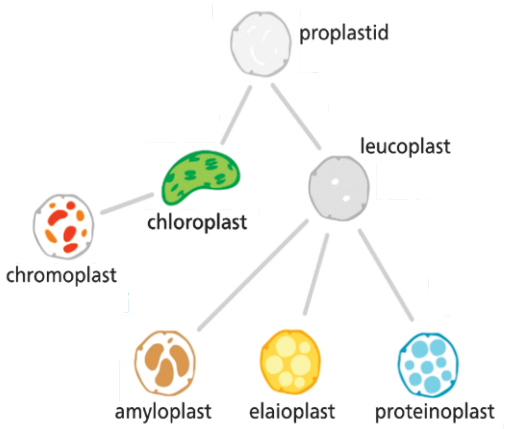


Fig. 1.23: Types of plastids

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.

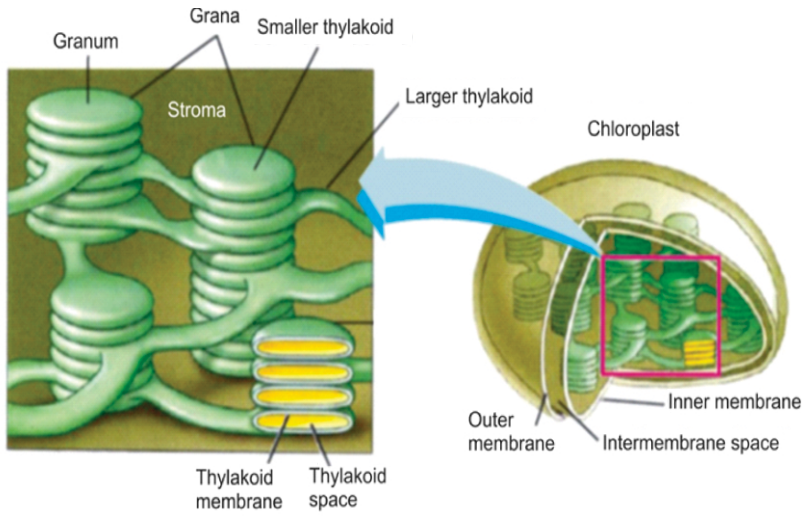


Fig. 1.24: Chloroplast

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.

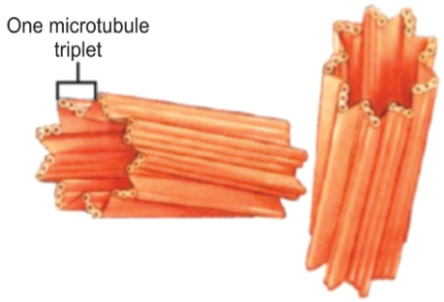


Fig. 1.25: Centrioles

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.

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.

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.

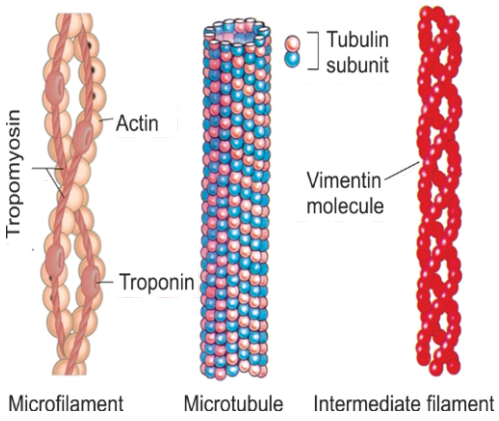


Fig. 1.26: Three types of cytoskeleton

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.

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).

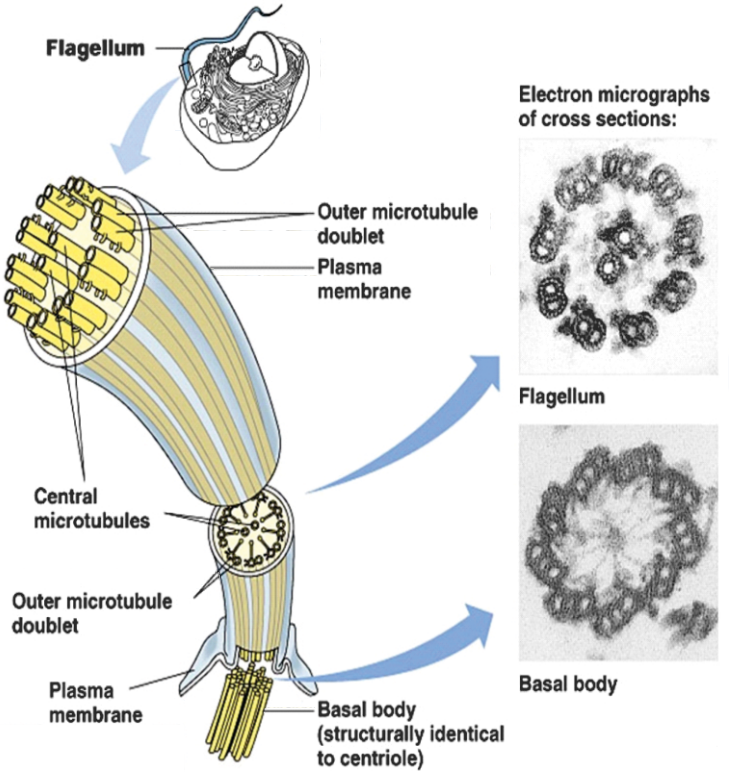


Fig. 1.27: Structure of a eukaryotic flagellum or cilium

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.

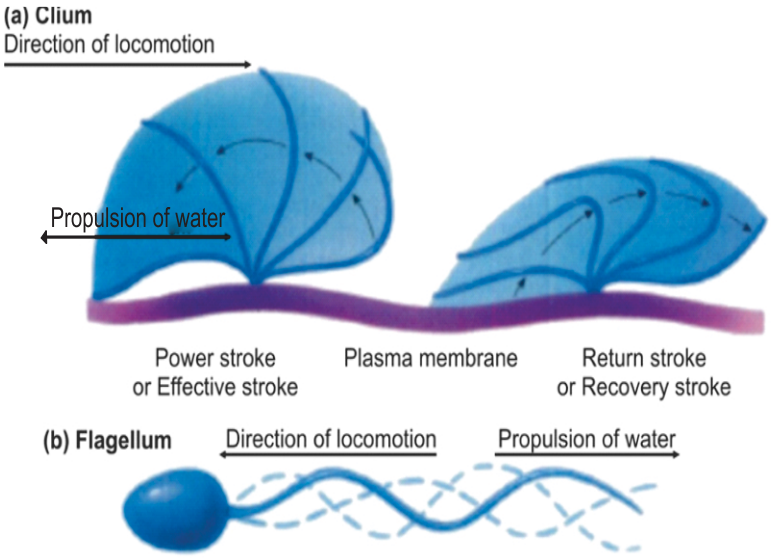


Fig. 1.28: Movement of cilia and flagella

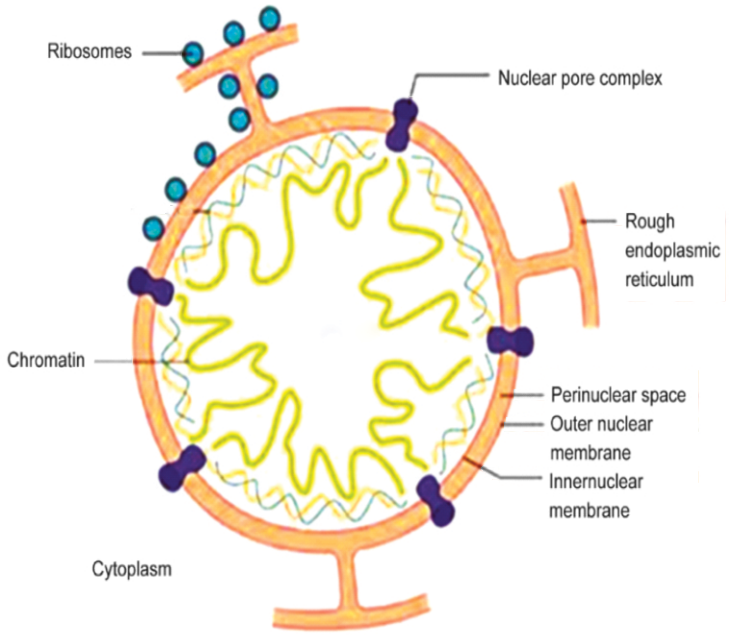


Fig. 1.29: Nucleus

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.

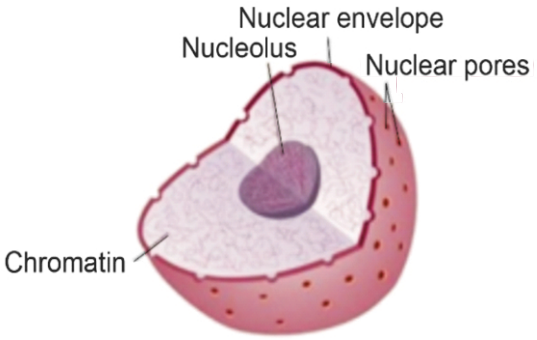


Fig. 1.30: Nucleolus

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.

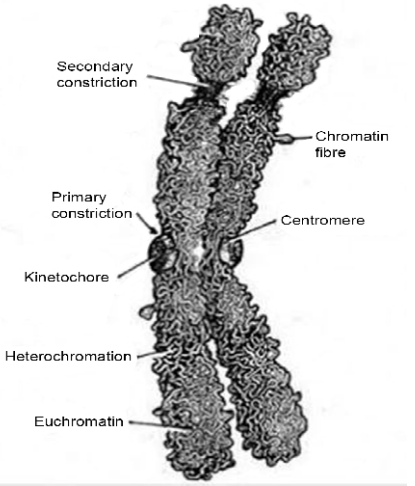


Fig. 1.31: A pair of chromosome

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?
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.

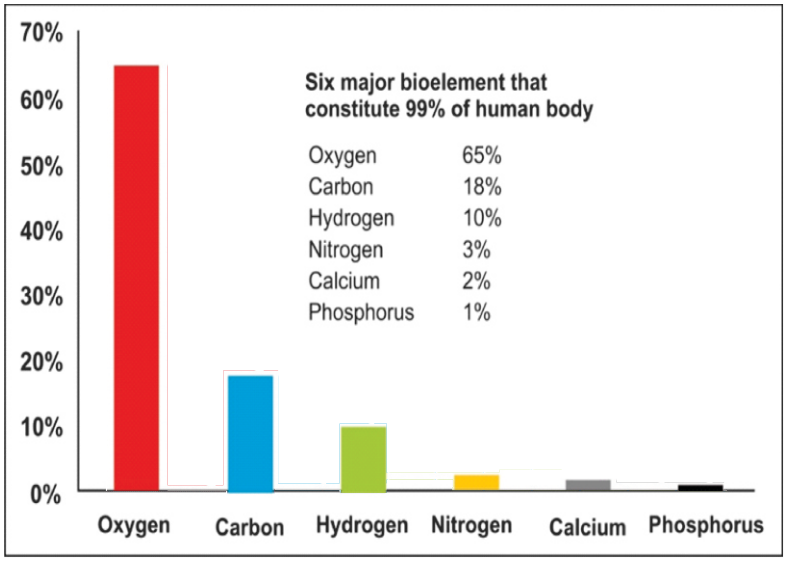
You have got a very brief introduction about biological molecules in IX-X biology course. This chapter caters the detailed study of carbohydrates, proteins, lipids and nucleic acid as well as the importance of water and the role of conjugated molecules.

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

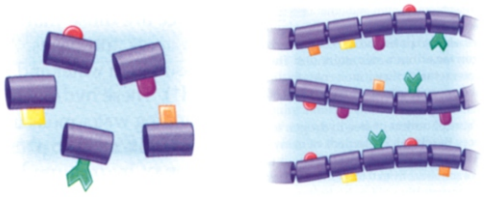


Fig: 2.2: Monomer and polymer

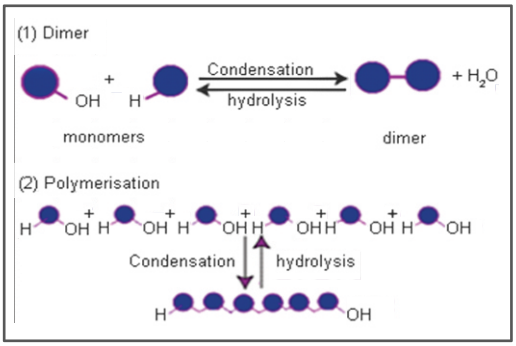


Fig. 2.3: Condensation and Hydrolysis

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.

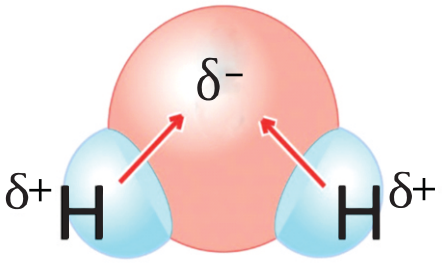


Fig: 2.4: Polarity of water molecule

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.

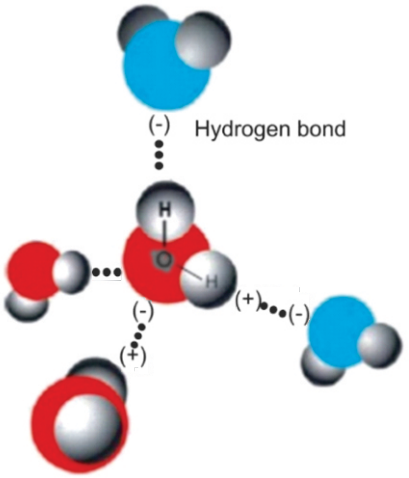


Fig: 2.5 Hydrogen bonds between water molecules

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^{o}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.

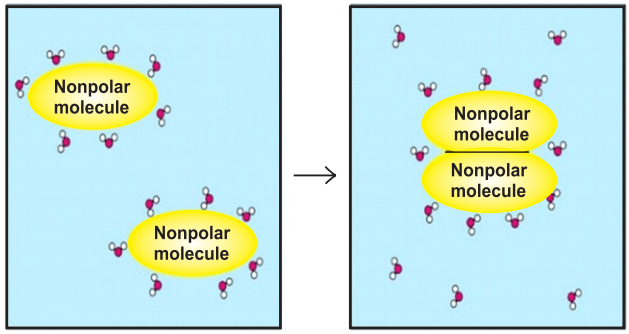


Fig: 2.6: Hydrophobic exclusion

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.

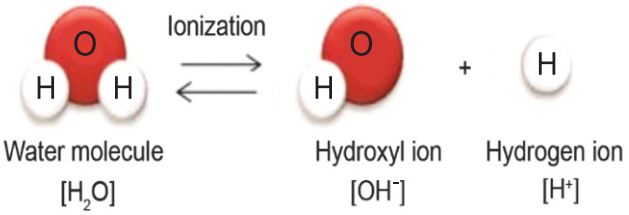


Fig: 2.7: Ionization of water

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.

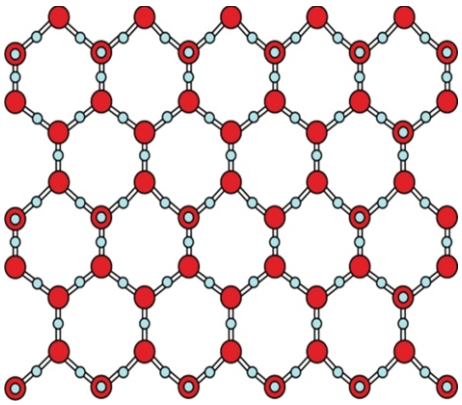


Fig: 2.8: Lattice likes arrangement of water molecules in ice

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.

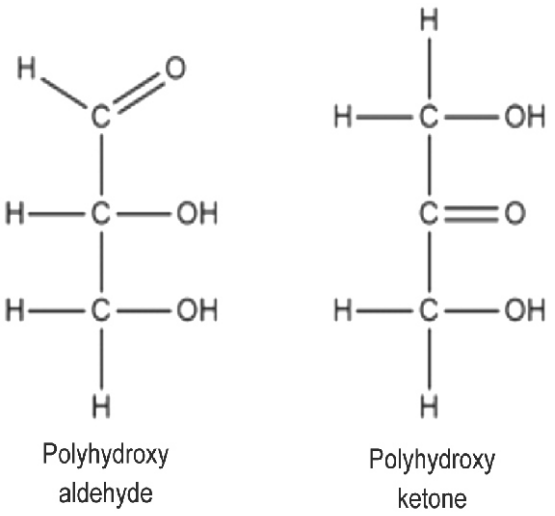


Fig: 2.9: Chemical nature of carbohydrates

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

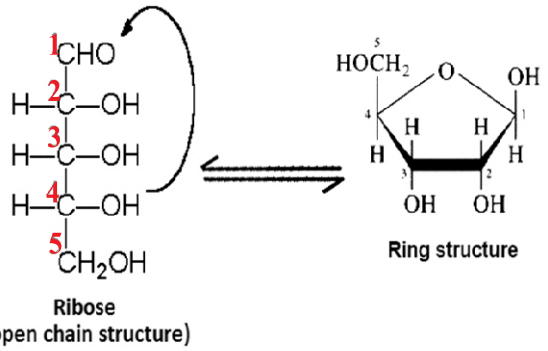


Fig: 2.10: Conversion of open chain into ring chain

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.

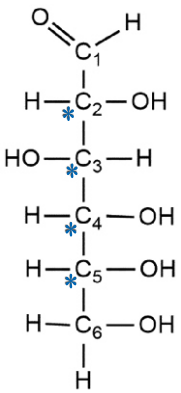


Fig: 2.11: Glucose open chain structure

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.

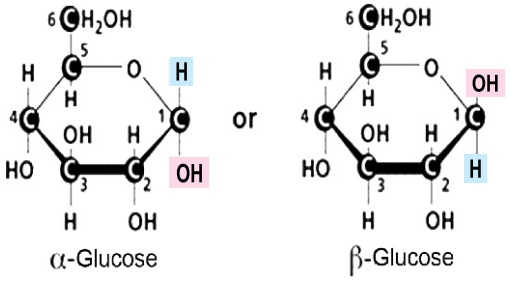


Fig: 2.12: *α* and *β* isomers of glucose

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.

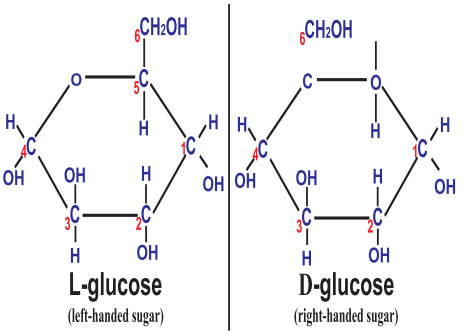


Fig: 2.13: An example of enantiomers

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.**

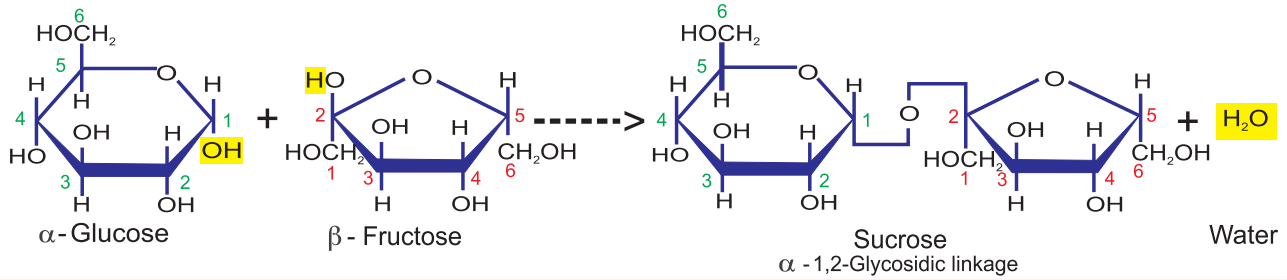


Fig: 2.14: Formation of sucrose

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.**

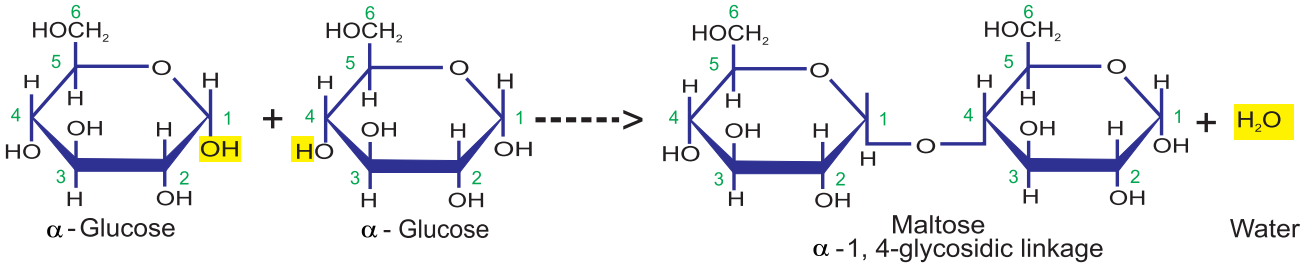


Fig: 2.15: Formation of maltose

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.**

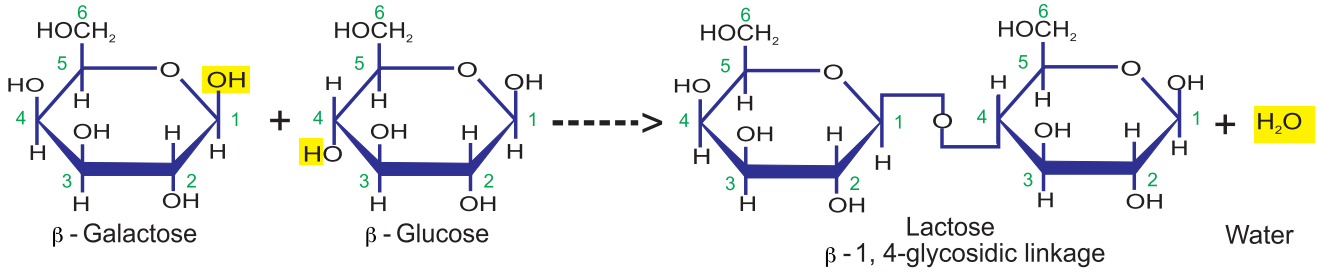


Fig: 2.16: Formation of lactose

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.

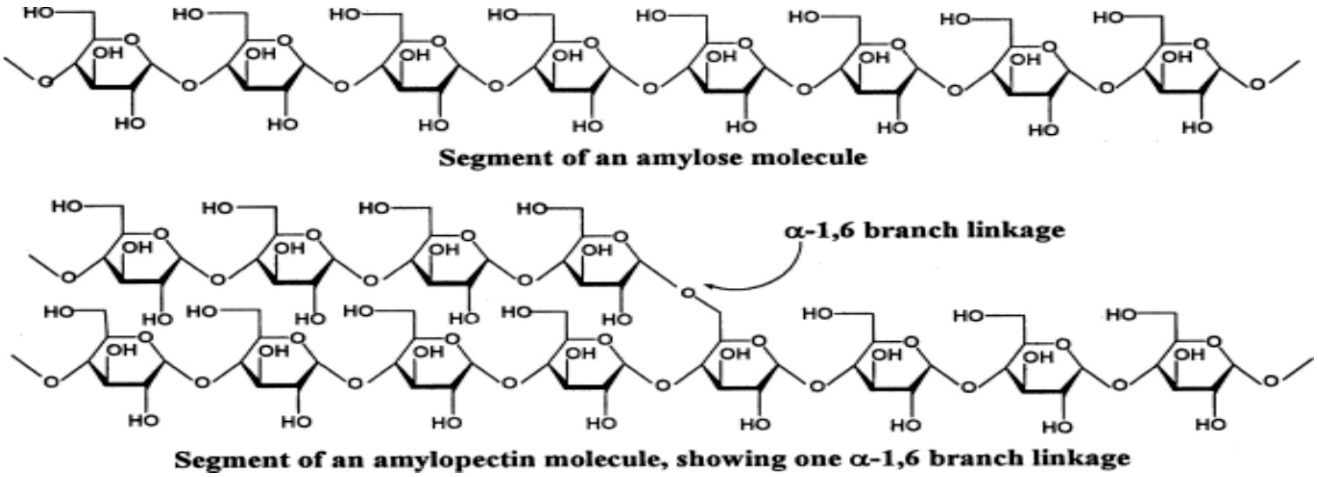


Fig: 2.17: Structure of starches

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

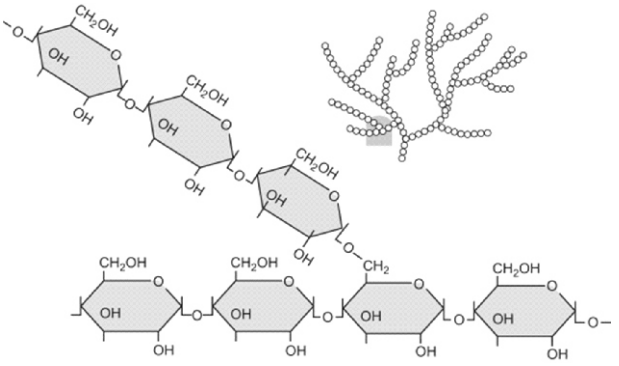


Fig: 2.18: Structure of glycogen

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.

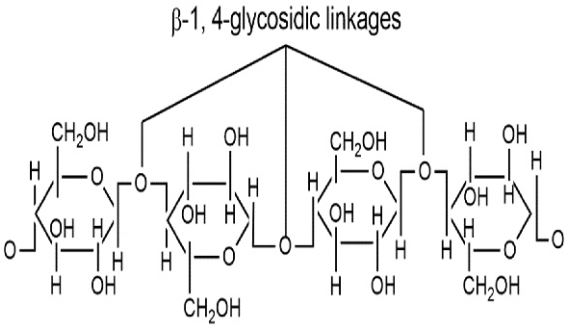


Fig: 2.19: Structure of cellulose

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.**

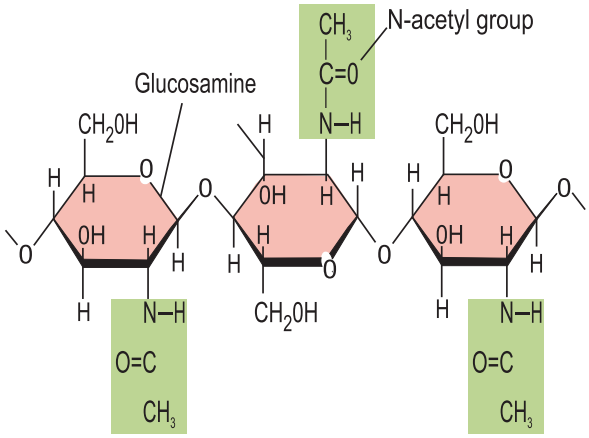


Fig: 2.20: Structure of chitin

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

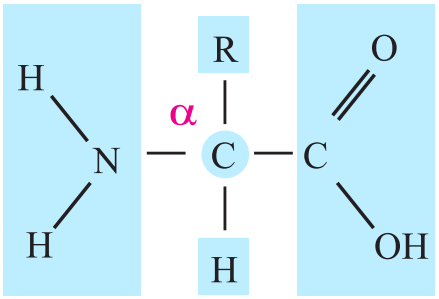


Fig: 2.21 General structure of an amino acid

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.**

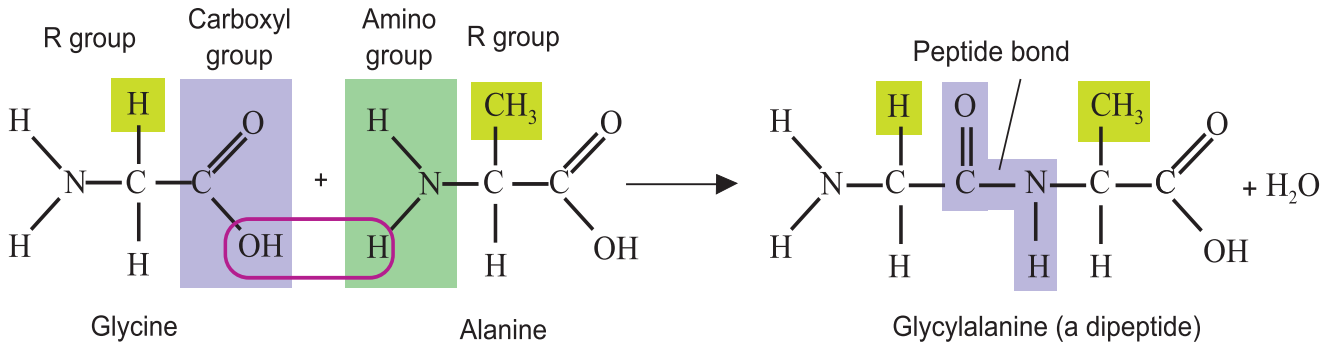


Fig: 2.22: Formation of a dipeptide and peptide bond

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.**

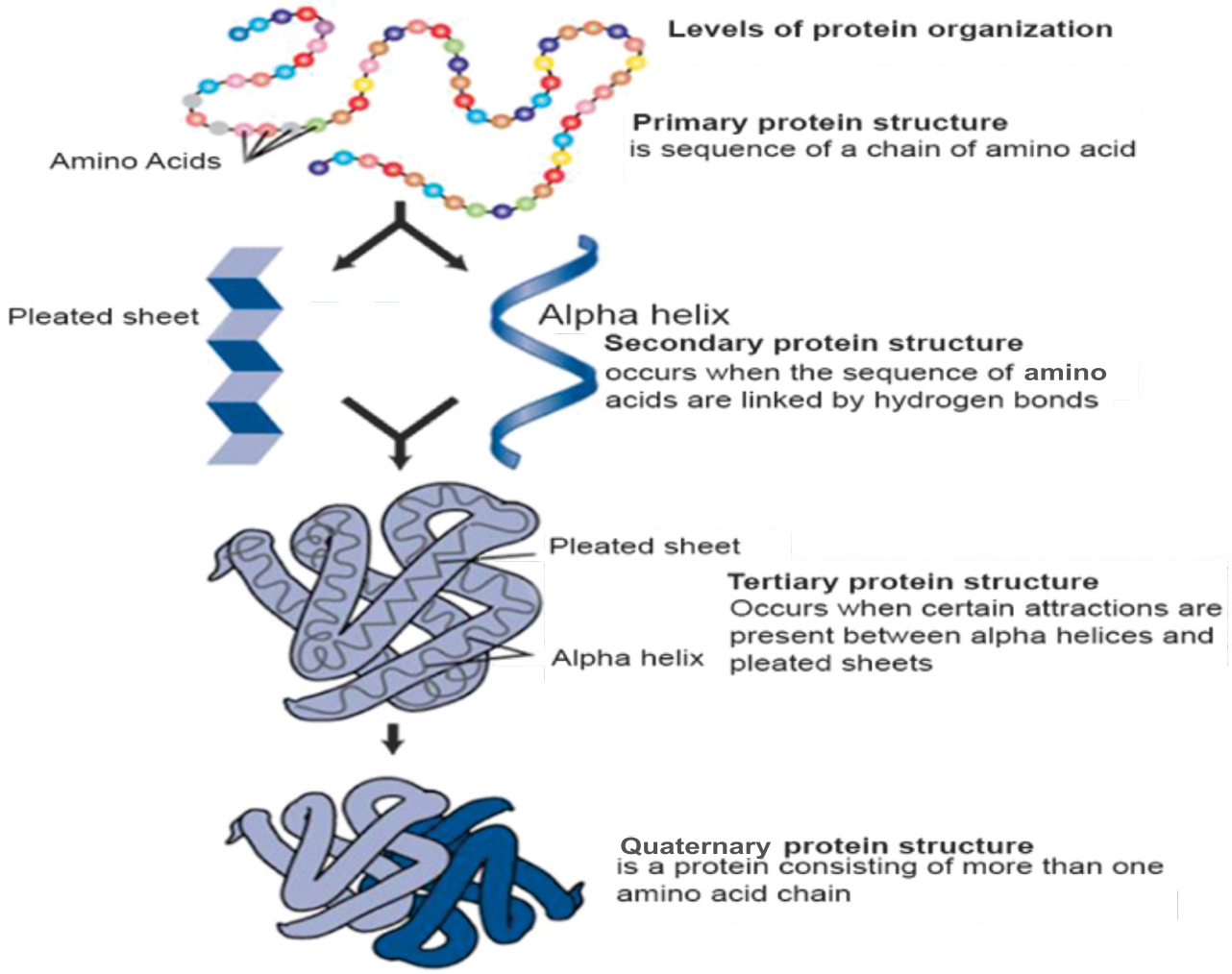


Fig: 2.23: Structural conformations in proteins

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.

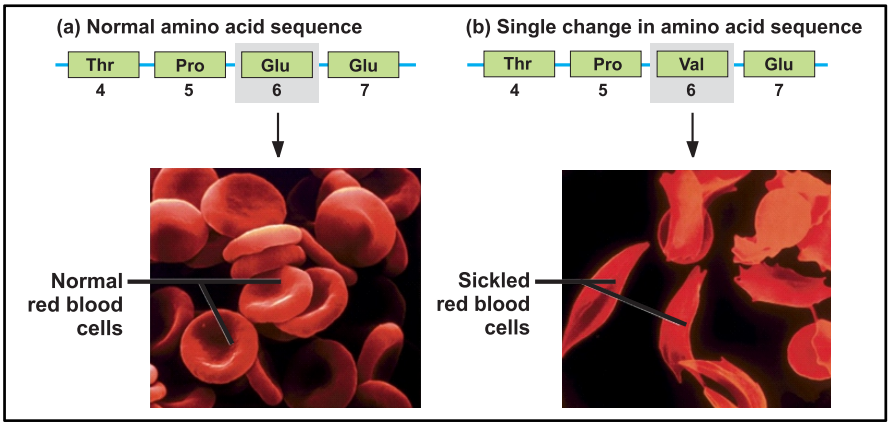


Fig: 2.24: Difference in *β*-chain of Hb^A and Hb^S

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.

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.**

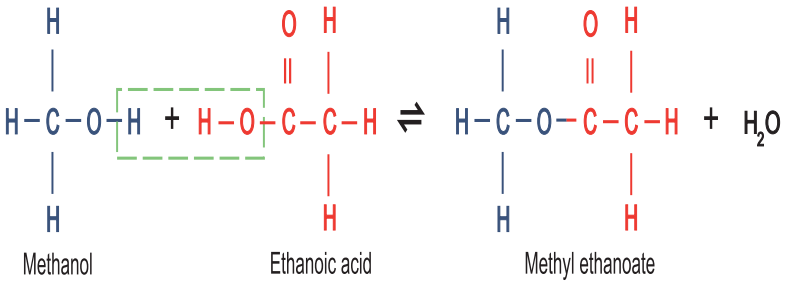


Fig: 2.25: Esterification

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.

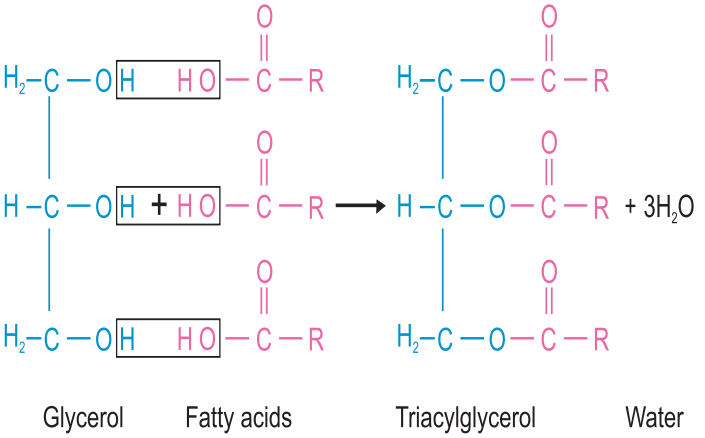


Fig: 2.26: Formation of a triacylglycerol (neutral lipid)

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	$CH_3(CH_2)_7CH{=}CH(CH_2)_7COOH$	4
4.Linoleic	Vegetable oils	18	$CH_3(CH_2)_4CH{=}CHCH_2CH{=}CH(CH_2)_7COOH$	-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

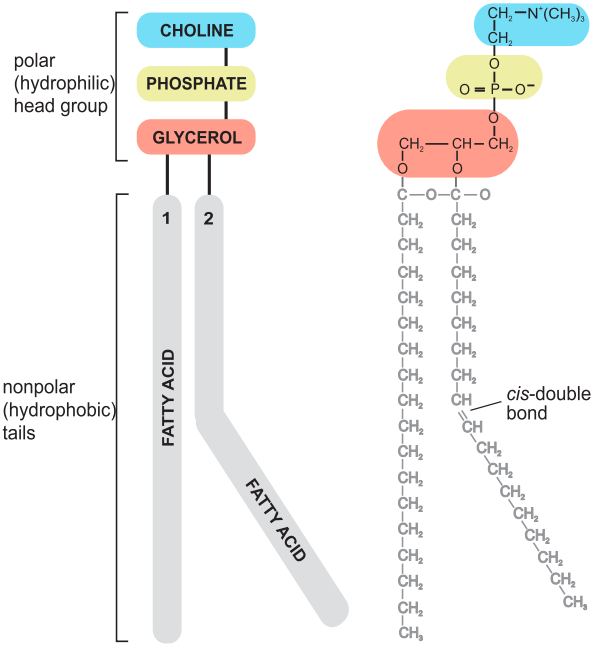


Fig. 2.27: Phosphatidylcholine (Lecithin)

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

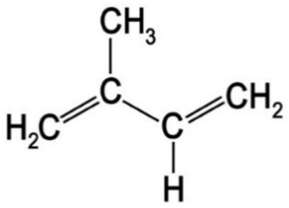


Fig. 2.28 Isoprene unit

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.

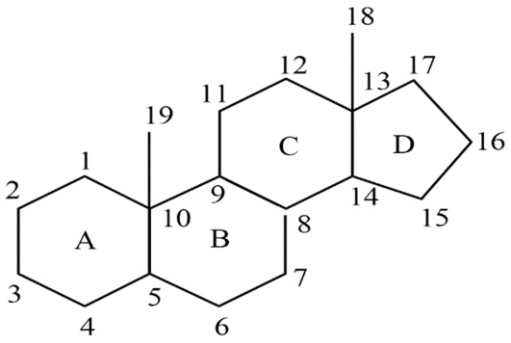


Fig. 2.29 Steroid nucleus

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

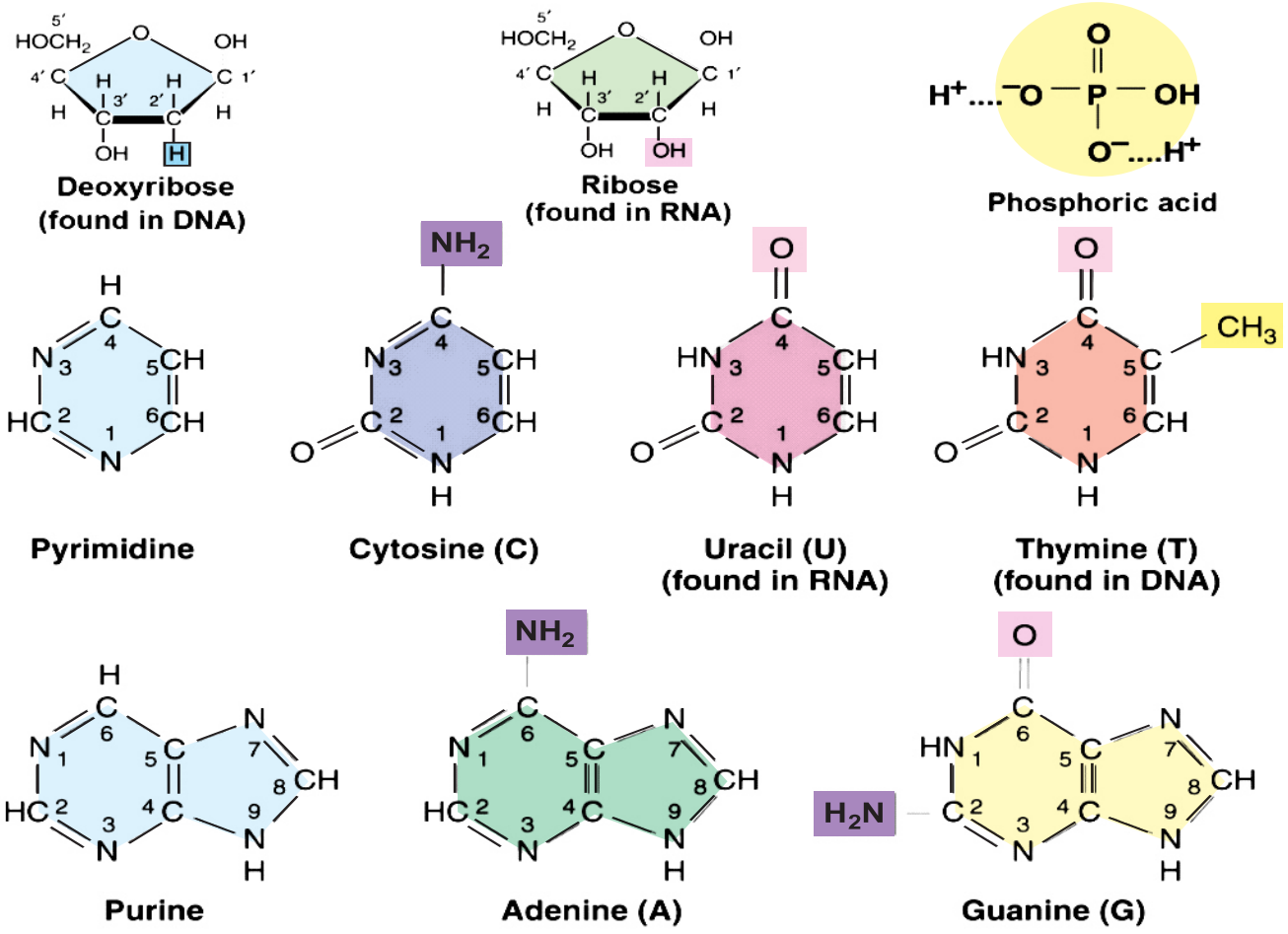


Fig. 2.30: Components of nucleotides

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).

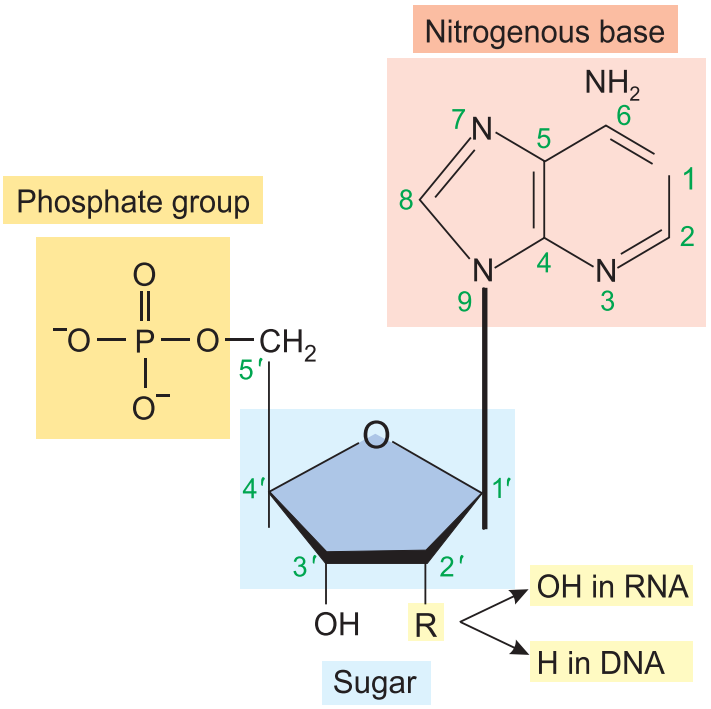


Fig. 2.31: Structure of a nucleotide

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'.

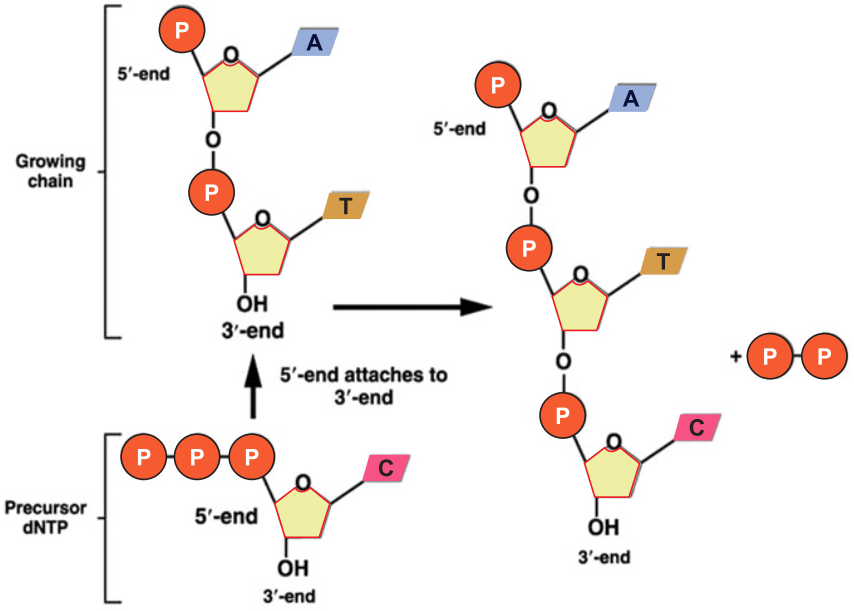


Fig. 2.32 Polymerization of nucleotides

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.

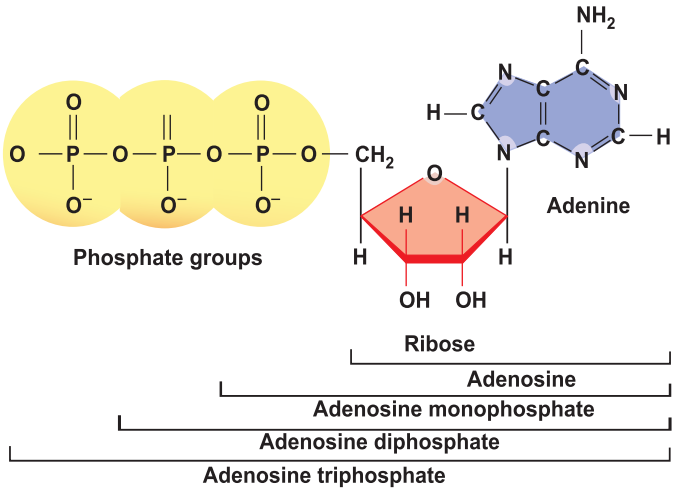


Fig. 2.33 Structure of ATP

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

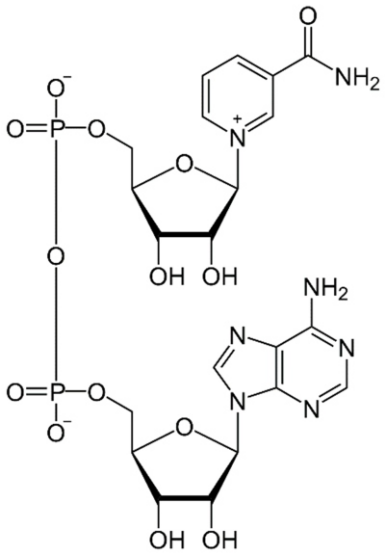


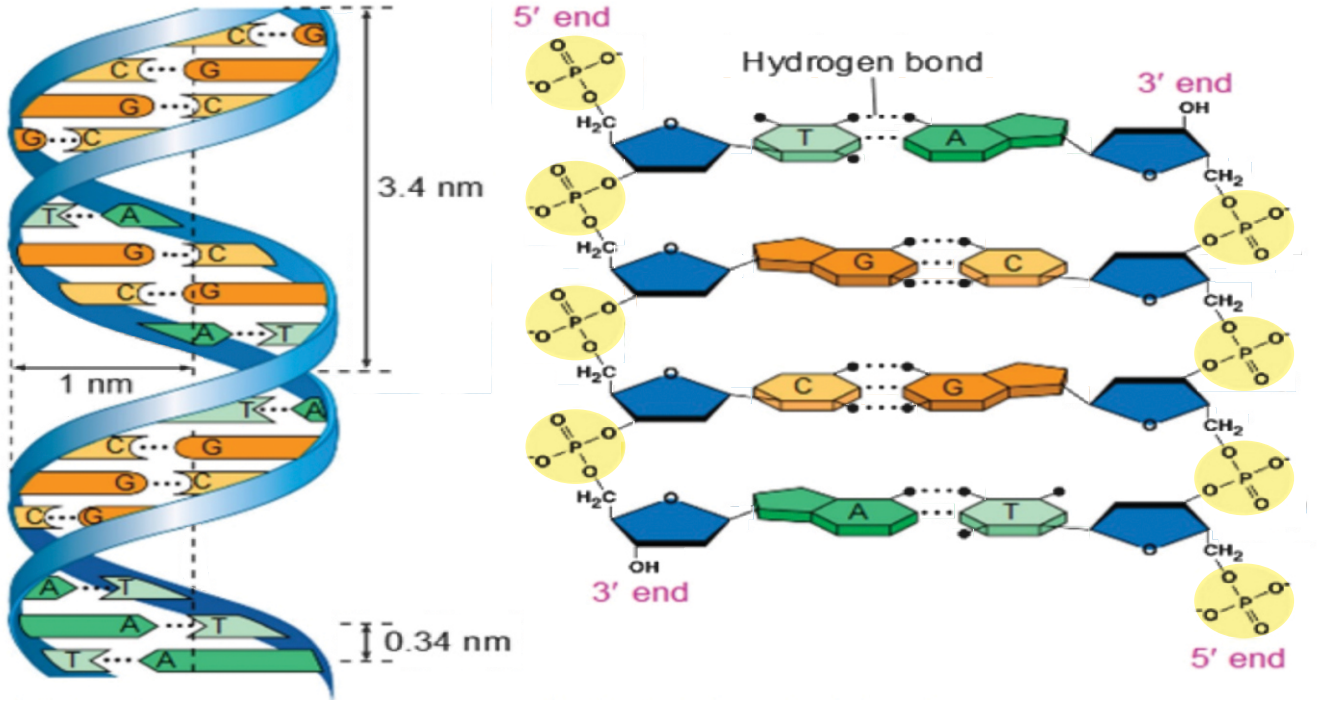
Fig. 2.34 Structure of NAD

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.

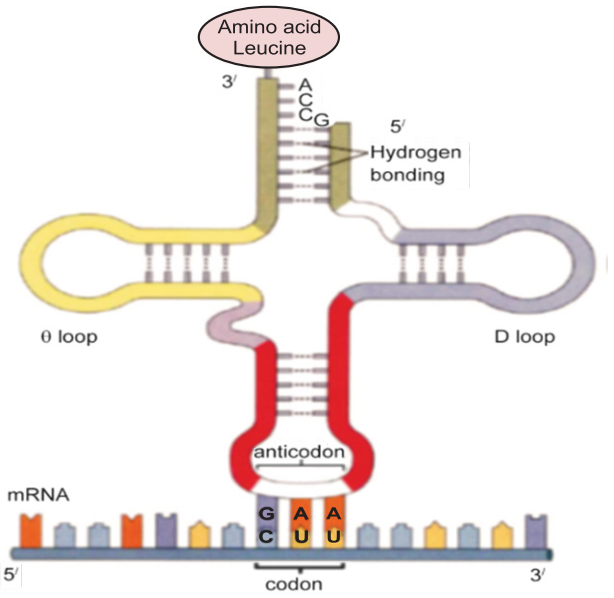


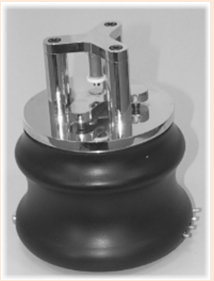
Fig: 2.36: Cloverleaf model of tRNA

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.

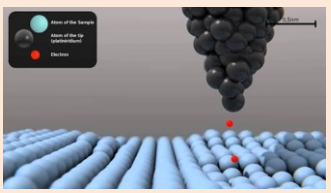
Science, Technology and Society Connections

- **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.

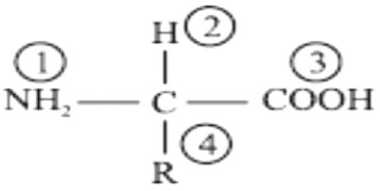
Activity

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.

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.

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.

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

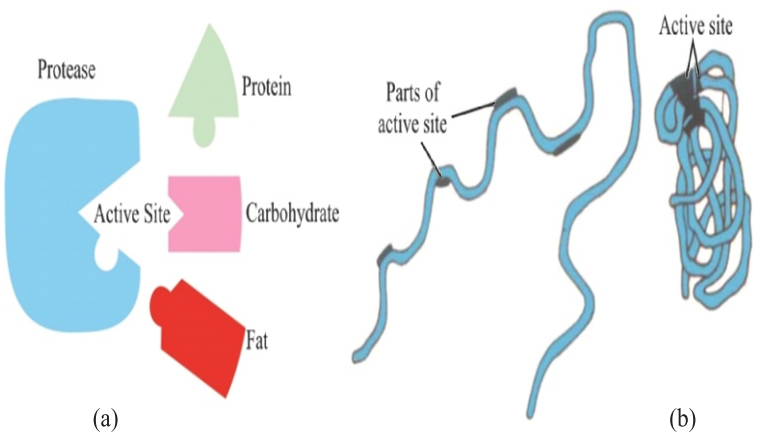


Fig: 3.1: Active site: (a) Which substrate fits the active site? (b) Grouping of amino acids of a polypeptide during the formation of tertiary structure to produce an active site.

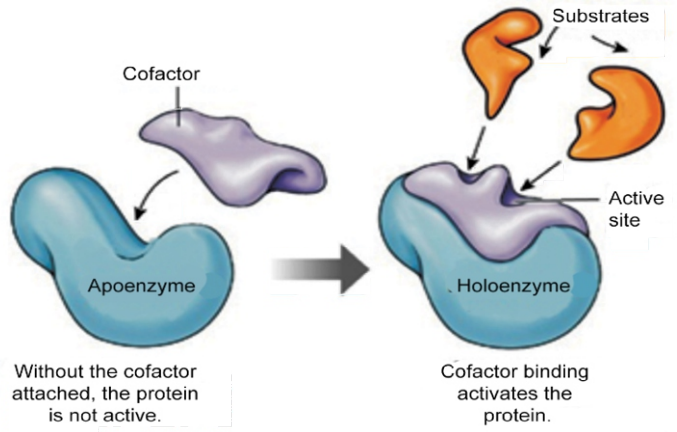


Fig. 3.2 Structure of enzyme

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**.

Glucose + ATP $\xrightarrow{\text{Hexokinase + } Mg^{+2}}$ **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.

Ethyl alcohol $\xrightarrow{\text{Alcohol dehydrogenase + } NAD^+}$ **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,

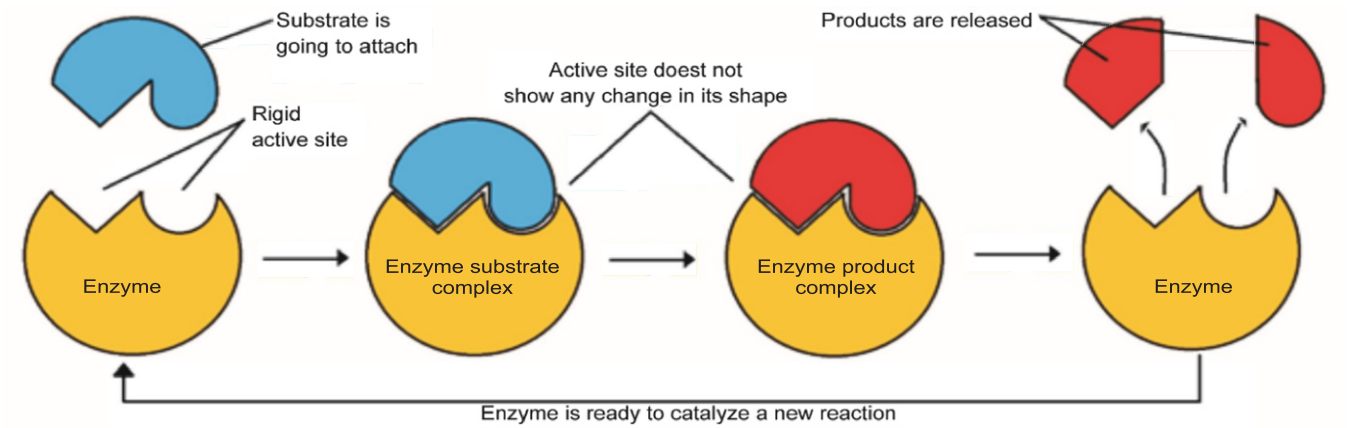


Fig: 3.3: Fischer's "Lock and Key" hypothesis of enzyme action

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.

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

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

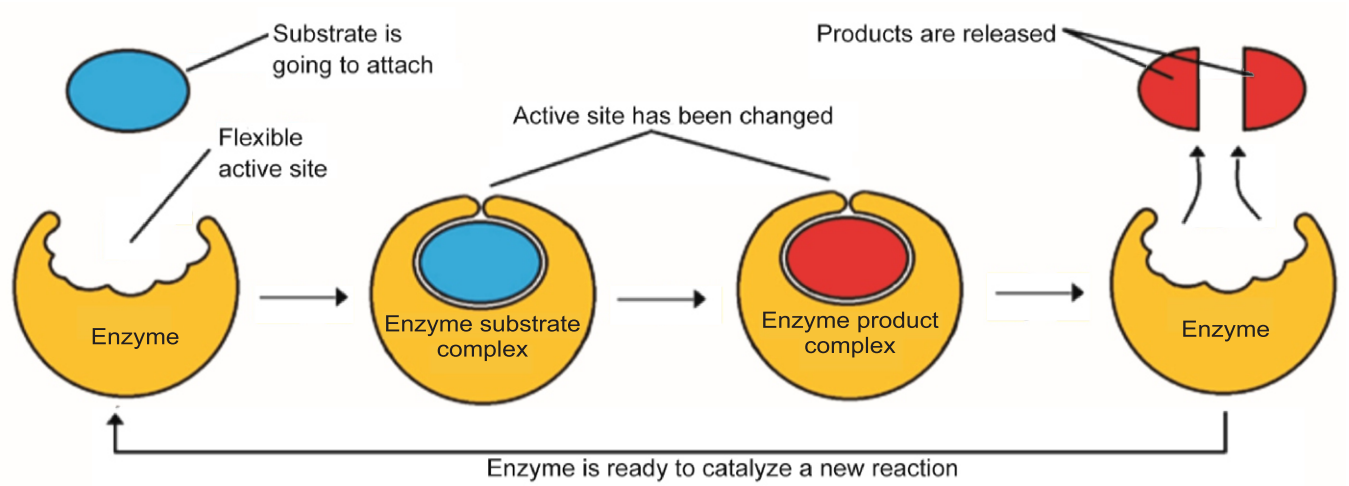


Fig: 3.4: Koshland's "Induced Fit" model of enzyme action

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.

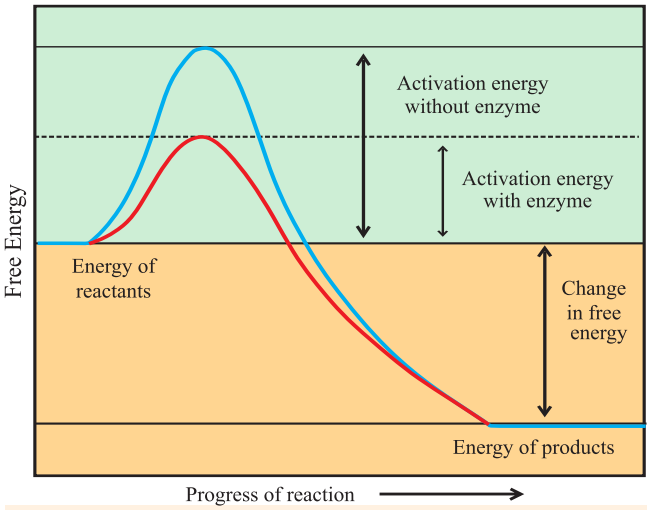


Fig: 3.5: Energy of activation: Enzymes speed the rate of chemical reactions because they lower the amount of energy required to activate the reactants and lower the need of activation energy

A + E ⟶ AE Complex + B ⟶ 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

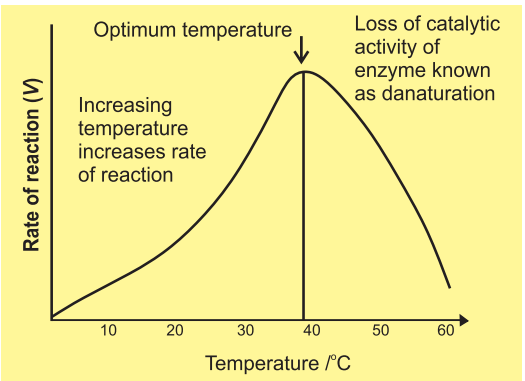


Fig: 3.6 (a): Effect of temperature on the rate of an enzyme controlled reaction

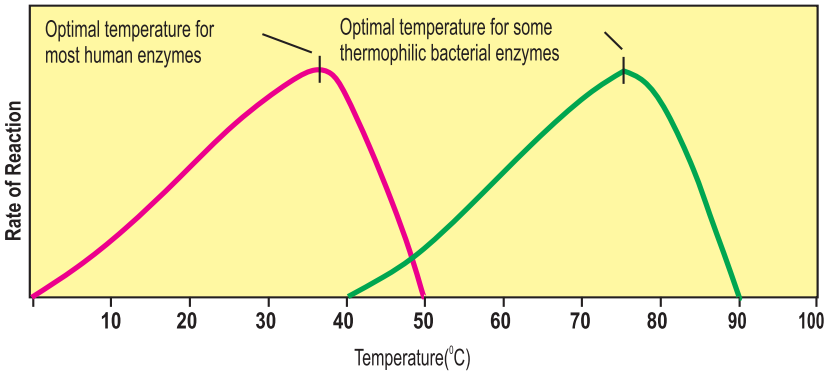


Fig: 3.6 (b): Optimum temperature for human enzymes and thermophilic bacteria

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.

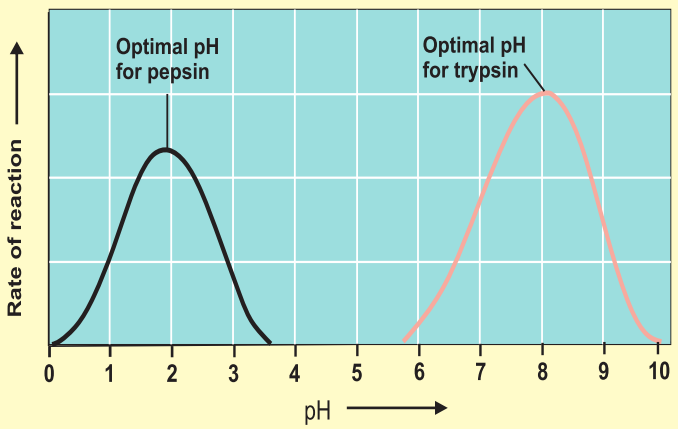


Fig: 3.7: Effect of pH on the rate of enzyme-controlled reaction

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.

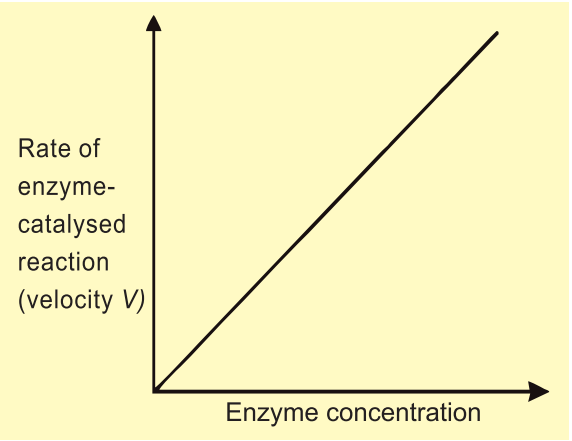


Fig: 3.8: Relationship between Enzyme concentration and the rate of an Enzyme-controlled reaction

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.

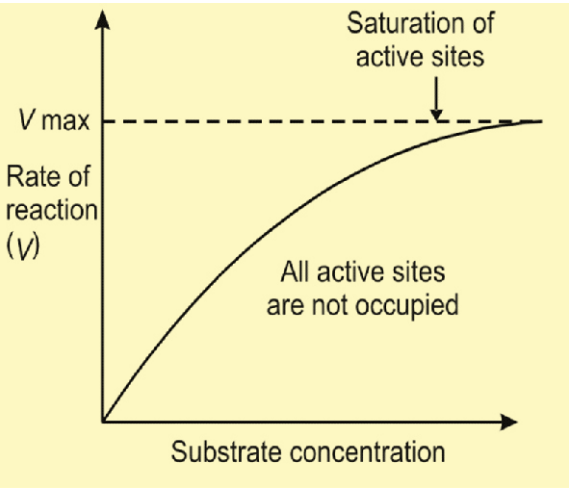


Fig: 3.9: Effect of Substrate concentration on the rate of Enzyme-controlled reaction

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.

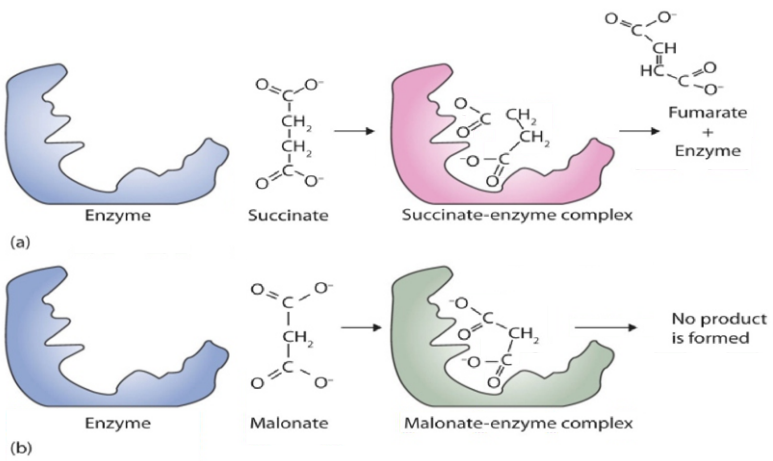


Fig: 3.10: Effect of malonate as competitive inhibitors

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.

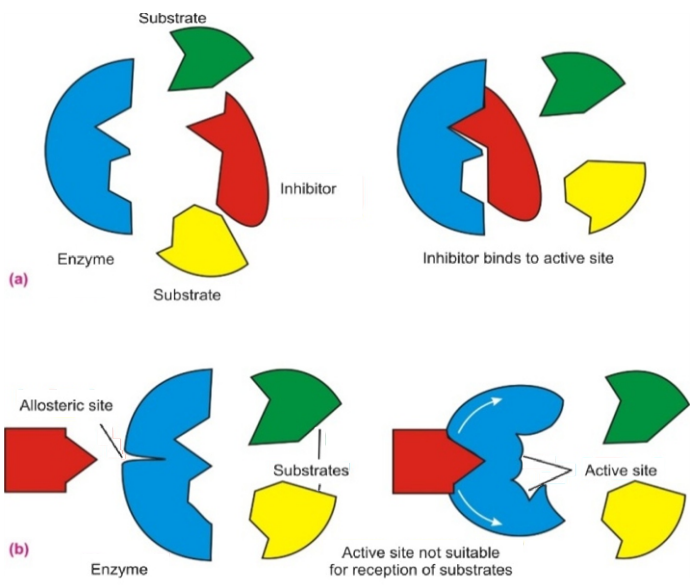


Fig: 3.11: (a) Competitive inhibition (b) Non-competitive inhibition

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.

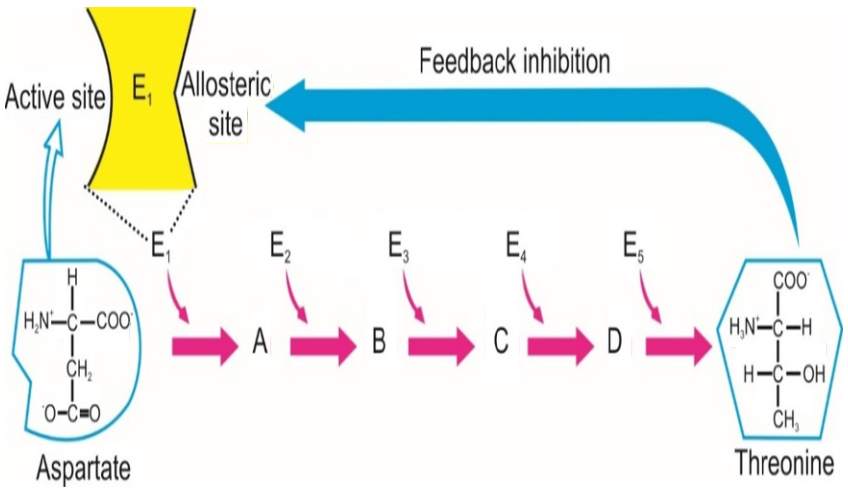


Fig: 3.12: Feedback inhibition

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	$A—B + C \longrightarrow A + C—B$
3.	Hydrolases	$A—B + H_2O \longrightarrow A—H + B—OH$
4.	Lyases	$A—B \rightleftharpoons A + B$ (reverse reaction syntheses)
5.	Isomerases	$A—B—C \rightleftharpoons A—C—B$
6.	Ligases (synthetases)	$A + B + ATP \longrightarrow A—B + ADP + Pi$

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^{++}

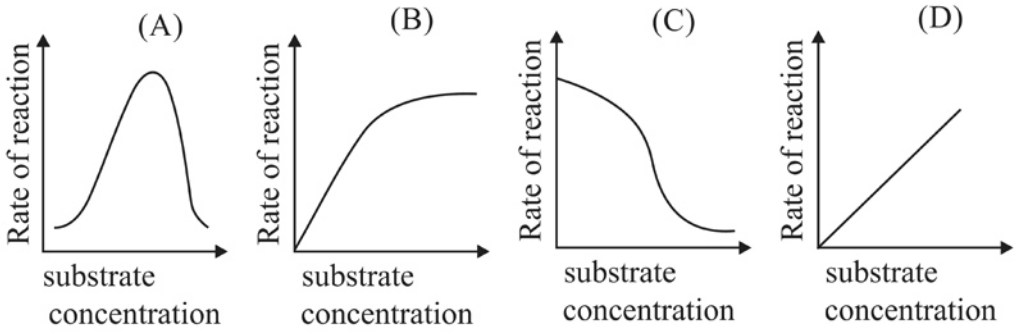
(C) both "a" and "b" (D) none of them

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

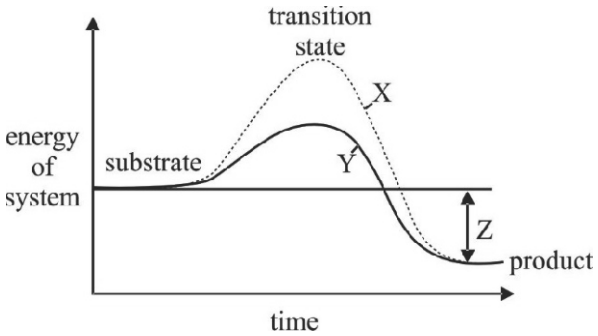
(A) active site (B) allosteric site

(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.

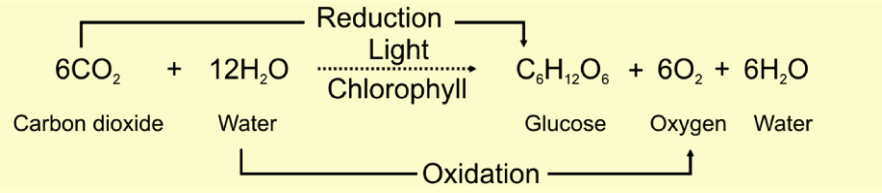
Living things cannot grow, reproduce, or exhibit any of the characteristics of life without a ready supply of energy. All metabolic reactions involve energy transformations. So the quantitative study of energy relationships in biological system is called **bioenergetics.** Biological energy transformations 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:



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

4.1.1 Role of Light

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.

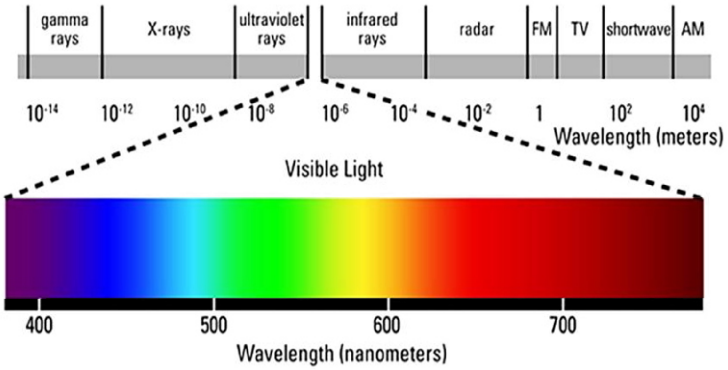


Fig. 4.1 Electromagnetic spectrum

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

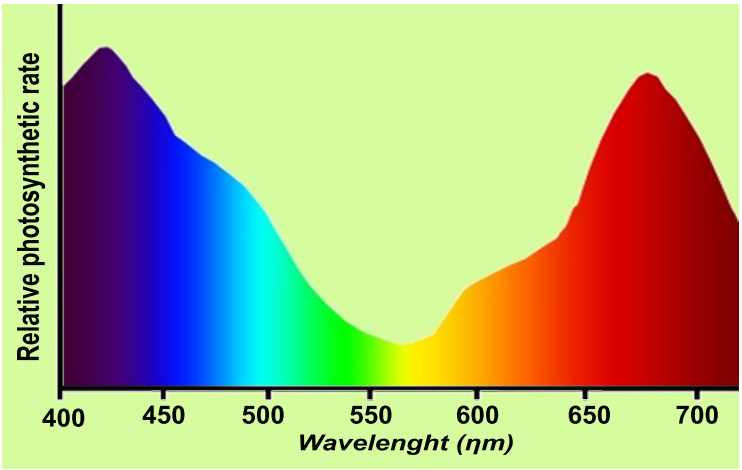


Fig. 4.2 Action spectrum of photosynthesis

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.

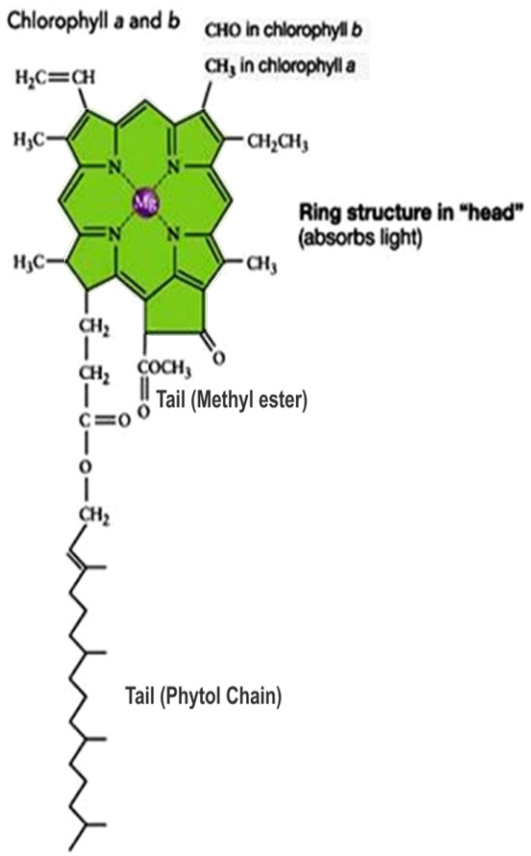


Fig 4.3: Structure of chlorophyll

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.

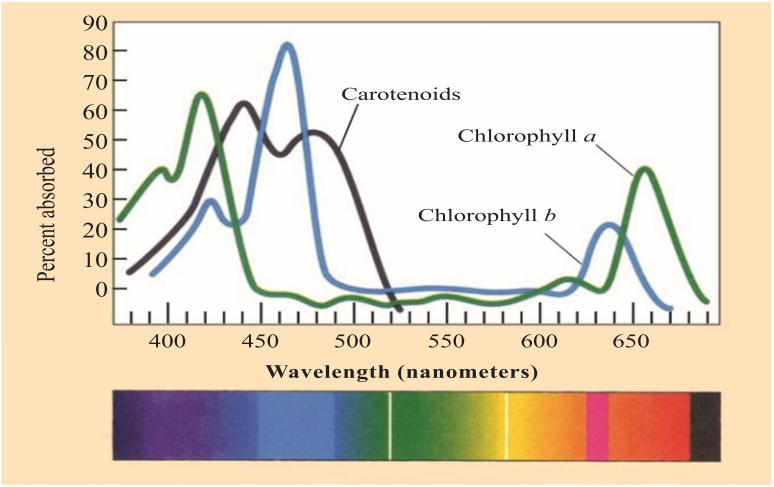


Fig: 4.4: Absorption spectra of different pigments

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.

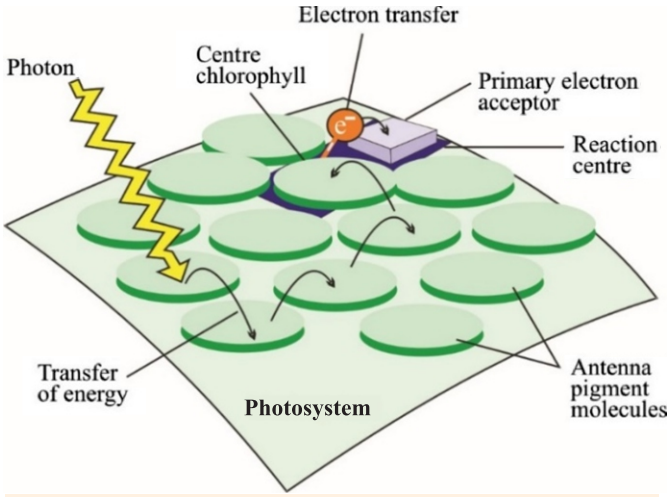


Fig: 4.5: Structure of photosystem

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.

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

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.

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

Carbon dioxide — Water — Glucose — Water — Oxygen

$$6C\mathbf{O_2} + 12H_2O \xrightarrow[\text{Chlorophyll}]{\text{Light}} C_6H_{12}O_6 + 6\mathbf{H_2O} + 6O_2$$

Carbon dioxide — Water — Glucose — Water — Oxygen

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

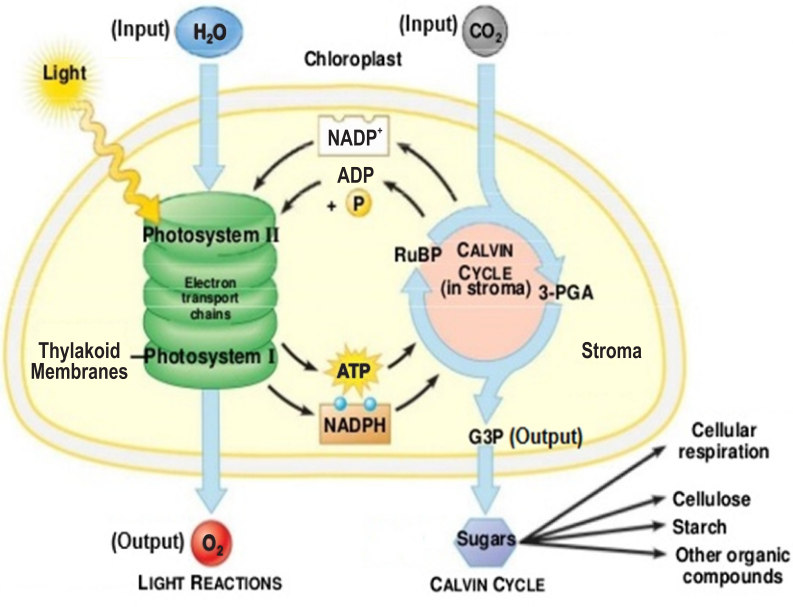


Fig: 4.6: An overview of photosynthesis

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 $½O_2$. 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.

$$H_2O \xrightarrow{\text{Photolysis of water}} 2H^+ + 2e^- + ½\ O_2$$

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**.

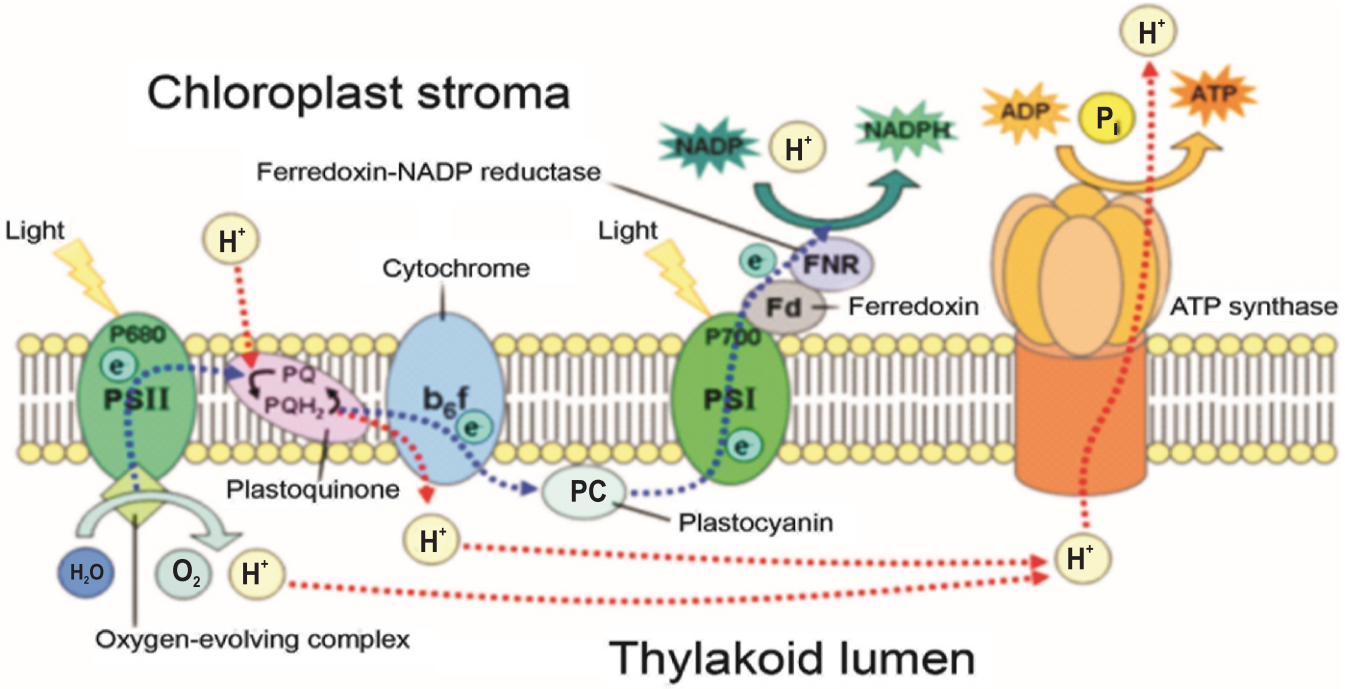


Fig: 4.7: Chemiosmotic synthesis of ATP during light reaction

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.

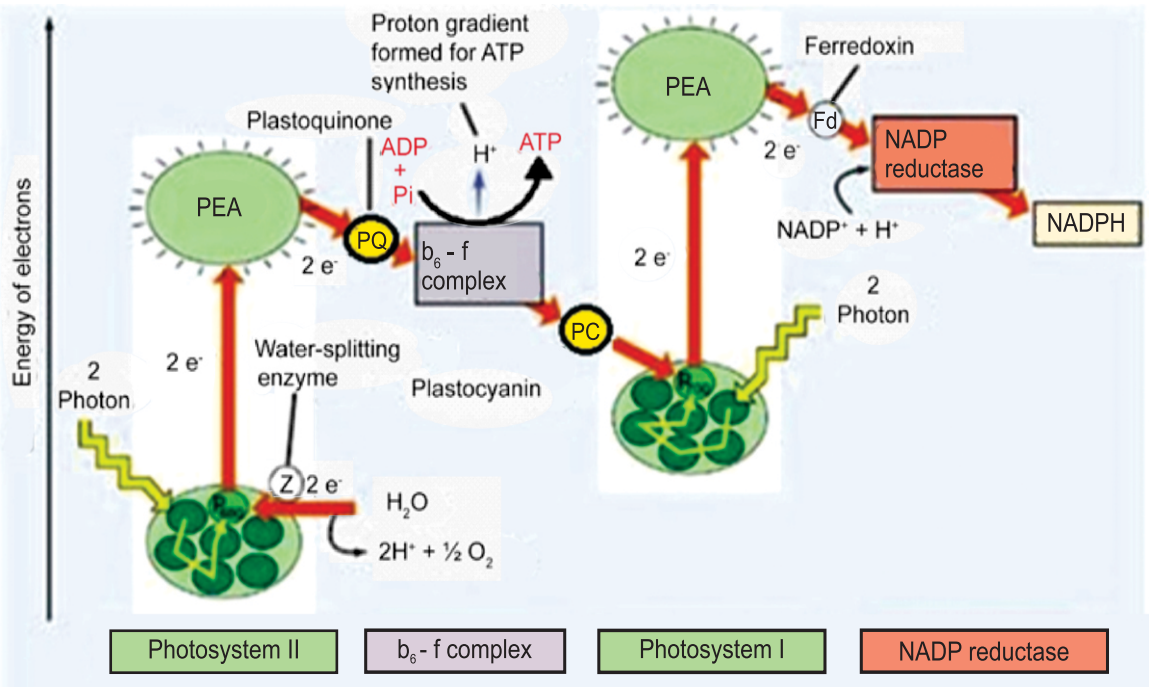


Fig: 4.8: Non-cyclic photophosphorylation (Z Scheme)

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 oxygen.

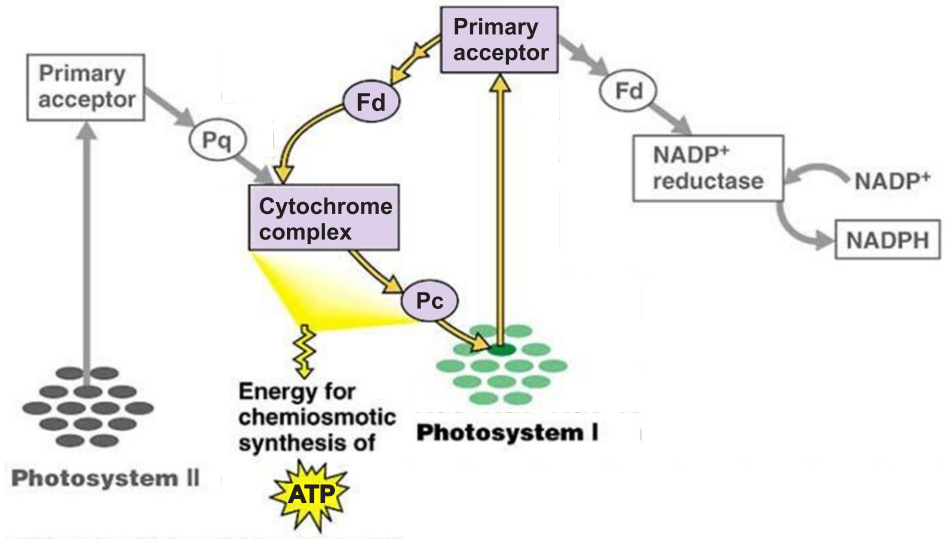


Fig: 4.9: Cyclic photophosphorylation

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.**

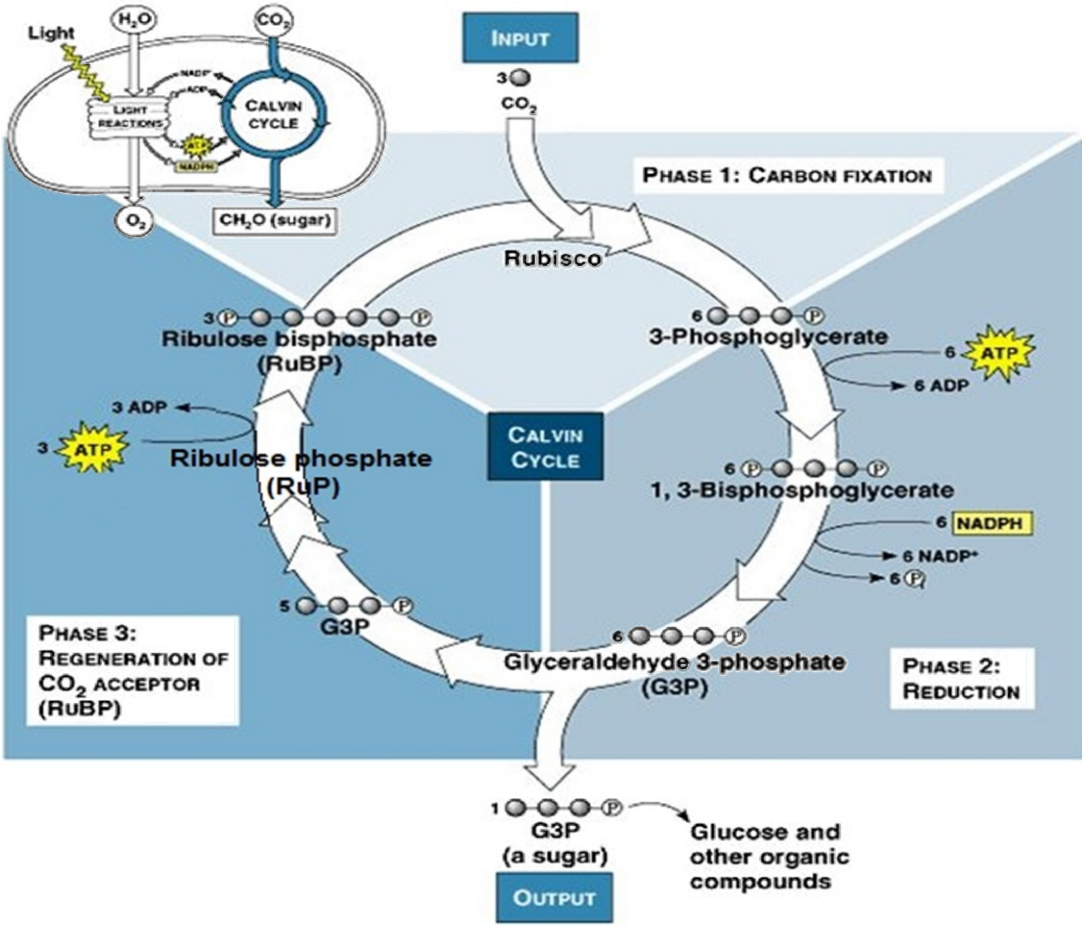
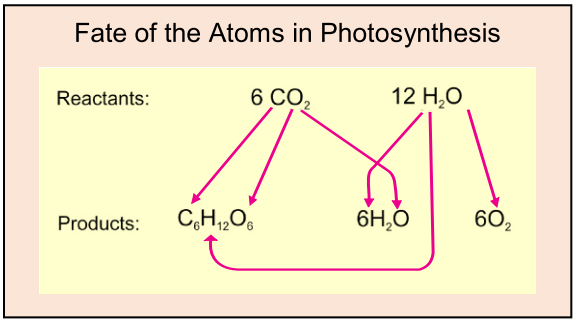


Fig 4.10: Calvin cycle

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.

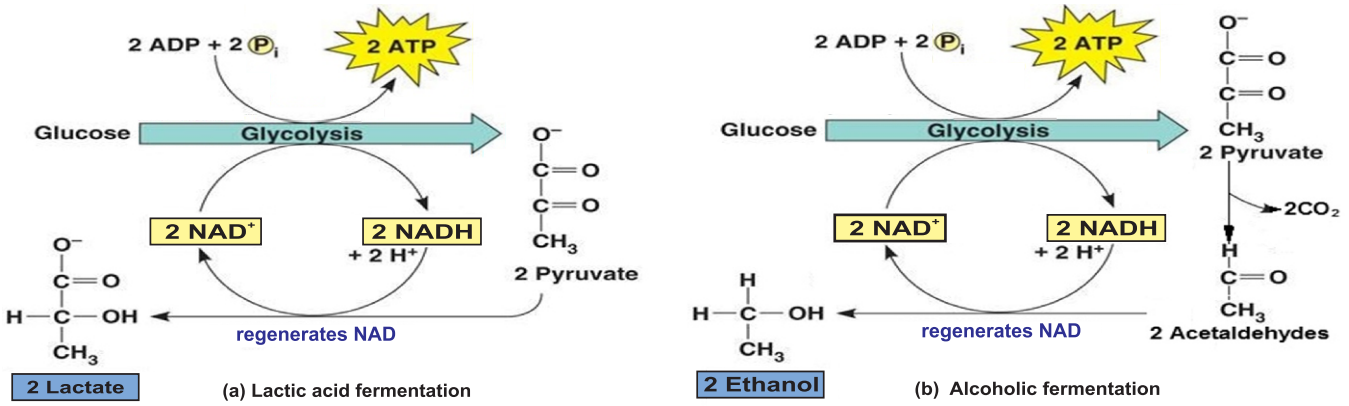


Fig: 4.11 Anaerobic respiration

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:

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

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

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.

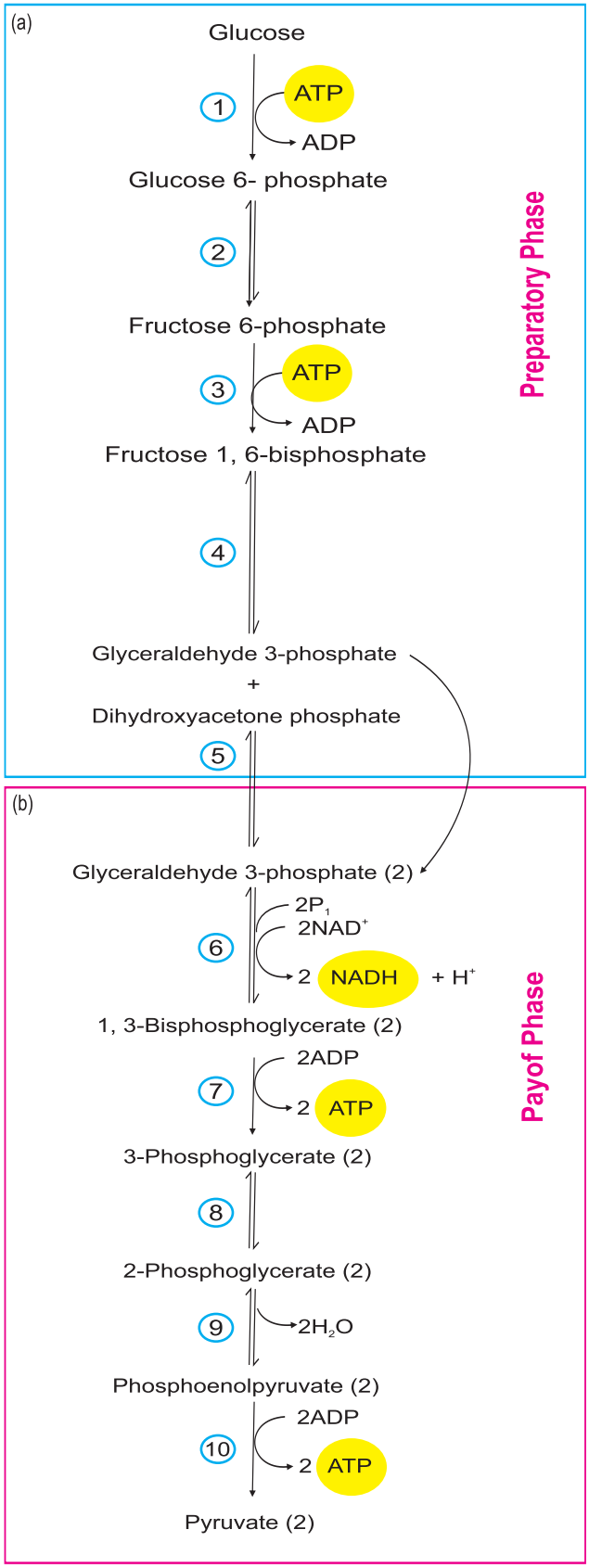


Fig: 4.13: Glycolysis

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.

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

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

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

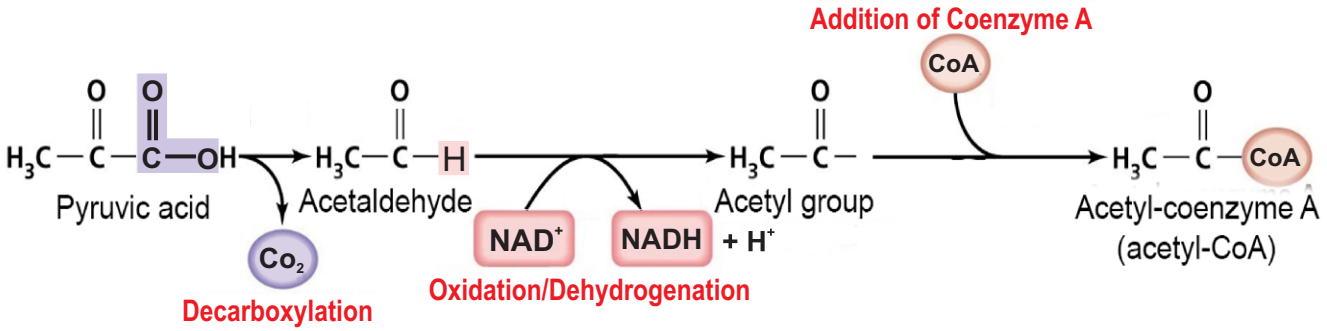


Fig: 4.14 Pathway of oxidation of pyruvate

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.**

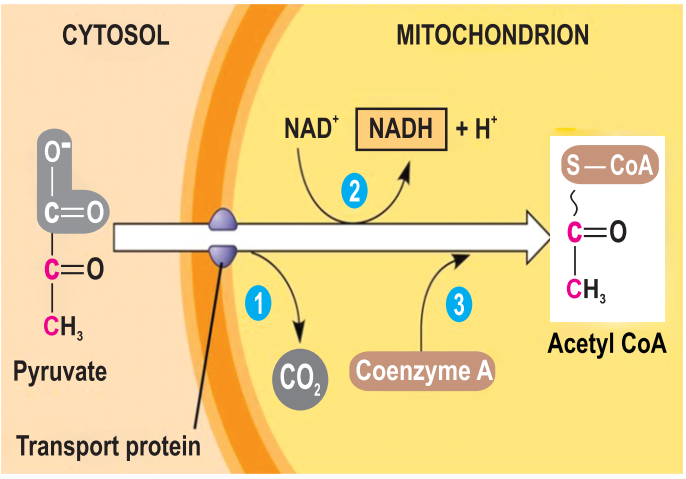


Fig: 4.15 Site of oxidation of pyruvate: Conversion of pyruvate to acetyl CoA, the junction between glycolysis and the citric acid cycle.

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.

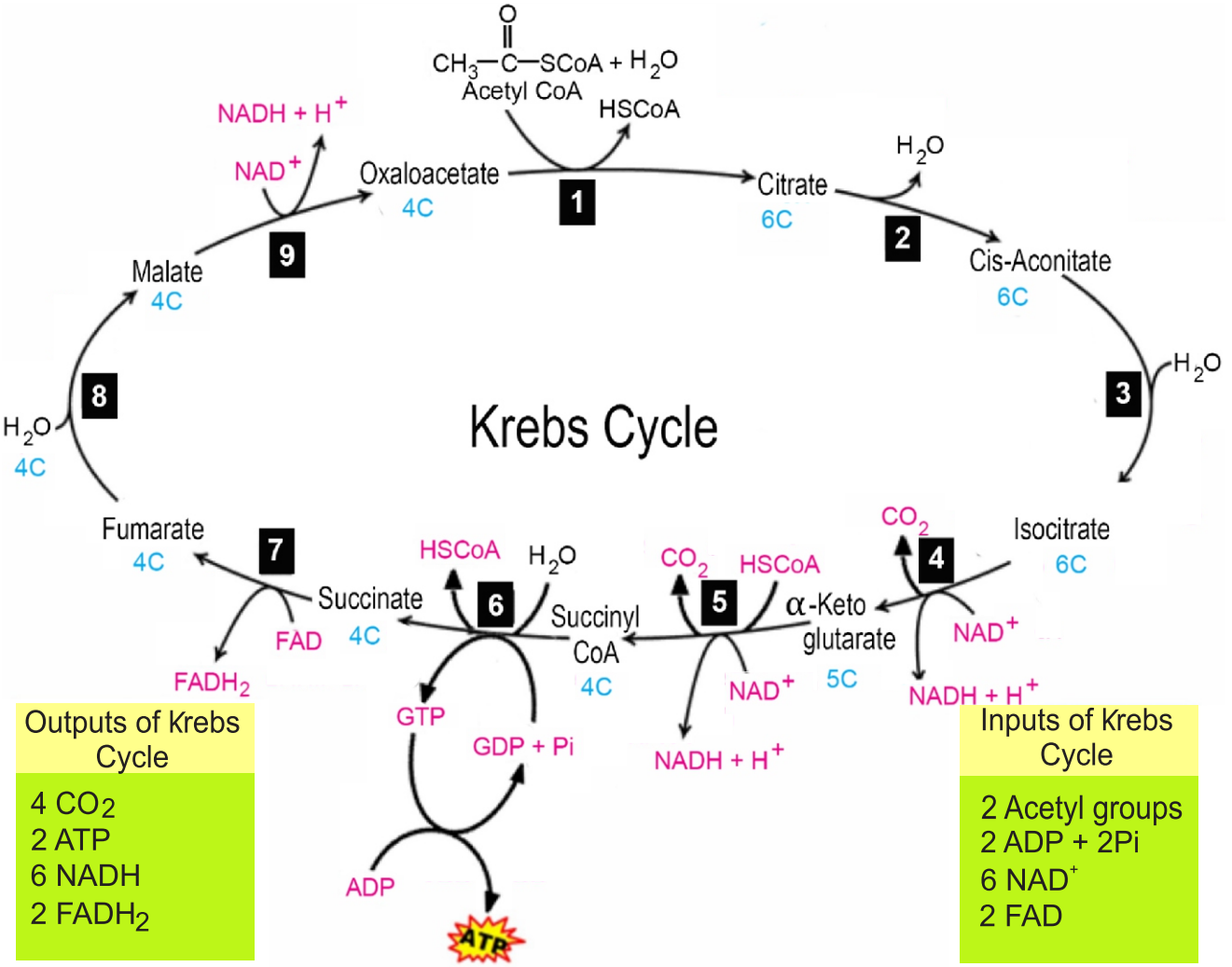


Fig: 4.16 Krebs cycle (Citric acid cycle or TCA cycle)

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).**

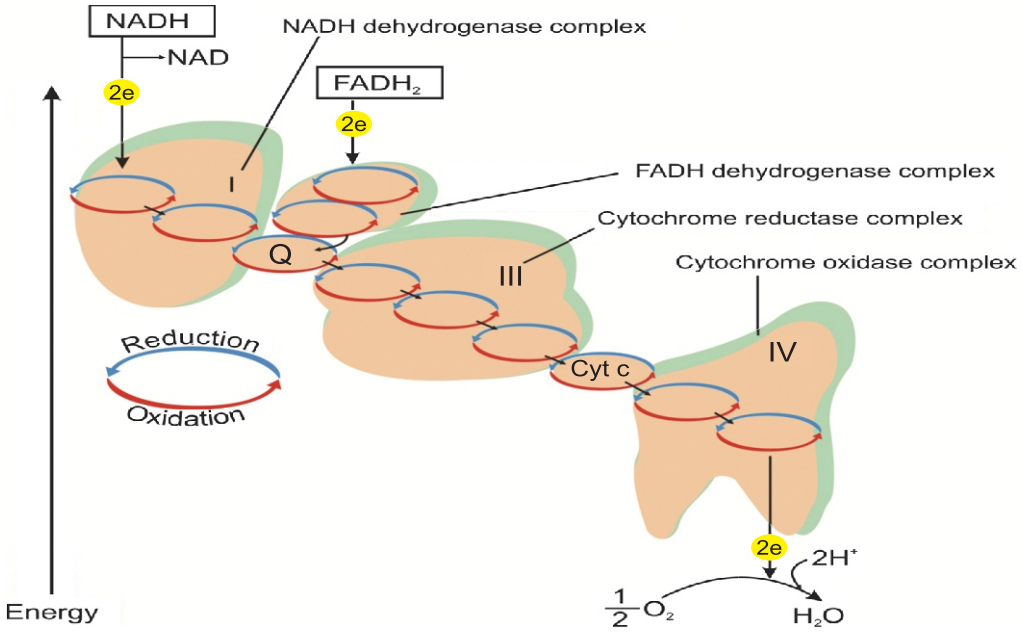


Fig: 4.17 Sequence of electron carriers in respiratory ETC

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.

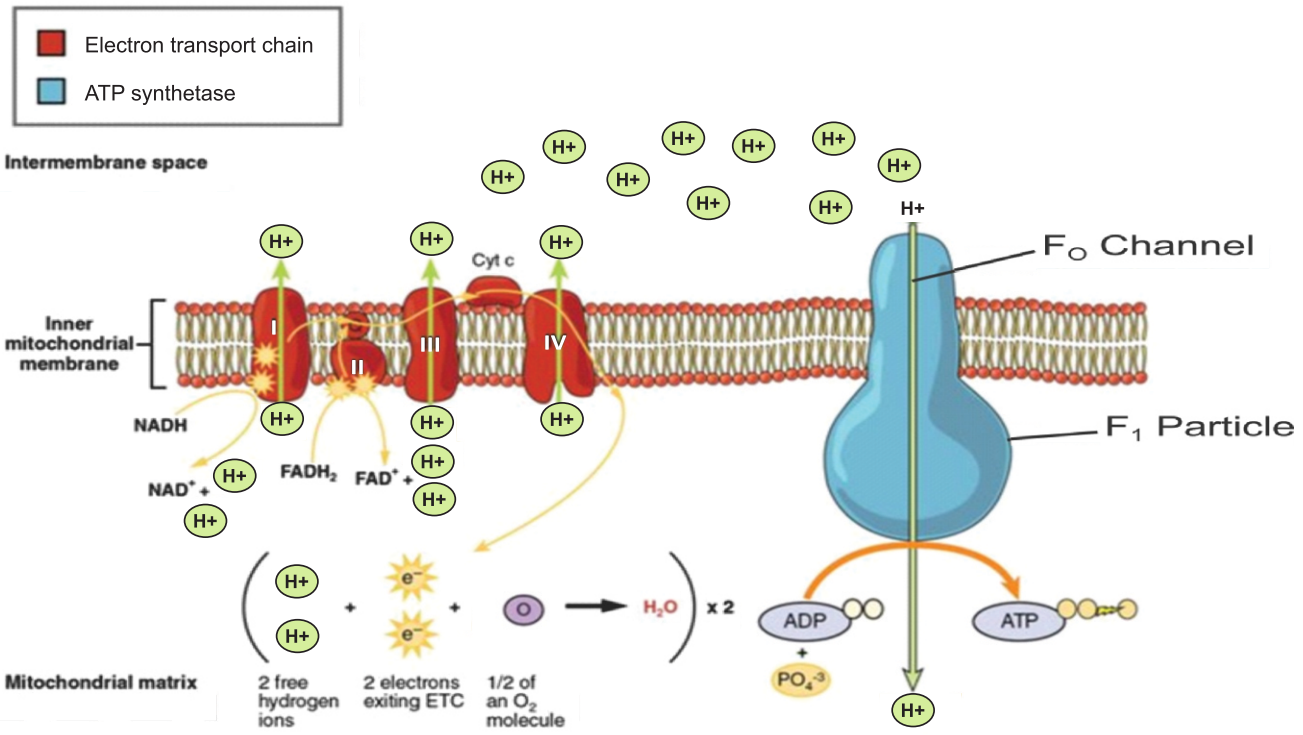


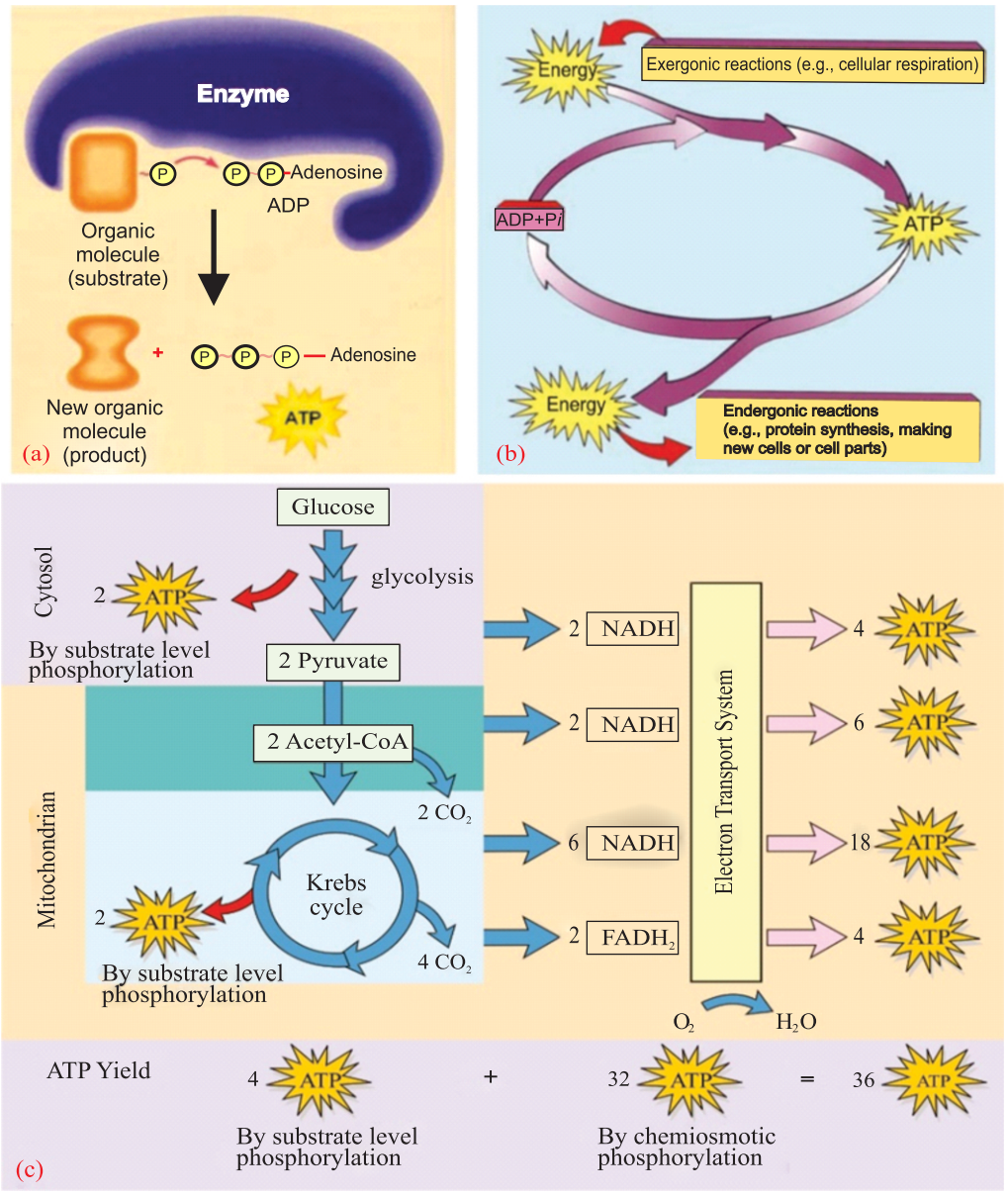
Fig: 4.18: Mechanism of chemiosmosis in respiratory electron transport chain

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 (7^{th} reaction) and when phosphoenol pyruvate is converted into pyruvate (10^{th} 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.

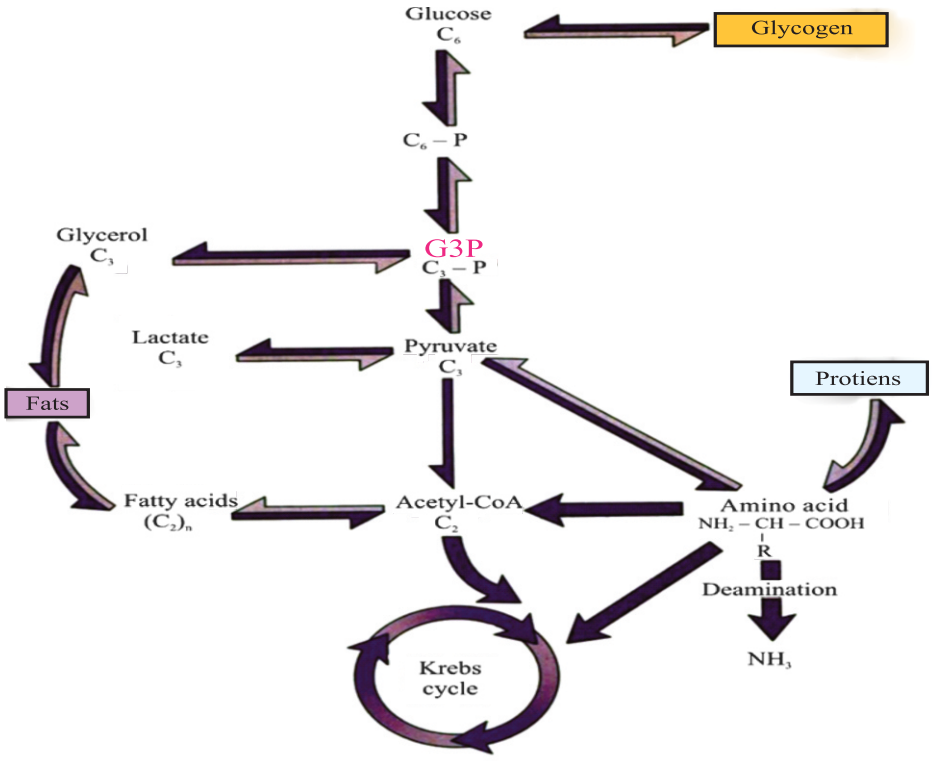


Fig: 4.20: The matabolic pool concept: When they are used as energy sources carbohydrates, fats and proteins enter degradative pathways at specific points. Degradation produces metabolites that can be used for synthesis of other compounds.

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.**

$$RuBP + O_2 \longrightarrow Phosphoglycolate + Phosphoglycerate \longrightarrow Glycolate$$

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.

$$Glycolate \longrightarrow Glycine$$

$$2\ Glycine \longrightarrow Serine + CO_2$$

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.

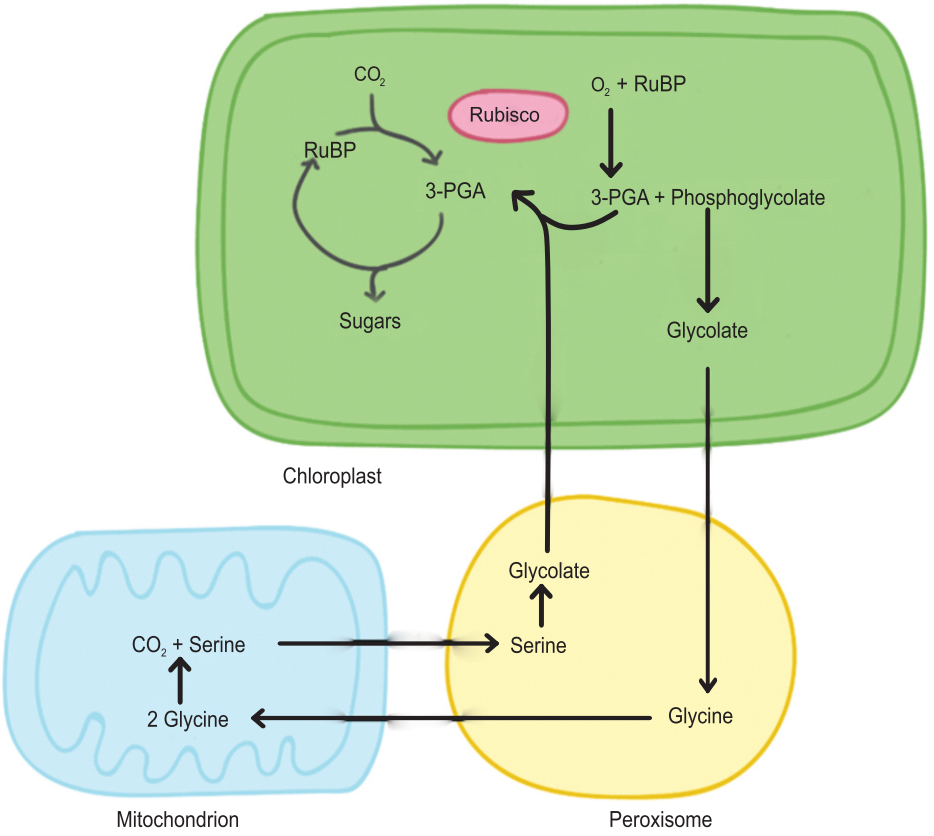


Fig: 4.21: Schematic representation of pathway involved in photorespiration in chloroplast, peroxisomes and mitochondria

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.

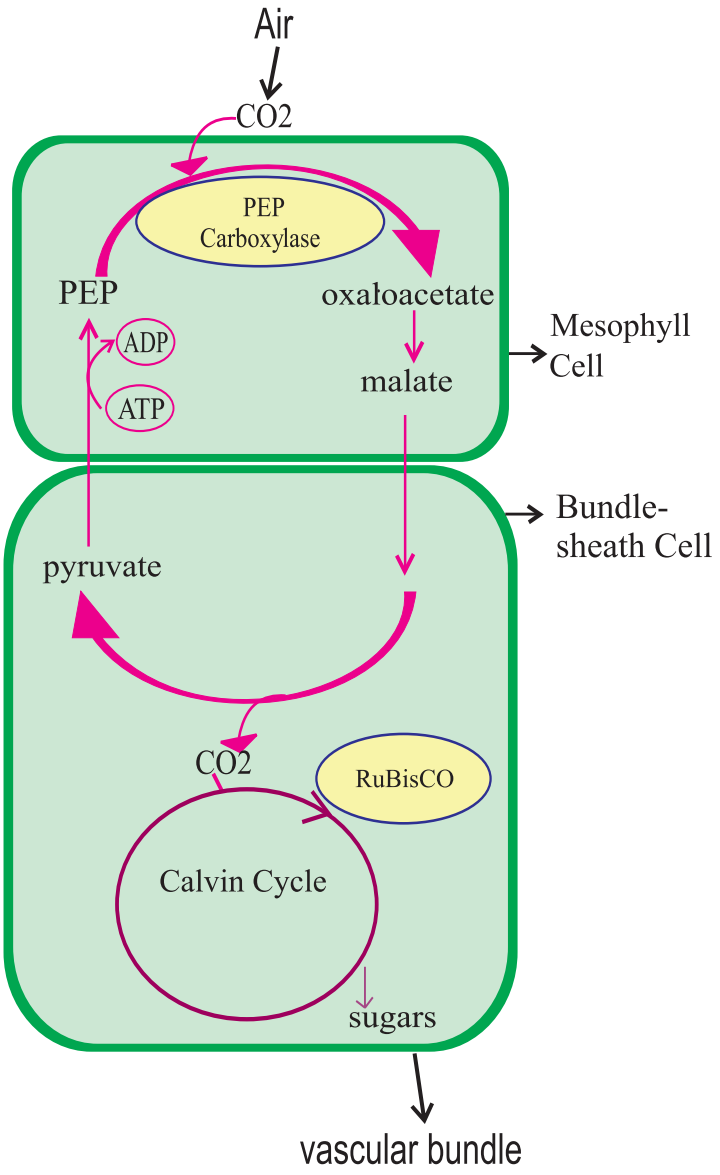


Fig. 4.22: C_4 photosynthesis

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

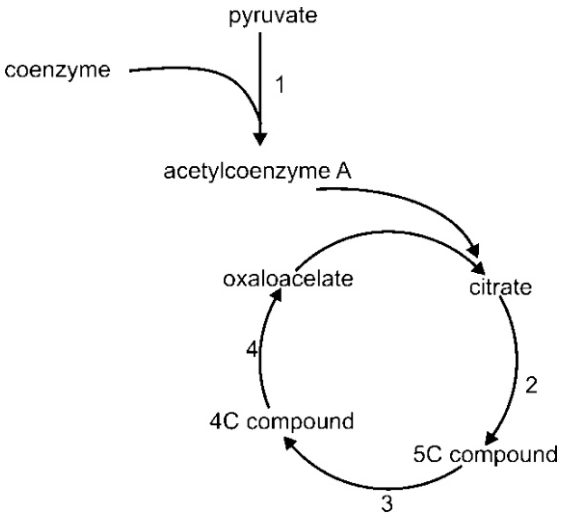
(A) oxidative (B) photolysis

(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.

About the Content Authors

Prof. Jawaid Mohsin Malick

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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Prof. Abid Ali Mughal

Prof. Abid Ali Mughal is serving as Assistant Professor and Head of Biology Department, Islamabad Model College for Boys, H-9, Islamabad. He started his teaching career as lecturer in Botany at F. G. Degree College for Men, Wah Cantt in 2003. Before that he had also served as Research Fellow in Plant physiology and Biotechnology divisions of Nuclear Institute of Agriculture, Tandojam Dist. Hyderabad, which is an agricultural research centre of Pakistan Atomic Energy Commission. He did his M.Sc. (Hons), Botany in 2002 from University of Sindh, Jamshoro and was awarded Gold Medal. He did M.Phil. Biotechnology from Quaid-i-Azam University in 2009. His field of specialization is Plant physiology and genetic engineering. He is Principal Author of Textbook of Biology for Grade-12 according to National Curriculum 2006, published by Khyber Pakhtun Khua Textbook Board Peshawar. He has also been Resource Person in the demonstration and laboratory sessions of Teacher's Training Workshop on "Laboratory Methods in Biology", held at Department of Animal Science, Quaid-e-Azam University Islamabad. He is now Ph.D Research Scholar in the Department of Environmental sciences, University of Arid Agriculture, Rawalpindi.

Approved by National Curriculum Council, Secretariat
Ministry of Federal Education & Professional Training
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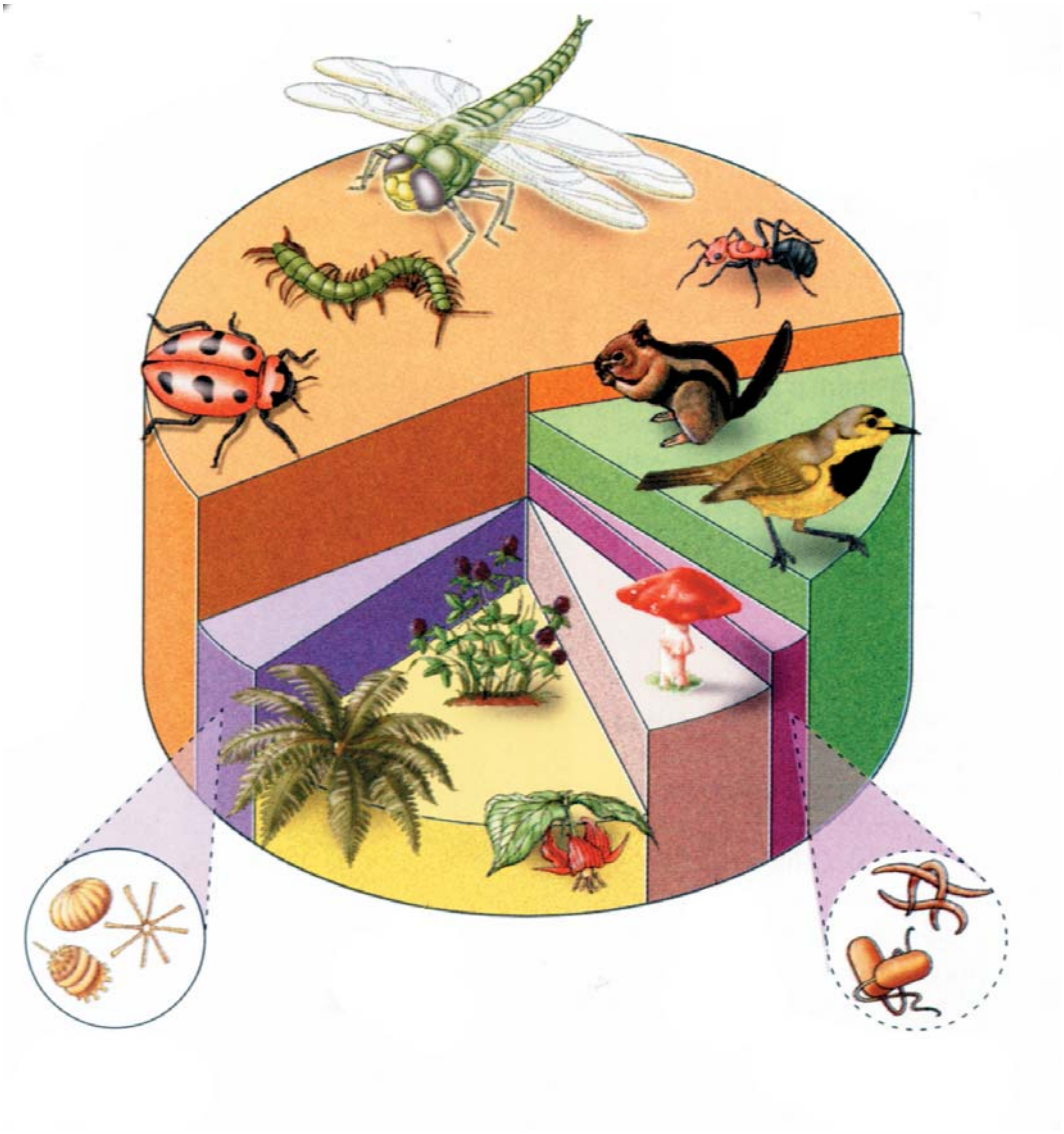
SECTION 2

Biodiversity



CHAPTER 5

ACELLULAR LIFE

Major Concepts:

Number of allotted teaching periods: 10

5.1 Viruses: Discovery and Structure (2 Periods)

5.2 Parasitic Nature of Virus (2 Periods)

5.3 Life cycle of Bacteriophage (1 Period)

5.4 Life cycle of Human Immunodeficiency Virus (HIV) (2 Periods)

5.5 Viral Diseases (2 Periods)

5.6 Prions and Viroids (1 Period)

You or any one of your family members must have suffered from common cold in which there is watering of eyes, dry throat, production of watery mucus from nose and it is difficult to breath through nose. You must have heard about influenza in which there is raised temperature, headache, dry cough etc. Everyday you read in the newspapers about bird flu, plio, 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.

5.1 VIRUSES-DISCOVERY AND STRUCTURE

Viruses are not cells, they are not capable of independent replication, can synthesize neither their own energy nor their own proteins and are too small to be seen in the light microscope.

Viruses-Living or Nonliving

Viruses are a link between living and nonliving worlds. 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. The DNA or RNA can undergo mutation. (3) They reproduce using the metabolic machinery of the host cell they infect. (4) 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 are nonliving infectious particles. They enter living organism and cause disease. They do not have a cellular structure, which is the basis of all life.

History of Virus

The word virus is derived from a Latin word venom meaning 'poison'. The study of virus is known as **virology**.

Tobacco Mosaic Disease was thought to be caused by bacteria. In 1892 **Iwanowsky** extracted the juice from the leaves of tobacco having tobacco mosaic disease. In order to remove bacteria the juice was passed through a very fine filter made of porcelain (a fine earthenware, white thin). 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 i.e. the viruses that can pass through a filter which has pores too small for bacteria to pass through are called **filterable viruses**.

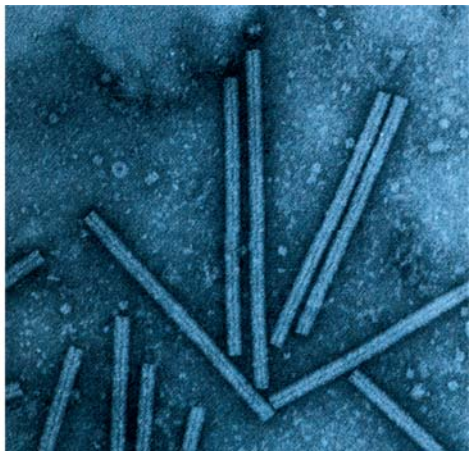


Fig: 5.1 (a) Tobacco Plant Infected with Virus (b) Ultra Structure of Tobacco Mosaic Virus

Classification of Virus

Virus classification is based mainly on phenotypic characteristics, including morphology, nucleic acid type, mode of replication, host organisms, and the type of disease they cause.

Baltimore Classification

David Baltimore, a Nobel Prize-winning biologist, devised the Baltimore classification system, which places viruses into one of seven groups. These groups are designated by **Roman numerals** and separate viruses based on their mode of replication, and genome type. Viruses can be placed in one of the seven following groups:

Group	Nature & Examples
I	Double-stranded DNA viruses: e.g HSV1 (oral herpes), HSV2 (genital herpes), VZV (Varicella zoster virus) (chickenpox), Poxviridae (smallpox)
II	Single-stranded DNA viruses: e.g. family Parvoviridae and bacteriophage.
III	Double-stranded RNA viruses: e.g. Rotavirus
IV	Positive-sense single-stranded RNA viruses: e.g picornaviruses, Hepatitis A virus, Hepatitis C virus and rubella virus.
V	Negative-sense single-stranded RNA viruses: e.g. influenza virus, measles, mumps and rabies.
VI	Reverse transcribing Diploid single-stranded RNA viruses: e.g. HIV
VII	Reverse transcribing Circular double-stranded DNA viruses: e.g. hepatitis B

Viruses are also classified on the bases of their hosts e.g. plant viruses, bacteriophage viruses and animal viruses. **Plant viruses** occur as parasites in plants e.g. tobacco mosaic viruses attack leaves on tobacco plant. This is an RNA virus with a helical capsid. **Bacteriophage** attack bacteria. It is a DNA virus with a polyhedral head and a helical tail. **Animal Viruses** occur as parasites in animals. Human immunodeficiency viruses attacks human being. It is an RNA virus.

Shape and Size of Virus

Viruses vary in shapes. The polio virus particles are little spheres that look like tiny golf balls. Tobacco mosaic virus is a rod shaped and helical virus, while some phage viruses look like tadpoles. So viruses have several shapes, such as spherical, needle like and cubical. Most forms are **icosahedral** with upto twenty sides. Viruses can be seen only under electron microscope. Viruses vary in size from 17nm to 1000nm.

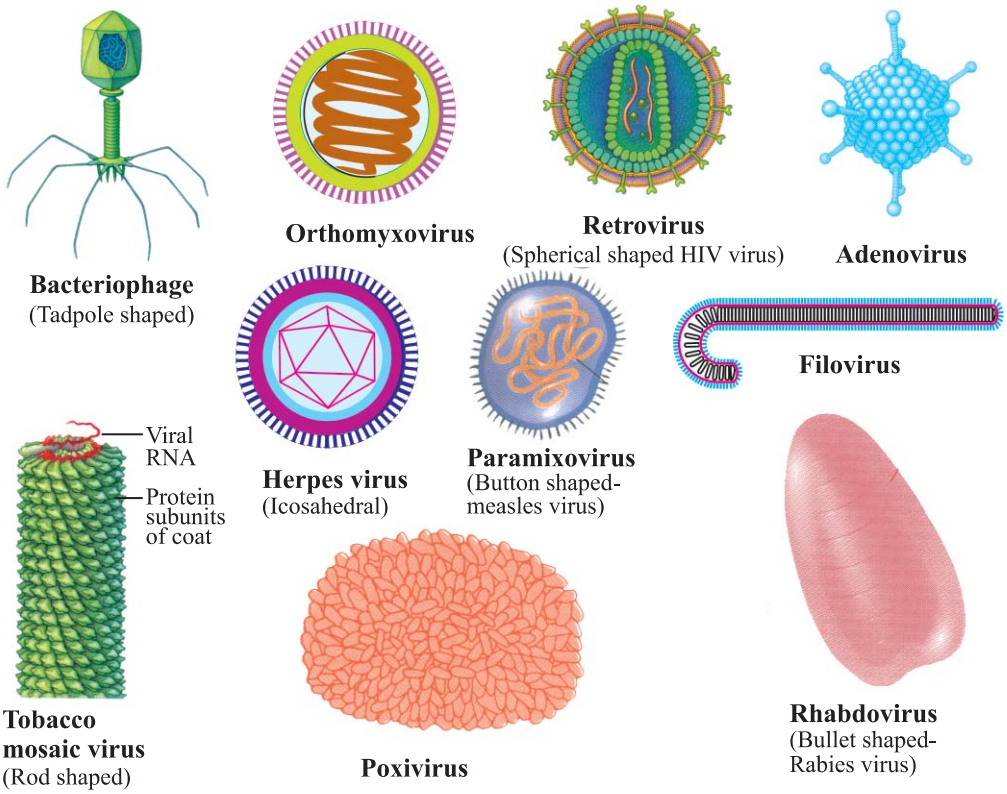
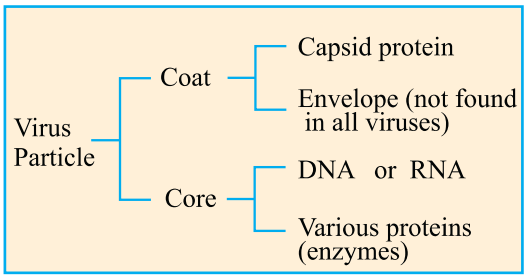


Fig: 5.2 Shapes and Types of viruses

Structure of Model Viruses

Viruses have a very simple structure. The **core** is the genetic matter, which is either DNA or RNA, which may be single stranded or double stranded. The **capsid** is the protective coat of protein surrounding the core. **Nucleocapsid** is the combined structure formed by the core and capsid. A few viruses have an additional lipoprotein layer around the capsid derived from the cell surface membrane of the host, called **envelope**. Capsids are often built up of identical repeating subunits called **capsomers**. There are two

forms of symmetry in virus capsid. When the capsomers are arranged in 20 triangles, it is called **iocosahedral**. When the capsomers are arranged in a hollow coil that appears rod shaped, it is called **helical**.



Now we will discuss the structure of bacteriophage, flu virus and HIV to explain the structure of model viruses.

Bacteriophage

The word phage means 'eater'. A bacteriophage or simply phage consists of nucleic acid, capsid, end plate, tail and tail pin. The interior **core** is the nucleic acid. The phage has DNA which is also known as its **genome**. The outer coat of protein surrounding the nucleic acid is called **capsid** or head. The head is hexagonal and made up of protein subunit the **capsomers**. The tail is hollow tubular and made up of proteins. It consists of six fibres. The protein sheath around the tail is contractile. The fibres are attached to end plate or **base plate**. It is the last part of the tail. The end plate has **tail pins**.

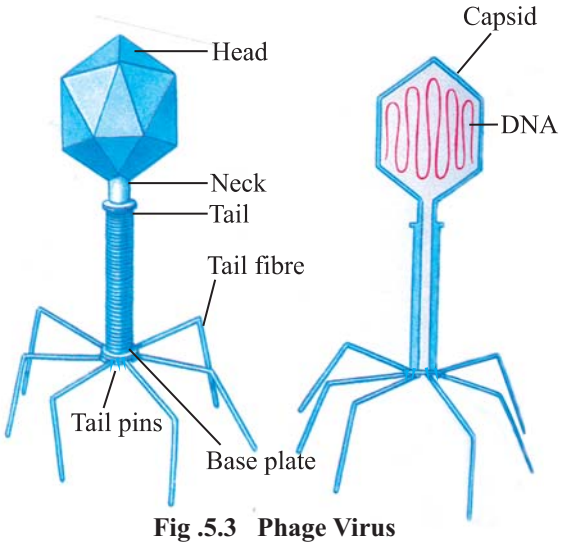


Fig .5.3 Phage Virus

Influenza or Flu Virus

Influenza virus exists in three forms called A, B, C. Influenza viruses are the only members of orthomyxovirus family. The term 'myxo' refers to the observation that these viruses interact with mucin

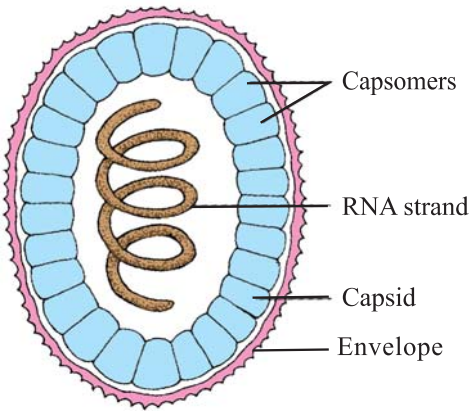


Fig: 5.4 Influenza virus (Orthomyxovirus)

(glycoproteins) and 'ortho' is added to distinguish them from the paramyxovirus. Influenza virus is composed of a segmented single-stranded **RNA genome**, a helical nucleoprotein and an outer lipoprotein envelope. The **virion** (the complete, mature and infectious, particle is known as virion) contains an RNA dependent RNA polymerase, which transcribes genome into mRNA. The genome is therefore not infectious. The envelope is covered with hemaglutinin and a neuraminidase, both are the type specific antigens.

Science Titbits

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.

Science, Technology and Society Connections

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

Human Immunodeficiency Virus

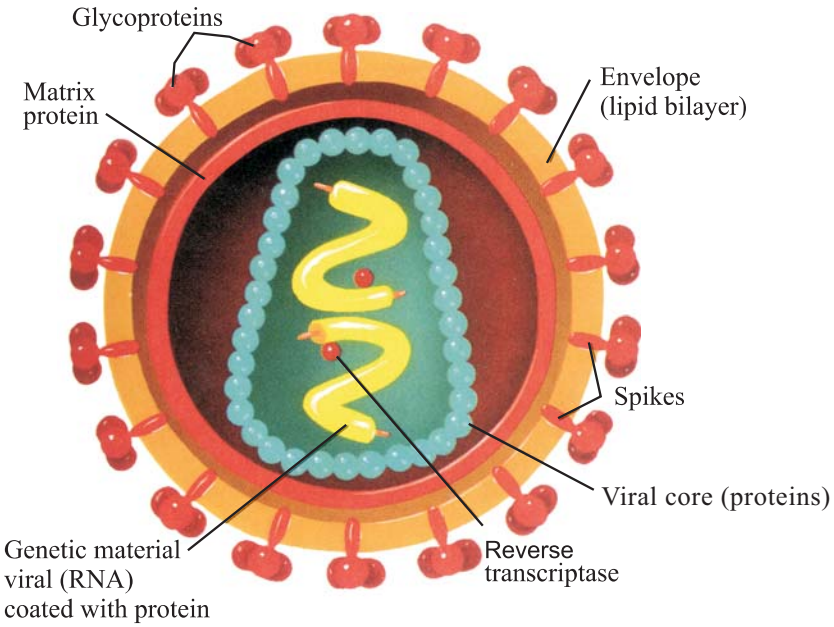


Fig: 5.5 Human Immunodeficiency Virus (HIV) (cross section)

Human Immunodeficiency Virus (HIV) is a retrovirus and spherical in shape. The **core protein** is somewhat cone shaped. It is surrounded by a **envelope** (lipid bilayer) derived from the host cell membrane. The virus core contains: (1) Two identical molecules of single stranded RNA and is said to be diploid. (2) Three viral enzymes-protease, reverse transcriptase and integrase. The viral core (nucleocapsid or capsid) is composed of protein. The viral core is surrounded by a matrix protein which lies underneath the virion envelope. The viral envelope has glycoprotein spikes.

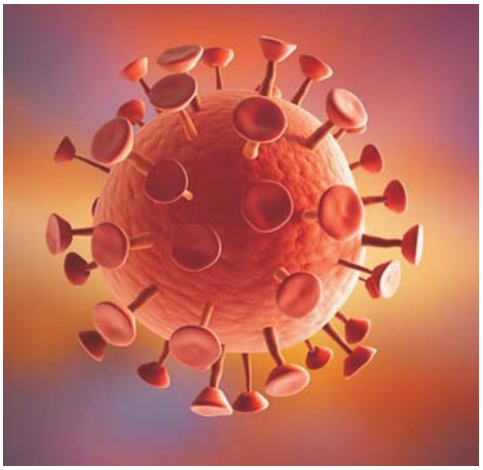


Fig: 5.6 Human Immunodeficiency Virus (HIV)

Skills: Interpreting and Recording

- Make a list of names of five plant and animal viruses that have DNA or RNA.
- Draw labelled diagrams of bacteriophage, flu virus and HIV.

Science, Technology and Society Connections

Justify how the invention of Electron Microscopy revolutionized the science of microscopic organisms.

5.2 PARASITIC NATURE OF VIRUS

Viruses are obligate parasites, which means they cannot multiply outside a living cell. Viruses infect all sorts of cells, from bacterial cells to human cells.

Specificity of Viruses on their Hosts: Viruses 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 blood cells, the poliovirus reproduces in spinal nerve cells, the hepatitis viruses infect only liver 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, herpes simplex virus type 1 attaches to the fibroblast growth factor receptor, rabies virus to the acetylcholine receptor and human immunodeficiency virus to the CD4 protein on helper T lymphocytes. What could cause this remarkable parasite-host cell correlation?

Science Titbits

To maintain animal viruses in the laboratory, they are sometimes injected into live chick embryos. Today, host cells are often maintained in tissue culture by simply placing cells in a glass or plastic container with appropriate medium.

It is now believed that viruses are derived from the cell they infect; the nucleic acid of viruses came from their host cell genomes. Therefore, viruses must have evolved after cells came into existence and new viruses are probably evolving even now.

How do Viruses complete their Life Cycles?

Viruses are Obligate Parasites. Reproduction of Viruses occurrs in the living cells of the host. Viruses cannot reproduce on their own. They must invade cell, take over the cell's internal machinery and instruct the machinery to build enzymes and new viral structural proteins. Then they copy the viral genetic material enough times so that a copy be placed in each newly constructed virus. Finally they leave the host cell. The invading virus also blocks the synthesis of any host DNA, RNA or protein. This features forces the host cell to construct only viral proteins and copies of the viral genetic material. For reproduction viruses must complete the following five steps: (1) Adsorption and penetration, (2) Uncoating of virus, (3) Transcription, translation and replication, (4) Viral assembly, (5) Release of virion.

(1) Adsorption and Penetration: Viruses may be engulfed by their host cell (endocytosis). Some viruses have surface protein that bind to receptors on the host cell's membrane and stimulate endocytosis. Other viruses are coated with an envelope that can fuse with the host cell membrane.

(2) Uncoating. The nucleic acid is released from the capsid into the nucleus or cytoplasm.

(3) Transcription, Translation, Replication: For RNA viruses these usually take place in cytoplasm and for DNA viruses these usually take place in the nucleus.

(4) Viral Assembly: The viral genetic material and enzymes are surrounded by their protein coat.

(5) Release of Virions: Viruses emerge from the cell by "budding" from the cell membrane or by bursting the cell.

How a Virus Survives Inside a Host Cell, Protected from the Immune System?

Viruses circumvent (to surround) the host immune response by: (1) Blocking complement activation e.g. vaccinia (vacca virus) or using complement receptor to enter B lymphocytes e.g. Espein Barr Virus (EBV). (2) Inhibiting interferon induced antiviral response e.g. adenovirus, EBV and HIV (3) Blocking production of cytokines or response to cytokines e.g. cowpox, adenovirus. (4) Suppressing major histocompatibility complex e.g. adenovirus (5) Reducing B-cell activation e.g. EBV. (6) Changing their own genetic constitution so rapidly that vaccines/antibodies of host against them become ineffective.

How Virus Employs to Pass Over Unfavourable Conditions When it Does Not Have a Host to Complete its Life Cycle?

Virus does not have acellular, cellular or spore forms as parasites. When there is no host or when there are unfavourable conditions, outside the cells viruses may form crystals e.g. Tobacco Mosaic Virus (TMV). Some remain in saliva e.g. EBV (cause mononucleosi lesion on the tongue), in respiratory droplets e.g. Influenza A virus, measles virus, Varicella zoster virus (chicken-pox), in respiratory aerosol e.g. small-pox virus, in the faeces e.g. adenoviruses.

Skills: Interpreting and Recording

- Record the symptoms of flu in any individual.
- Make a list of names of at least five viruses in plants and animals that are specific for specific host.

Swine flu is an infection by any one of several types of swine flu virus. A virus subtype H1N1, H1N2, and H3N2 are the most common strains world wide. The H1N1 viral strain implicated in the 2009 flu pandemic among humans often called swine flu. Its vaccine is available.

5.3 LIFE CYCLE OF A BACTERIOPHAGE

The virus which lives in a bacterium as parasite is called **bacteriophage** or **phage**. Bacteriophages show two types of relationships with the host: Master-slave relationship i.e. Lytic cycle and Host-guest relationship i.e. Lysogenic cycle.

Lytic Cycle

It is a **master slave relationship.** The process of lytic cycle of a phage virus consists of the following stages:

The head determines what kind of cell the virus particle will be able to attach and assists the insertion of the core into the host cell. One of the bacteriophage makes contact with the cell surface of *Escherichia coli* (*E.coli*) bacteria.

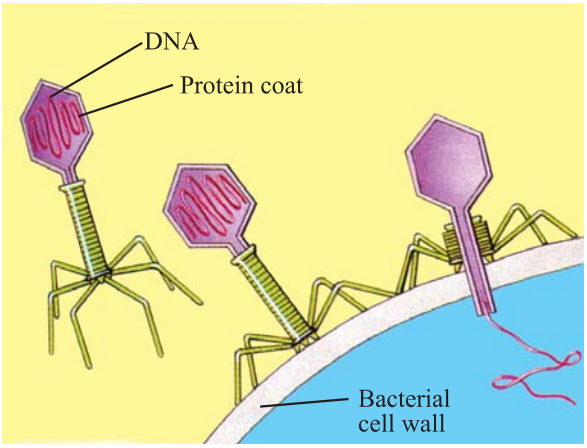


Fig. 5.7 Insertion of Core into the Bacterium

Proteins in its tail fibres 'recognize' proteins on the bacterial cell surface. The protein sheath contracts and the contents of the bacteriophage head are injected into the bacterium.

Once within the cell, some of the **bacteriophage genes** take up the control and use host's RNA polymerase (enzyme), tRNA, ribosomes etc. to produce enzymes that will make many copies of the phage DNA.

As fresh copies of **phage DNA** accumulate, the proteins of the capsid are being formed, as per other genes of the invader phage. The proteins then collect around the nucleic acid forming the six sided head and tail. New viruses appear within 12 to 15 minutes after infection.

The rest of the genes of the invader phage form the enzyme called **lysozyme**. The lysozyme attacks the bacterial cell wall from the inner side. Eventually the cell ruptures about 30 minutes after the insertion of the phage DNA, and releases new viruses. The cycle is now complete and ready to be repeated. This cycle of the phage is called lytic cycle.

Lysogenic Cycle

The lysogenic cycle is a **host guest relationship**, which is a peaceful relationship. Certain DNA containing bacterial viruses referred to as temperate bacteriophage can infect a cell without producing progeny viruses or damaging the host. This association is called lysogeny i.e. host guest relationship. It occurs by the following mechanism:

After penetration, the viral DNA directs production of proteins that specially bind to the virus DNA and turn off replication of viral DNA.

The viral DNA then integrates into and becomes a physical part of the host chromosome. The integrated virus DNA is now called a phage, or prophage.

The viral DNA replicates whenever the bacterial chromosome doubles, so all the progeny cells inherit one copy of the prophage in the chromosome and thus carry the potential for producing lysogenic or temperate bacteriophage.

This cycle of phage is called the **lysogenic cycle**. Sometimes the phage becomes reactivated and reproduces like lytic phase.

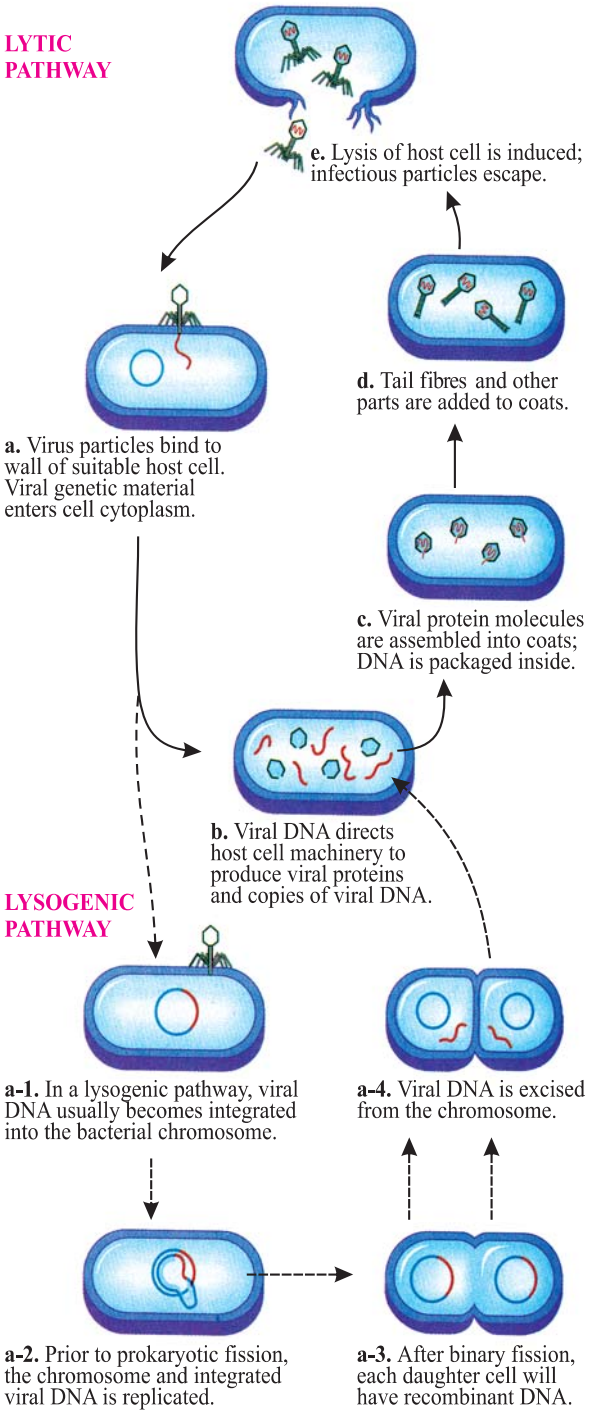


Fig: 5.8 Life Cycle of a Bacteriophage

Usage of Bacteriophage in Genetic Engineering

Genetic engineering can produce cells that contain recombinant DNA and are capable of producing new and different protein. **A. Harshey** and **M. Chase** used bacteriophage to prove DNA as the hereditary material.

Bacteriophage known as lambda can be used as vectors for carrying foreign DNA. After lambda attacks a cell the DNA is released from the virus and enters bacteria. Here it may direct the reproduction of many more viruses. Each virus in the bacteriophage clone contains a copy of the foreign gene. A clone is a large number of cloned bacteriophages that are identical to the original virus. A genome is the full set of genes of an individual. A genomic library is a collection of bacteria or bacteriophage clones; each clone contains a particular segment of the DNA from a foreign cell.

When you make a genomic library an organism's DNA is simply sliced up into pieces and the pieces are put into vectors (plasmids or viruses), that are taken up by the host bacteria. The entire collection of bacteriophage clones or bacteria that results therefore contains all the genes of the organism.

Phage library:Viral DNA is removed from a bacteriophage such as lambda and is used to make recombinant DNA. The virus containing the recombinant DNA infects a host bacterium. Cloning is achieved when the virus reproduces and then leaves the host cell.

Science Titbits

Virus studies helped to establish molecular genetics. Now molecular genetics helps us to understand viruses

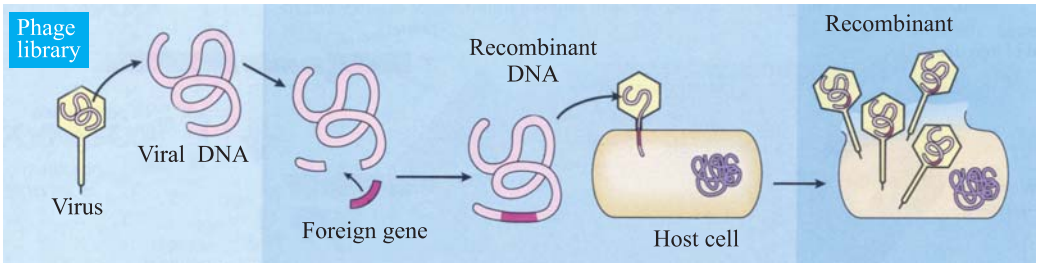


Fig: 5.9 Way of Preparation of a Genomic Library

Skills: Interpreting and Recording

- Make a list of the sequence involved in the lytic life cycle of a bacteriophage.

5.4 LIFE CYCLE OF HIV

HIV is a retrovirus. It causes 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. In 1986 the virus was named HIV. Luc Montagnier director of the World Foundation for AIDS research and prevention and Francoise Barre-Sinoussi of the Pasteur Institute were awarded Nobel Prize in 2008 for discovering the virus.

Life Cycle: The primary hosts of HIV are certain immune cells. These are macrophages and lymphocytes. HIV encounters the white blood cells collectively called T4 cells. How does HIV recognize T4 cells? Or what is the reason of specification of HIV on its host cells? The initial step in the penetration or entry of HIV into the cell is the binding of the virion (glycoprotein) 120 envelope protein to the CD4 protein (a receptor) on the surface of T4 cells. The virion gp 120 protein then interacts with a second protein on the cell surface one of the **chemokine receptors**.

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 double stranded viral RNA in the cytoplasm along with virus enzymes. The enzyme called **reverse transcriptase** synthesizes a double strand of DNA complementary (cDNA) to virus RNA. The cDNA then **integrates** into the host cell DNA. The viral DNA can integrate at different sites in the host cell DNA and multiple copies of viral DNA can integrate. Integration is mediated by a virus encoded endonuclease (integrase).

The integrated DNA is now called **provirus**. Viral mRNA is transcribed from the proviral DNA by the host cell RNA polymerase and translated into several **large proteins**, which are then cleaved by the virus-encoded **protease** to form the virion structural proteins. The immature virion forms in the cytoplasm and cleavage by the viral protease occurs as immature virion buds from the cell membrane. It is this cleavage process that results in mature, infectious virion.

Immunity is primarily the result of the action of the B lymphocytes and T lymphocytes (white blood cells). T lymphocytes are also known as T cells. There are different types of T cells e.g. helper T cells, which regulate immunity by enhancing the response of other immune cells. The virus attacks helper T cells and certain other cells and causes deficiency of the human immune system. The patient becomes increasingly susceptible to other diseases. HIV preferentially infects and kills helpers

(CD4) T lymphocytes and the virus does not cause any disease itself. As the virus affects the human immune system, so the virus has been named Human Immunodeficiency Virus (HIV).

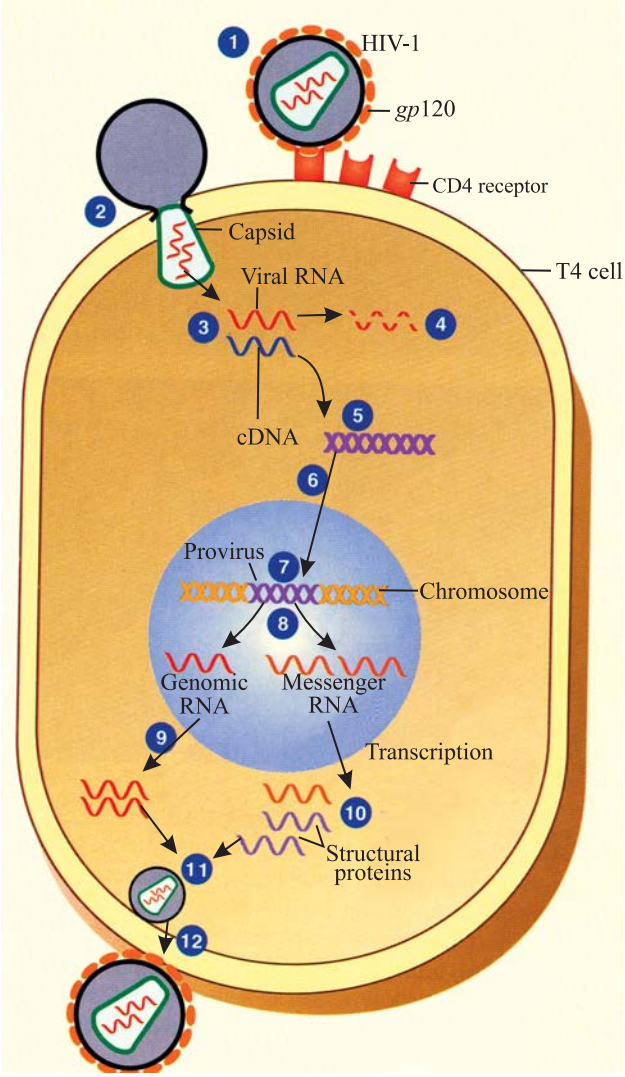


Fig: 5.10 Life Cycle of HIV (Retrovirus) 1. Attachment: Spike combines with receptor. **2. Penetration:** Virus enters cell and uncoating occurs. **3. Reverse transcription:** Produces cDNA strand. **4. Break down:** Viral DNA breaks down. **5. Replication:** Produces double-stranded cDNA. **6. Integration:** Viral DNA passes on when cell reproduce. **7. Provirus:** The integrated DNA is known as provirus. **8. Transcription:** Produces many strands of mRNA. **9. Biosynthesis:** Genomic RNA is formed. **10. Formation of protein:** Structural proteins are formed. **11. Maturation:** Assembly of viral components. **12. Release:** Budding gives virus an envelope.

Symptoms of AIDS

An HIV infection can be divided into 3 stages: Asymptonic Carrier, AIDS Related Complex (ARC), Full Blown AIDS.

Asymptonic Carrier: Symptoms that may include are fever, chills, aches, swollen lymph glands and an ichy 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.

AIDS Related Complex (ARC): The most common symptoms of ARC 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, inability to think clearly, loss of judgment and depression.

Full Blown AIDS: In this final stage, there is severe weight loss and weakness due to persistent diarrhoea and usually one of several opportunistic infections. These are called opportunistic infections because the body can usually prevent them, only a severely weakened immune system gives the opportunity to get started. For example Pneumocystis carinii pneumonia, Kaposi sarcoma (a form of cancer) etc are opportunistic infection.

Opportunistic Diseases that may Attack an AIDS Victim

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. Getting this opportunity of less or no immune system i.e. weak defence system a person suffering from AIDS is attacked by diseases called opportunistic diseases. e.g., Kaposi's sarcoma (cancer or lesion on skin) is the most common opportunistic malignancies associated with HIV and are considered AIDS defining illness.

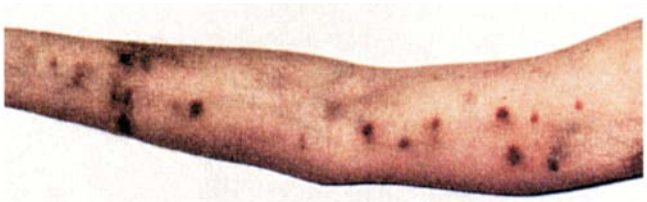


Fig. 5.11 This photograph shows the multiple lesions of the skin cancer, Kaposi's sarcoma, on the arm of a patient with AIDS.

Critical Thinking

How do retroviruses differ from other animal viruses?

Treatments of AIDS

The aims of HIV treatment is to reduce the viral load to an undetectable level as long as possible and to reduce transmission by using antiviral drugs.

Treatment: The decision to start therapy is a major one. It is dependent upon the symptom status of the patient, the CD4 count, the **viral load** (it is the quantity of virus at which it is detected in an organism) and wishes of the patient. Starting therapy early will allow the potential development of drug resistance and thereby reduce drug options for the future. Currently, there is clear move to delay therapy until there are clinical or immunological indications to commence and not just on the basis of high viral load. Nevertheless, the risk of HIV related opportunistic infection increases and treatment is less effective. The higher the viral load the faster the CD4 count falls. So a potent combination is always used, i.e. they are often on more than 10 different medications. AIDS patients are now surviving for prolonged period.

Critical Thinking

Why antibiotics do not work against viruses?

Control Measures against the Transmission of HIV

It can be controlled by preventing transfer of body fluid (blood, serum, semen etc), from patient to unaffected person. The following behaviour 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 any one. Special care to be taken at barber's shop or hair cutting saloons, beauty saloons. (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,

Skills: Interpreting and Recording

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

GLOBAL SUMMARY, UNAIDS 2008 STATISTICS

Number of people living with HIV in December 2007

Adults: 30.8 million, Women: 15.5 million, Children <15: 2.5 million.

AIDS Death in 2007: Adults: 1.7 million, Children <15: 330 000

Courtesy: *NACP, Pakistan & The News International, Islamabad, 01-12-09 (World AIDS Day).*

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.

AIDS in Pakistan

The first case of AIDS in a Pakistani citizen was reported in 1987 in Lahore. In 1993, the first recognized transmission of HIV infection through breastfeeding in Pakistan was reported in the city of Rawalpindi. Currently classified by WHO/UNAIDS high-risk country for the spread of HIV infection, Pakistan has recently witnessed changes in the epidemiological trends of the disease owing particularly to rapid rise in infection among injecting drug users. According to UNAIDS estimates, in 2009 there are 6000 registered cases and 97400 to 1,25,000 of estimated cases, or 0.1 percent of the adult population in Pakistan, are infected with HIV although cases reported to the National AIDS Control Programme are less. Data analysis indicates that most infections occur between ages of 20-44 years, with men outnumbering females by a ratio 5 : 1.

Skills: Interpreting and Recording

- **List the factors responsible for the spread of AIDS.**

Factors for Vulnerability to AIDS

a) High risk behaviour among Injecting Drug Users (IDUs)

b) Unsafe practices among sex workers and men who have sex with men (MSM).

d) Inadequate blood transfusion screening and high level of professional donors.

e) HIV infected mother can pass to the fetus via the placenta or to an infant via the mother's milk.

f) By use of contaminated needles of syringes, dental surgical instruments. Instruments used, and sharing of used towels at barber's saloons or beauty saloons.

Science, Technology and Society Connections

Correlate the social and cultural values of a country with prevalence of AIDS.

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.

Hepatitis

There are several types of hepatitis A,B,C,D,E, and G hepatitis (L. *itis* inflammation) is an inflammation of liver.

Hepatitis "A"

Cause: Hepatitis A virus (HAV) causes hepatitis A. It is a typical enterovirus. It has a single stranded, RNA genome and a nonenveloped icosahedral nucleocapsid.

Transmission: HAV is transmitted by the fecal-oral route.

Symptoms: Fever, anorexia, nausea, vomiting and jaundice are typical. Dark urine, pale feces are seen.

Treatment and Prevention: No antiviral therapy is available. Active immunization with a vaccine containing inactivated HAV is available. Vitamin "B" complex if anorexia is marked and medicine for jaundice is given. Observation of proper hygiene e.g. sewage disposal and hand washing after bowel movements is of prime importance.

Hepatitis "B"

Cause: It is caused by HBV. It has a partially stranded double stranded DNA, icosahedral nucleocapsid core and an envelope.

Symptoms: It is similar to hepatitis A, but more severe which can lead to cirrhosis and death.

Transmission: The three main modes of transmission are via blood, sexual contact and perinatally from mother to newborn.

Treatment and Prevention: Alpha interferon and some nucleoside analogues are effective against HBV. Vaccine is highly effective in preventing hepatitis "B". All blood transfusion should be screened.

Science Titbits

HBV can also be transmitted through surface contact with dried blood or other potentially infectious materials while HIV dries up on dry surface so it is not transmitted.

Hepatitis "C"

Cause: It is caused by HCV. It is an enveloped virion, having single stranded positive polarity RNA. (see glossary)

Transmission: It is primarily transmitted via blood.

Symptoms: Fever, anorexia, nausea, vomiting and jaundice are common. Dark urine, pale faces are seen. Cirrhosis of liver may occur.

Treatment and Prevention: A combination of alpha interferon and ribavirin is the treatment choice for chronic hepatitis C. No vaccine is available. Blood transfusion should be screened as preventive measure.

Hepatitis "D"

Cause: It is caused by D virus or delta virus. It is a defective virus i.e. it can replicate only in cells infected with HBV.

Transmission: HDV is transmitted by the same means as is HBV.

Symptoms: As in hepatitis B but more severe.

Treatment and Prevention: Treatment, immunization and prevention same as HBV.

Hepatitis "E"

HEV is a nonenveloped, single stranded RNA virus. It is transmitted through water. Clinically it resembles hepatitis "A". There is no antiviral treatment and vaccine.

Hepatitis "G"

In 1996 hepatitis G virus was isolated. The role of HGV in the causation of liver disease has yet to be established.

Herpes

Cause: It is caused by herpes simplex virus type-1 and type-2. They have double stranded DNA and icosahedral core surrounded by lipoprotein coat.

Transmission: HSV-1, is transmitted primarily in saliva, whereas HSV-2 is transmitted by sexual contact.

Symptoms: HSV causes several forms of primary and recurrent diseases, e.g. Gingivostomatitis, Herpes labialis, Keratoconjunctivitis, Encephalitis. HSV-2 causes several diseases, e.g. Genital Herpes, Neonatal Herpes.

Treatment: Antiviral drugs are used to treat Herpes.

Prevention: Avoid contact with vesicular lesion or ulcer.

S.T.S Connections

Suggest ways to rid human civilization of viruses.

Poliomyelitis

Cause: It is caused by polio virus which is an enterovirus. The virus is small, nonenveloped, have icosahedral nucleocapsid and a single stranded RNA. The genome has a positive polarity i.e. on entering the cell, it functions as the viral RNA.

Transmission: Polio virus is transmitted by the fecel oral route. It replicates in the oropharynx and intestinal tract and spread to blood and central nervous system.

Symptoms: The virus replicates in the motor neuron located in the anterior horn of the spinal cord. Death of these cells results in paralysis of the muscles innervated by those neurons. Non-paralytic poliomyelitis manifests as aseptic meningitis with fever, headache and stiff neck. In paralytic poliomyelitis flaccid paralysis is predominant finding. Painful muscle spasm may also occur. 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, inactivated vaccine) and the live, attenuated vaccine (sabin vaccine, oral vaccine).

Cotton Leaf Curl Disease

Cotton leaf curl is a serious disease of cotton and several other malvaceous plant species The disease is, at this time, endemic throughout Pakistan and epidemic in Western India. Affected cotton plants exhibit a range of symptoms such as leaf curling, stunted growth and a poor yield of cotton fibre. In addition, affected plants may develop leaf-like outgrowths from the veins on the undersides of leaves.

Fig: 5.12 Cotton Leaf Curl Disease

Cause: The viruses associated with the CLCuD complex on the Indian subcontinent, five of which have been identified. These are all single component begomoviruses (genus Begomovirus family Geminiviridae).

Transmission: This disease is transmitted by the whitefly *Bemisia tabaci*.

Symptoms: The symptoms in cotton usually appear within 2-3 weeks of inoculation by *Bemisia tabaci* and are initially characterized by a deep downward cupping of the youngest leaves. This is followed by either upward or downward curling of the leaf margins, swelling and darkening of the veins as well as the formation of enations (outgrowth) on the veins, which frequently (dependant on variety) develop into cup-shaped, leaf-like structures

Treatment and Prevention: Control of CLCuD is mainly based on insecticide treatments against the insect vector (*Bemisia tabaci*). Roguing, the removal of affected plants, particularly of ratoon cotton from the previous seasons crop, is recommended but appears to have little affect in reducing the incidence of the disease.

Table 5.3 Losses Due to Cotton Leaf Curl Disease, in Punjab, Pakistan

Year	Affected Area (000 ha)			Loss in Production (000 bales)	Loss in Pak Rupees (Million)
	Partial	Complete	Total		
2002-03	357.7	2.05	359.58	265.0	2253
2003-04	489.5	14.12	503.62	514.2	4589
2004-05	1267.4	31.37	1298.77	987.1	9229
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

Source: The Pakistan Cottongrower, 2009, CCRI, Multan. Data 2005-06 not recorded.
Courtesy: Mr. Sardar Mustafa, PARC, Islamabad. Mr. Tariq Mehmood, CCRI, Multan

Table 5.4 Economic Loss From Viral Infections of Bird Flu in Pakistan

Year	Losses in Pak Rs. (Million)
2004-2005	8 Million
2006-2007	24 Million

Source: Pakistan Poultry Association, Pakistan.
Courtesy: Dr. Khalid Naeem and Dr. Afzal, National Agriculture Research Council, Islamabad.

Science, Technology and Society Connections

Interpret how viral infections cause global economic loss.

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

There are four exceptions to the virus like: Defective, pseudovirons, prions and viroids. They are called atypical viruslike agents.

Prions

Structure: Prions are infectious particles that are composed solely of proteins, i.e. they contain no detectable nucleic acid, so they are different from viruses. Further more 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 glycoprotein with a molecular weight of 27,000- 30,000. This protein is encoded by a **single cellular gene**.

Diseases Caused by Prions in Man

Prions cause certain slow diseases called "transmissible spongiform encephalopathies, in man e.g. Kuru, Creutzfeldt-Jacob Disease, Fatal Familial Insomni in man. Prions also cause diseases in animals e.g. Scrapie, Visna, Bovine spongiform encephalopathy (mad cow disease).

Viroids

Viroids consist solely of a single molecule of circular RNA without a protein coat or envelope. There is extensive homology between bases in the viriod RNA, leading to large double stranded regions. The RNA is quite small and apparently does not code for any protein. Nevertheless, viriods replicate but the mechanism is unclear. They cause several plant diseases e.g. in potato, coconut, apple, peach, etc., but are not implicated in human diseases.

Exercise

SECTION I : MULTIPLE CHOICE QUESTIONS

Select the correct answer

1. Viruses are considered nonliving because

   A) they do not mutate. B) they do not locomote

   C) they cannot reproduce independently D) have nucleic acid.

2. 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

3. Which step in the lytic cycle follows attachment of virus and release of DNA into the cell?

   A) production of lysozome B) disintegration of host DNA

   C) assemblage D) DNA replication

4. 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 ends

   D) viruses do not need ribosomes for protein formation

5. Which part of an animal virus is not reproduced in multiple copies?

   A) envelope B) protein

   C) capsid D) ribosome

6. 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

7. Which of the following illness is caused by a retrovirus?

A) typhoid B) malaria

C) AIDS D) sleeping sickness

8. The HIV primarily infects

A) plasma cells B) helper T cells

C) all white blood cells D) red blood cells

9. Poliomyelitis affects

A) motor neuron B) sensory neuron

C) brain D) muscles

10. HIV attaches to

A) CD4 protein B) nucleoprotein

C) lipoprotein D) glycoprotein

SECTION II : SHORT QUESTIONS

1. What are the components of bacteriophage virus?
2. What do you mean by AIDS, HIV an TMV?
3. Why are viruses called “obligate parasite”?
4. Distinguish between the lytic and lysogenic cycle of becteriophage?
5. What are the uses of bacteriophage in genetic engineering?
6. How are viruses classified on the basis of their hosts?
7. What are the ways to control HIV?
8. How are viruses specific?
9. What is the difference between prions and viroids?

SECTION III : EXTENSIVE QUESTIONS

1. How viruses were discovered? Give the classification of viruses.
2. Describe the structure of bacteriophage, flu virus and HIV?

3. Discuss the parasitic nature of virus?
4. How does a virus survive inside a host cell protected from the immune system?
5. Describe the life cycle of HIV? What are the treatment of AIDS and the control measures against the transmission of HIV? What are the social problems related to AIDS.
6. Write notes on: (a) hepatitis, (b) herpes, (c) poliomyelitis, (d) cotton leaf curl disease.
7. Historically biologists thought that viruses, because of their simple structure, evolved before cellular organisms. Based on what you have learned about viruses, present an argument against this hypothesis.

ANSWER MCQS

1. C 2. C 3. B 4. C 5. C 6.C 7.C 8.B 9.A 10.A

SUPPLEMENTARY READING MATERIAL

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2. Madar, S.S. Biology, 6ht edition, WCB, McGraw-Hill, USA, 1998.
3. Taylor, D.J., Green, N.P.O. and Stout, G.W. Biological science 3rd Ed. Cambridge university press, reprint, 2004.

USEFUL WEBSITES

1. www.newsscientist.com
2. www.prenhiall.com/~audesirk
3. www.mhhe.com/scienemath/biology/mader

www.learningall.com

CHAPTER 6

PROKARYOTES

Major Concepts:

Number of allotted teaching periods: 14

6.1 Taxonomy of Prokaryotes (2 Periods)

6.2 Archaea (1 Period)

6.3 Bacteria: Ecology and Diversity (3 Periods)

6.4 Structure; Shape and Size of Bacteria (2 Periods)

6.5 Modes of Nutrition in Bacteria (2 Periods)

6.6 Growth and Reproduction in Bacteria (1 Period)

6.7 Importance of Bacteria (1 Period)

6.8 The Bacterial Flora of Human (1 Period)

6.9 Control of Harmful Bacteria (1 Period)

As we have seen in section 1.4 that all cells can be grouped into two broad categories: prokaryotic cells and eukaryotic cells. All prokaryotes have a simple structure than eukaryotes. All prokaryotes lack a membrane bound nucleus. They have no membrane bound organelles or microtubules and their flagella are simple, compared to eukaryotes.

6.1 TAXONOMY OF PROKARYOTES

In 1969 American biologist **Robert H. Whittaker** proposed five-kingdom system that incorporated the basic prokaryotic-eukaryotic distinction which has been modified by **Lynn Marguis** and **Karlene V. Schwarts** in 1988. They assigned a separate kingdom **Monera** for all the prokaryotes.

www.learningall.com

Phylogenetic Position of Prokaryotes

In biology, phylogenetics (Greek: *phyle*, tribe, race and *genetikos*, relative to birth, from *genesis*, birth) is the study of evolutionary relatedness among various groups of organisms (e.g., species, populations). Phylogeny (or phylogenesis) is the origin and evolution of a set of organisms, usually a set of species.

The term "bacteria" was traditionally applied to all microscopic, single-celled prokaryotes. However, molecular systematics showed prokaryotic life to consist of two separate domains, originally called **Eubacteria** and **Archaebacteria**, but now 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.

A major step forward in the study of bacteria was the recognition in 1977 by **Carl Woese** that archaea have a separate line of evolutionary descent from bacteria. This new phylogenetic taxonomy was based on his discovery that the genes encoding ribosomal RNA are ancient and distributed over all lineages of life with little or no lateral 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**.

The ancestors of modern bacteria were single-celled microorganisms that were the first forms of life to develop on Earth, about 4 billion years ago. For about 3 billion years, all organisms were microscopic, and bacteria and archaea were the dominant forms of life.

Gene sequences can be used to reconstruct the bacterial phylogeny, and these studies indicate that bacteria diverged first from the archaeal/eukaryotic lineage. The most recent common ancestor of bacteria and archaea was probably a hyperthermophile that lived about 2.5 billion to 3.2 billion years ago.

6.2 ARCHAEA

The microorganisms Archaea were originally called archaebacteria (GK; *archaios*, ancient). They are prokaryotic cells that are found in extreme environments thought to be similar to those of the Earth. Further investigations have revealed that these unusual microorganisms are different enough from bacteria to be incorporated into their own domain, archaea.

Unifying Features of Archaea

The unifying features of archaea are: (1) The plasma membranes of archaea contain unusual lipids that allow them to function at high temperatures. (2) Lipids of archaea contain glycerol linked to branched chain hydrocarbons in contrast to lipids of bacteria that contain glycerol linked to fatty acids. (3) 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.(4) Methanogenesis the ability to form methane, is one type of metabolism that is performed only by some archaea. (5) Most archaea are autotrophs and use molecular hydrogen and reduced elemental sulphur, carbon dioxide and water. (6) There is no photosynthetic archaea. (7) 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: AAACUUAAAG

Researchers have **identified** about a dozen of these molecular "signatures" short rRNA sequences that distinguish eubacteria from archaea. Interestingly in a number of cases, including the one above, the sequence in archaea is identical to that of eukaryotes.

Table 6.1 Differences Between Eubacteria and Archaea

Main Features	Eubacteria	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

Most Archaea Inhabit Extreme Environments

Many of the extreme environments to which the modern archaea are adapted resemble conditions that were common to primitive Earth but somewhat rare today. Archaea includes (a) Methogens, (b) Halophiles, (c) Thermoacidophiles.

The **methogens** (*methano*, methane, *gen*, producer) are found in anaerobic environments in swamps, marshes and in the intestinal tracts of human and other animals where they produce methane from hydrogen gas and carbon dioxide coupled to the formation of ATP. This methane, is also called **biogas** e.g., *Methanobacterium formicom.* The **halophiles** (*halo*, salt, *philes*, lover) 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 e.g. *Holobacterium halobium*. The **thermoacidophiles** (heat and acid lovers) are isolated from extremely hot, acidic environments such as hot springs, geysers, submarine thermal vent and around volcanoes e.g., *Pyrulobus fumarii*.

6.3 BACTERIA: Ecology and Diversity

The kingdom Prokaryotae is made up of organisms commonly known as bacteria. The study of bacteria is called **bacteriology** and is an important branch of microbiology. The Dutch scientist **Anton van Leeuwenhoek** first discovered bacteria in 1674, using a single-lens microscope of his own design. He called them "animalcules" and published his observations in a long series of letters to the Royal Society. **Christian Gottfried Ehrenberg** introduced the name bacterium in 1882. It is derived from the Greek word *bacterion-a*, meaning "small stuff".

Occurrence of Bacteria in the Widest Range of Habitats

Eubacteria a huge group of prokaryotes is found just everywhere and upon which nearly all other forms of life depend. Here we will discuss some of the structural features that help eubacteria thrive in a great variety of environments.

Bacteria having **flagella** can move toward more favourable places or away from less favourable one. **Pili** help bacteria stick to each other and to surfaces such as rocks in flowing streams or to the lining of human intestine. Bacteria form **endospores**. Under harsh conditions the outer cell may disintegrate, but the endospore survives all sorts of trauma, including lack of water and nutrients, extreme heat or cold and most poisons. When the environment becomes more hospitable, the endospore absorbs water and resume growth.

Some endospores can remain dormant for centuries. Not even boiling water kills most of these resistant cells. The mass of **branching cell chains** or **filaments** is a structural feature unique to the eubacterial group called **actinomycetes**. These bacteria are very common in soil, where they break down organic substances. The filaments enable the organism to bridge dry gaps between soil particles.

Table:6.2 The Major Phylogenetic Groups of Bacteria

GROUP	CHARACTERISTICS OF THE GROUP	REPRESENTATIVE GENERA OF THE GROUP
Aquificales	Extremely thermophilic bacteria, the oldest branch of the bacterial domain.	*Aquifex*
Thermotogales	Extremely thermophilic bacteria.	*Thermotoga*
Green nonsulfur bacteria	Most bacteria in this group are photosynthetic, some are thermophilic.	*Chioroflexus Thermomicrobium*
Deinococci	The Dinococcus subgroup are Gram-positive bacteria that are resistant to radiation. The Thermus subgroup are Gram-negative thermophilic bacteria.	*Deinococcus Thermus*
Proteobacteria (purple bacteria)	Includes a phenotypically diverse group of Gram-negative bacteria. Some are phototrophic but do not produce oxygen during photosynthesis, some are chemotrophic and some members are capable of nitrogen fixation.	*Escherichia Salmonella*
Gram-positive bacteria	This group includes endospore-forming bacteria, lactic acid bacteria, anaerobic and aerobic cocci, mycoplasmas, filamentous actinomycetes, etc.	*Staphylococcus Clostridium, Bacillus Mycoplasma*
Cyanobacteria	Phototrophic bacteria that produce oxygen during photosynthesis.	*Nostoc, Anabaena Oscillatoria*
Chlamydiae	Bacteria that lack peptidoglycan and contain a protein cell wall; live as obligate intracellular parasites of animal cells.	*Chlamydia*
Planctomycetes	Gram-negative bacteria that divide by budding.	*Planctomyces*
Bacteroides and relatives	Gram-negative, rod-shaped bacteria. It includes fermentative anaerobes and respiring aerobes.	*Bacteroides Flavobacterium*
Green sulfur bacteria	Green phototrophic bacteria that do not produce oxygen during photosynthesis.	*Chlorobium*
Spirochetes	Gram-negative helical or spiral-shaped cells with a distinctive corkscrew motility.	*Spirochaeta Leptospira, Borrelia*

Diagnostic Features of the 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. The table 6.2 shows the diagnostic features of the twelve major groups of bacteria.

CYANOBACTERIA - The Most Prominent Photosynthetic Bacteria

Cyanobacteria (Gk. *kyanoa*, blue and *bacterion*, rod) are Gram-negative. The **habitat** of cyanobacteria is any damp place, salt water, fresh water, in moist soil, on damp rock tree trunks, hot springs (with temperature up to 85°C). The **mode of life** may be epiphytic or symbiotic. They are symbiotic with a number of organisms, such as liverworts, ferns and even at times invertebrates like corals. In association with fungi they form lichens. It is presumed that cyanobacteria were the first colonizers of land during the course of evolution. The **forms of life** are that they (a) may be unicellular and solitary (b) in the form of colonies (c) in the form of filaments attached end to end.

The **prokaryotic features** of cynobacteria are: (a) nuclear membrane is absent (b) the chromosomes do not have protein combined with DNA (c) membrane bound organelles are absent. **Cell wall** contains muramic acid, which is found only in prokaryotes. The cell wall is often surrounded by mucilaginous sheath. The **genetic material** is a circular strand of DNA. Many **ribosomes** are present in the cytoplasm.

Photosynthesis takes place in the extensive system of membrane, which is located in the outer zone of the cytoplasm. Oxygen is released during photosynthesis. Cyanobacteria use phycobilins as accessory pigment. Phycocyanin a blue pigment is their predominant phycobilins. They are believed to be responsible for first introducing oxygen into the primitive atmosphere.

Sexual reproduction is absent in cyanobacteria. Asexual reproduction takes place by: (a) Cell division e.g. unicellular form. (b) Fragmentations is the breaking of the body of the organism into small pieces of fragments. It takes place at weak points next to **heterocyst** forming **hormogonia**. (c) Certain cells of the filament, may become enlarged. The walls become thick. They contain reserve food and DNA. These are the resting stages called **akinetes**. After resting stage, the wall of the akinete ruptures and a short filament of cells is released. (d) Spore

formation is not common. Sometimes the heterocyst forms **endospores**. The nuclear material divides and then the cytoplasm of the heterocyst divides within the parent cell wall and many spores called endospores are formed. Each spore forms a new *Nostoc* filament.

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

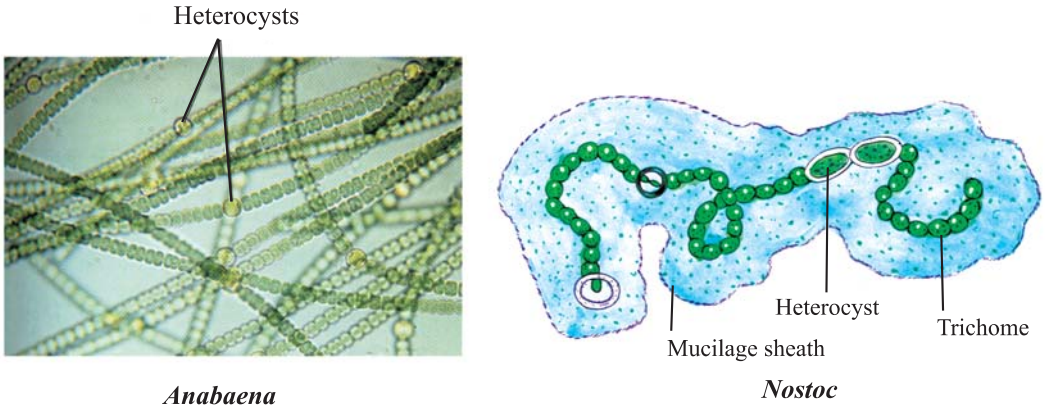


Fig. 6.1 Cyanobacteria

6.4 STRUCTURE: Shape and Size of Bacteria

A typical bacterium consists of cell wall, cell membrane, cytoplasm, genetic material, and specialised structures outside the cell wall.

The **cell wall** is the outermost component common to all bacteria. Cell wall is absent in *Mycoplasma* species, which are bounded by cell membrane. Some bacteria have surface feature external to the cell wall such as capsule, flagella and pili.

The cell wall is a multilayered structure located external to the cytoplasmic membrane. It is composed of an inner layer of **peptidoglycan** and an outer membrane that varies in thickness and chemical composition depending upon the bacterial type. The peptidoglycan provides structural support and maintains the characteristic shape of the cell.

Peptidoglycan is a complex interwoven network and surrounds the entire cell and is composed of a singly covalently linked macromolecule. It is

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

The **capsule** is a gelatinous layer covering the entire bacterium. It is composed of polysaccharide, except in the *Anthrax bacillus*, which has a capsule of polymerized D-glutamic acid. The sugar components of the polysaccharide vary from one species of bacteria to another. The capsule may play a role in the adherence of bacteria to human tissues.

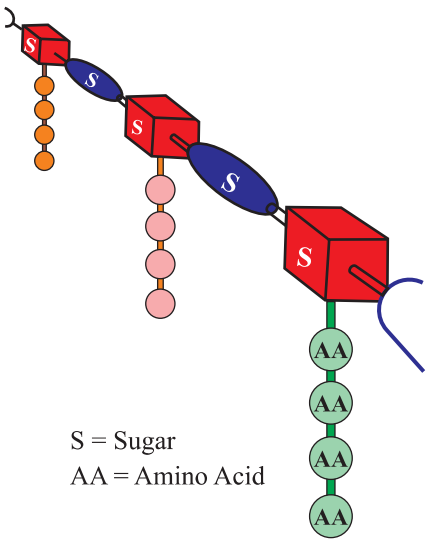


Fig: 6.2 Peptidoglycan

Cell Walls of Gram-Positive and Gram Negative Bacteria

The structure, chemical composition and thickness of the cell wall differ in Gram-positive and Gram-negative bacteria. (1) 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 protrude outside the peptidoglycan, whereas Gram-negative bacteria do not have it. (2) In contrast, the Gram-negative have a complex outer layer consisting of lipopolysaccharide, lipoprotein and phospholipid. Lying between the outer

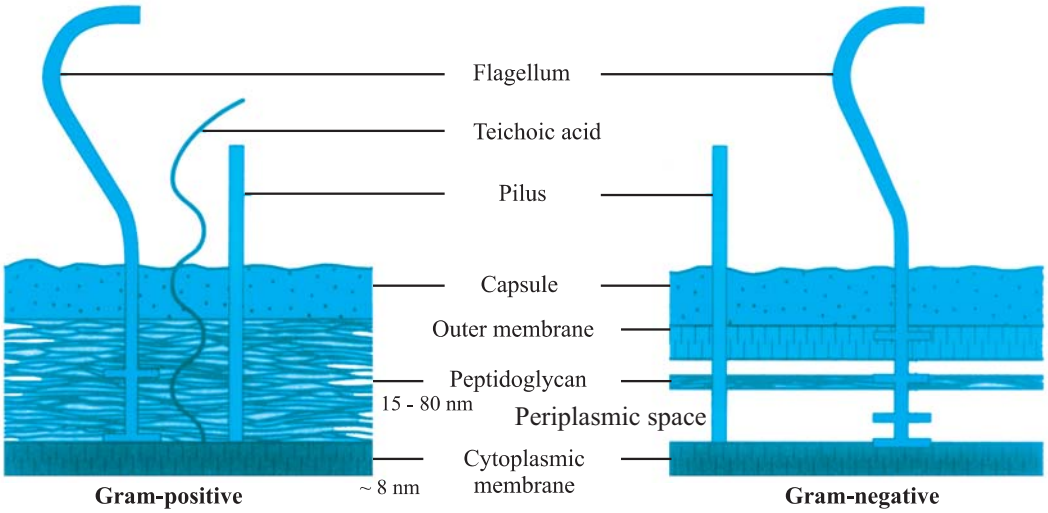


Fig: 6.3 Cell Wall of Bacteria

membrane layer and the cytoplasmic membrane in Gram-negative bacteria is the, which is the site,in some species of enzymes called β-lactamases that degrade penicillins and other β-lactum drugs.

Diversity of Shapes and Sizes in Bacteria

Bacteria have three main shapes: spherical, rod shaped and spiral.

Spherical: A **coccus** (*kokus*) is a spherical bacterium **Cocci** (*koksi*) generally appears in groups: (1) the groups consisting of two cells are called *diplococci*, (2) in the long chain called *streptococci*, (3) in irregular clumps that look like bunches of grapes called *staphylococci*, (4) **Cocci** may form packet of 4 cells called tetrad and (5) packet of eight cells called octate or sarcina. The example of cocci are: *Streptococcus pneumoniae*, *Neisseria meningitidis*.

Rod shaped: Bacilli are straight or rod shaped organisms. They are found in: (1) pairs, called *Diplobacillus*, (2) very short and *ovoid*, called *Coccobacilli*, (3) curved into a form resembling comma called *Vibrio*, (4) look like stack of coin called palisade. The examples of rod shaped bacteria are *Escherichia coli*, *Pseudomonas*.

Spiral: Spirochetes are spiral bacteria usually occur singly, seldom form colonies. They are thin walled flexible spiral rods. Relatively spirochetes are large and flexible e.g. *Treponema pallidum*.

Size of Bacteria: Bacteria range in size about 0.1 to 600μm over a single dimension.

Endospore Formation in Bactera

A single bacterium forms a single spore by a process called **sporulation**. The spore contains bacterial DNA, a small amount of cytoplasm, ribosomes, peptidoglycan, very little water and most importantly, a thick, keratin like coat. As the spore develops within the vegetative cell, so it has been named as **endospore**.

During germination the cell takes up water and enlarges. At the same time the wall disintergrates and a vegetative cell emerges. Endospore formation is not a means of reproduction since there is no increase in cell number during the spore cycle.

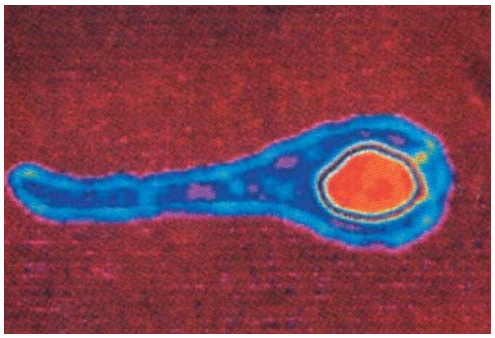
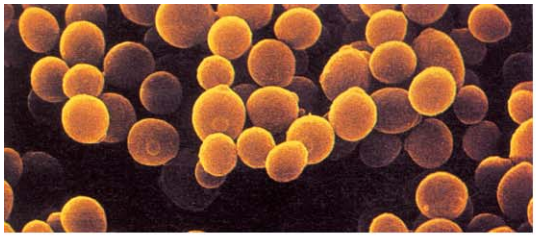
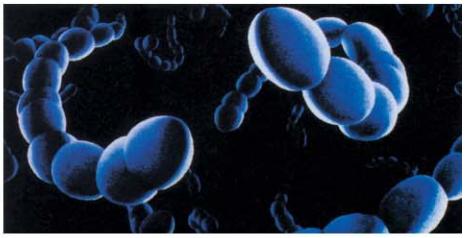


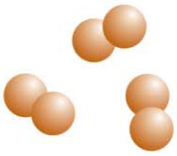
Fig: 6.4 Endospore



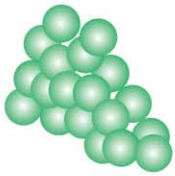
Cocci



Streptococci



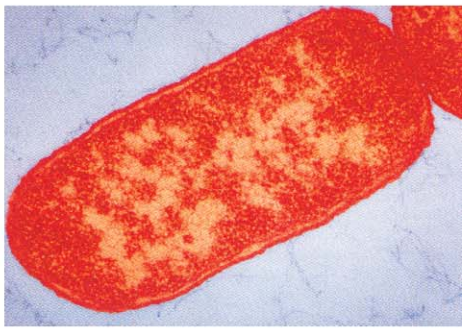
Diplococci



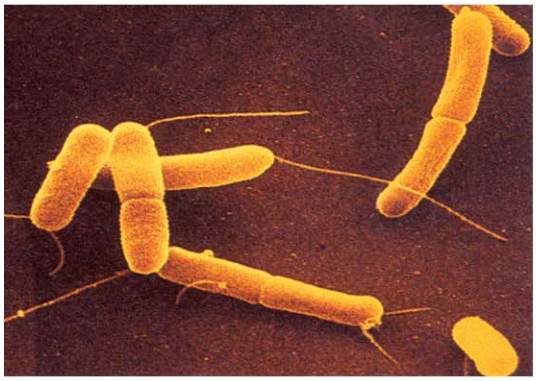
Staphylococci

Tetrad

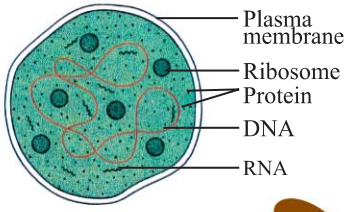
Octate



Bacillus *(E. coli)*



Diplobacillus

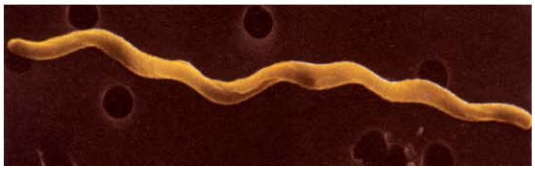


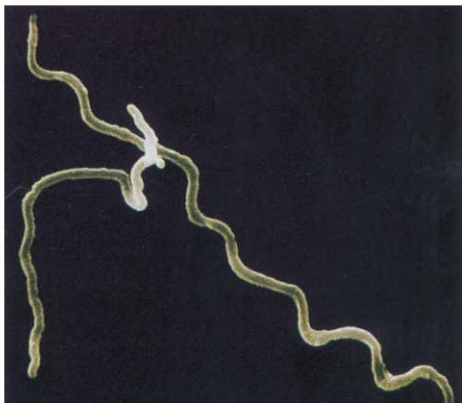
Mycoplasma

Vibrio

Palisade

Streptobacillus





Spirochete

Fig: 6.5 Forms of Bacteria

Motility in Bacteria

Motile bacteria can move using flagella, bacterial gliding, twitching motility or changes of buoyancy. A unique group of bacteria, the spirochetes, have structures similar to flagella, They have a distinctive helical body that twists about as it moves. In twitching motility, bacteria use their pili as a grappling hook, repeatedly extending it, anchoring it and then retracting it with remarkable force.

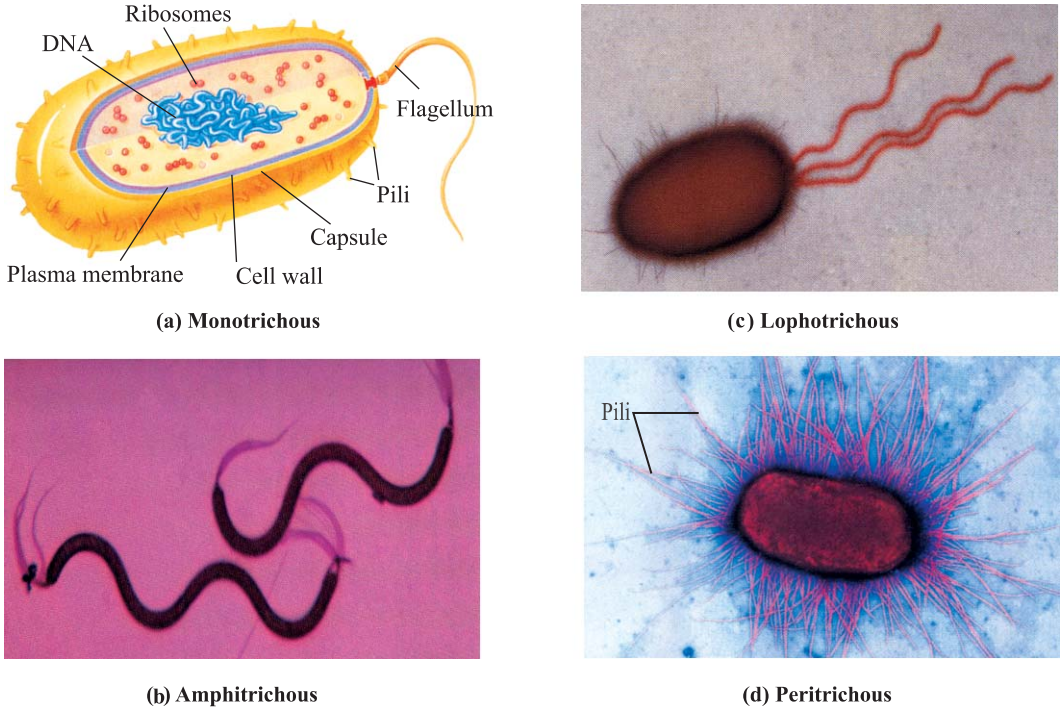


Fig: 6.6 Location of Flagella in Bacteria

Bacterial species differ in the number and arrangement of flagella on their surface; some have a single flagellum i.e. **monotrichous**, a flagellum at each end i.e **amphitrichous**, clusters of flagella at the poles of the cell i.e. **lophotrichous**, while others have flagella distributed over the entire surface of the cell i.e. **peritrichous**. Many bacteria (such as *E. coli*) have two distinct modes of movement: forward movement (swimming) and tumbling. The tumbling allows them to reorient and make their movement a three-dimensional random walk.

Motile bacteria are attracted or repelled by certain stimuli in behaviors called **taxes**: these include chemotaxis, phototaxis and magnetotaxis. Several species move inside host cells by usurping the cytoskeleton, which is normally used to move organelles inside the cell.

Structure of Bacterial Flagellum

Many bacteria have fine thread like outgrowth called flagella (singular: *flagellum*). It is composed of a single protein **flagellin**, arranged in interwined chains, which are noncontractile protein, and lacks microtubules. Flagella are about twenty nanometers diameter and up to 20 micrometers in length. Bacterial flagella consists of three parts: a basal body, a hook and a filament (fig. 6.7). The **basal body** originates just beneath the cell membrane. It is a complex structure that produces rotatory motion. The **hook** connects the basal body to the filament. The **filament** is a hollow structure which consists of several protein chains twisted into a helical structure. The 360° rotation of the flagellum causes the cell to spin and move forward.

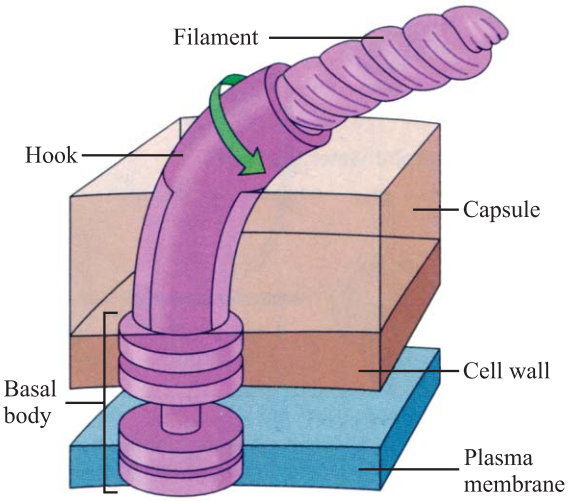


Fig: 6.7 Structure of Bacterial Flagellum

Genomic Organization in Bacteria

The genetic material of a typical bacterium, *Escherichia coli*, consists of a single circular DNA molecule and is composed of approximately 5 × 106 base pairs. This amount of genetic information can code for about 2000 protein.

Most bacteria have a single circular chromosome that can range in size from only 160,000 base pairs in the endosymbiotic bacteria *Candidatus Carsonella ruddii* to 12,200,000 base pairs in the soil-dwelling bacteria *Sorangium cellulosum*. Spirochetes of the genus *Borrelia* are a notable exception to this arrangement, they contain a single linear chromosome. Apart from bacterial chromosome many bacteria have accessory rings of DNA called **plasmids**. To date, 8 complete bacterial genomes have been sequenced.

6.5 MODES OF NUTRITION IN BACTERIA

Bacteria can be classified on the basis of method of obtaining energy and carbon. Carbon metabolism in bacteria is either **heterotrophic**, where organic carbon compounds are used as carbon sources, or **autotrophic**, meaning that cellular carbon is obtained by fixing carbon dioxide.

Autotrophic Nutrition in Bacteria

Autotrophy means self nourishing organisms. An autotrophic organism can obtain all the carbon it needs from CO_2 that is present in the atmosphere and that dissolves readily in water. There are two major groups of autotrophs: photosynthetic and chemoautotrophic.

Photosynthetic Bacteria: The photosynthetic bacteria contain unique type of chlorophyll called bacteriochlorophyll. The chlorophyll is incorporated in the membrane of their mesosomes, or dispersed in the cytoplasm. Like green plants, the photosynthetic bacteria use the energy of sunlight to make carbohydrates from CO_2.

$$2H_2S + O_2 \xrightarrow[\text{Chlorophyll}]{\text{Light}} (CH_2O)_n + H_2O + 2S$$

The examples of photosynthetic bacteria are Green sulphur bacteria, purple sulphur bacteria, purple non-sulphur bacteria. They use hydrogen sulfide (H_2S) instead of water.

Chemoautotrophic Bacteria: Certain colourless 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.

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

The energy thus produced is used by bacteria to make carbohydrate $(CH_2O)_n$.

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

The examples of chemoautotrophic bacteria are Nitrifying bacteria, Sulphur bacteria.

Heterotrophic Nutrition in 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: (a) Saprotroph bacteria (b) Parasitic bacteria.

Saprotroph Bacteria contain extensive enzyme system that break down the complex substances of humus to simpler compounds. The bacteria then absorb the simpler compounds, for example many soil bacteria. eg., *Pseudomonas*, *Azobacter*.

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

Respiration in Bacteria

Respiration may be aerobic or anaerobic, accordingly bacteria are known as **aerobic bacteria** e.g *Pseudomonas* and **anaerobic bacteria** e.g *Spirochaeta*. 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*.

Pigment Composition and Photosynthesis Mechanism in Cyanobacteria

Cyanobacteria contain a blue pigment called **phycocyanin** and a red pigment called **phycoerythrin**. The simplest mixture of chlorophyll and blue green pigment in some species produces the blue green colour that gives the entire group its common name. But those species that contain red pigments, appear red, purple brown or even black.

Cyanobacteria release oxygen during photosynthesis, which takes place in the extensive system of membrane. It is located in the outer zone of the cytoplasm. Their photosynthetic system closely resembles that of eukaryotes because they have chlorophyll "a" and photosystem II. They use water as an electron donor and generate oxygen during photosynthesis. Cyanobacteria use **phycobilins** as accessory pigments. Photosynthetic pigments and electron transport chain components are located in thylakoid membrane linked with particles called **phycobilisomes**. Phycocyanin (a blue pigment) is their predominant phycobilin and CO_2 in them is assimilated through Calvin cycle. Whereas in photosynthetic bacteria as we have already seen bacteriochlorophyll is located in mesosome and use light energy to make carbohydrates from carbon dioxide.

6.6 GROWTH AND REPRODUCTION IN BACTERIA

Bacteria reproduce by binary fission. Because one cell gives rise to two progeny cells, bacteria are set to undergo exponential growth (Logarithmic growth).

Number of cells:	1	2	4	8	16
Exponential	2^0	2^1	2^2	2^3	2^4

Thus one bacterium will produce 16 bacteria after four generation.

Phases of Growth

The curve in graph is known as a logarithmic or exponential curve. Such growth curves can be converted to straight lines by plotting the logarithms of growth against time. The growth cycle of bacteria has four major phases.

Lag Phase-No Growth: During the lag phase the bacteria are adapting to their new environment and growth has not yet achieved its maximum rate. The bacteria for example may be synthesising new enzymes to digest the particular spectrum of nutrients available in the new medium.

Log Phase-Rapid Growth Period: The log phase is the phase when growth is proceeding at its maximum rate, closely approaching a logarithmic increase in numbers when the growth curve would be a straight line.

Stationary Phase-Bacterial Rate of Death and Reproduction is Equal: Eventually growth of the colony begins to slow down and it starts to enter the stationary phase where growth rate is zero, and there is much greater competition for resources. Rate of production of new cells is slower and may cease altogether. Any increase in the number of cells is offset by the death of other cells, so that the number of living cells remains constant. This phase is a result of several factors, including exhaustion of essential nutrients, accumulation of toxic waste products of metabolism and possibly, if the bacteria are aerobic, depletion of oxygen.

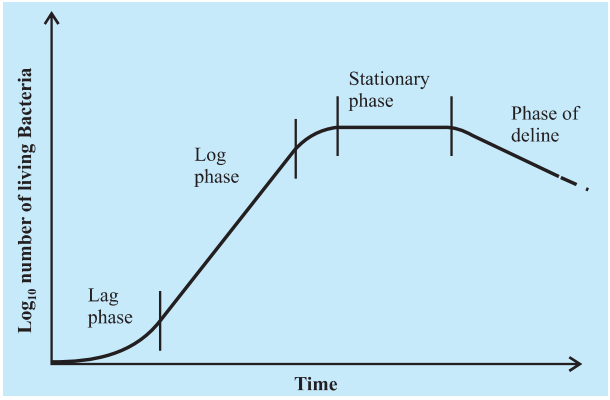

Fig: 6.8 Typical Growth of Curve of a Bacterial Population

Death Phase-Bacteria Start Dying: During the final phase, the death phase or phase of decline, the death rate increases and cells stop multiplying.

Reproduction in Bacteria

The two types of reproduction in bacteria are asexual reproduction and sexual reproduction.

Asexual Reproduction: Bacterial reproduction is mostly asexual. Bacteria reproduce asexually by cell splitting called fission. As the bacteria are divided into two so it is called **binary fission**. There is no mitosis in bacteria. First DNA is replicated. Then the two chromosomes move apart into separate nuclear region. The plasma membrane pushes inward to form a central transverse septum (partition wall). Next the cell wall grows inward within the transverse septum and eventually divides the cell into two. The interval time until the completion of next division is known as **generation time**. Under favourable condition i.e. when there is sufficient amount of water and nutrients and temperature is suitable, bacteria can divide rapidly. It takes 20 minutes to daughter cells to grow and start dividing again.

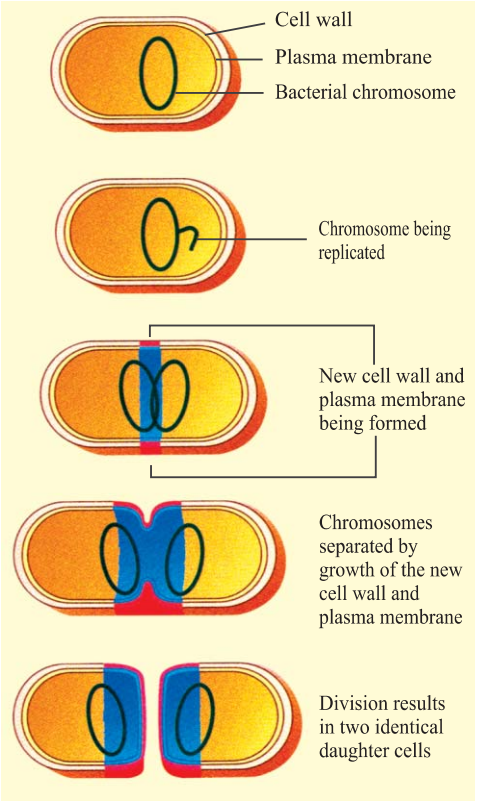

Fig: 6.9 Binary Fission in Bacteria

Sexual Reproduction: The sexual reproduction in bacteria is the genetic recombination i.e. DNA of two bacteria combine to give rise to a new type of bacteria called **recombinant**. The genetic recombination in bacteria occurs by conjugation, transduction and transformation.

Science Titbits

The doubling (generation) time of bacteria ranges from as little as 20 minutes for *Escherichia* coli to more than 24 hours for *Mycobacterium tuberculosis*. The doubling time varies not only with the species but also with the amount of nutrients, the temperature, the pH and the environmental factors.

Conjugation

Indirect proof of genetic recombination in bacteria was proved indirectly by **J. Lederberg** and **E.L. Tatum** (1946) and they were awarded Nobel Prize for this and other research works.

Experiment of Lederberg and Tatum

They took wild type of *Escherichia coli* bacteria. The bacteria were grown on minimal medium containing inorganic salts, glucose and from these materials **wild type** *Escherichia coli* can synthesize all substances necessary for growth and reproduction.

Irradiation with X-rays on these wild type bacteria caused mutation. Two types of nutritional **mutants** were taken out of many.

One strain called Y-10 required amino acid threonine, leucine and vitamin thiamine in the minimal medium for growth. Another strain called Y-24 required amino acids phenylalanine, cysteine and vitamin biotin in the minimal medium for growth.

The mixed cultures of strain Y-10 and Y-24 were grown in nutrition medium containing all the four amino acids and the two vitamins. Three types of bacteria were obtained (a) one were like parent Y-10 (b) another were like the parent Y-24 and (c) third group were like the wild type, as it could grow in the minimal medium.

From this experiment it was concluded that the offspring of the two mutant types were wild type and it is only possible when actual genetic recombination takes place.

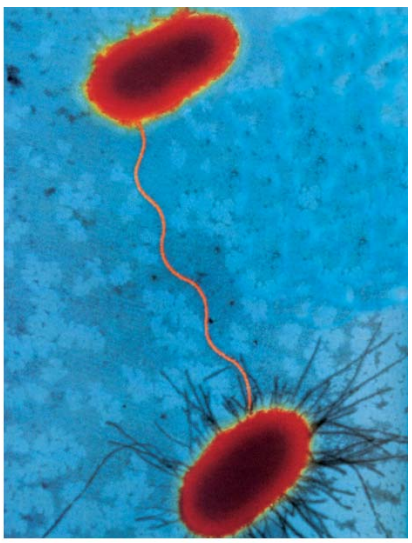

Fig: 6.10 Sexual reproduction in Bacteria by forming conjugation bridge

Direct Proof of Genetic Recombination

With the invention of electron microscope, the direct proof of genetic recombination was obtained. Mixture of the two mutants was observed using electron microscope. The mutants are easily distinguished by their structure. The bacterium that will give the DNA is called **donor** and the bacterium that will receive the DNA is called the **recipient**.

Method of Gene Transfer in Bacteria

Bacterial conjugation involves a plasmid that can be transferred during the conjugation process. In some instances, however a part of bacterial chromosomal genes are also transferred. Not all plasmids are involved in bacterial conjugation. Only one type of plasmid, the 'F' (fertility) plasmid, also called the F-factor takes part in conjugation. It forms pilus. The pilus forms the conjugation bridge, connecting the donor and the recipient bacterial cells. The F-plasmid replicates and transfers a copy to the recipient cell.

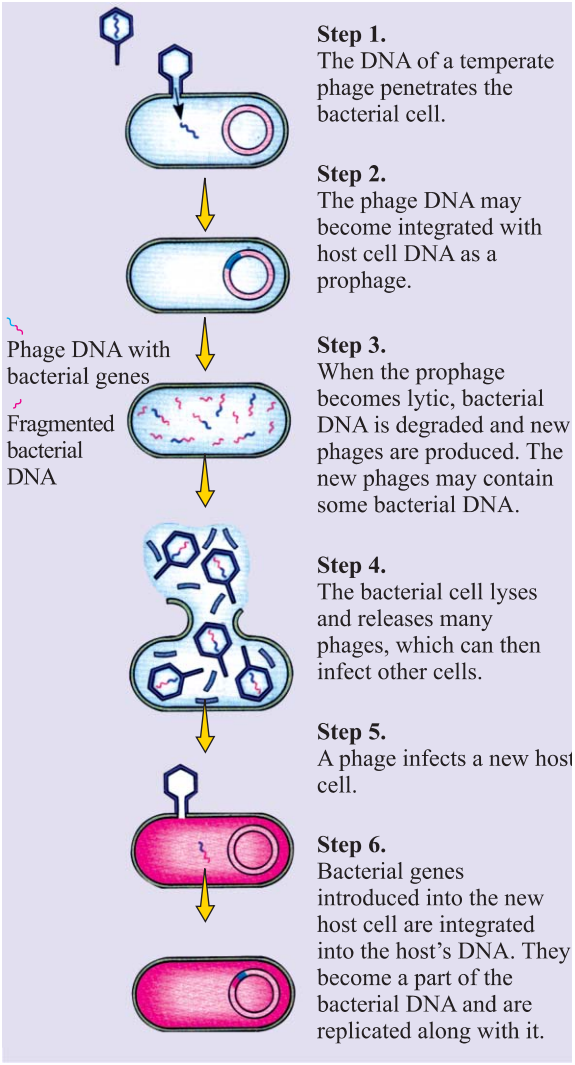

Fig: 6.11 Generalized transduction by a bacteriophage

Transduction

The transfer of genetic material from one bacterium to another bacterium through the third party-the virus, is called transduction.

Transformation

When bacteria die or when they are reproducing very rapidly, they release fragments of their DNA into their immediate environment. Transformation is the absorption of DNA into a cell. As a result the cell is transformed into a new type of cell. These cells are called **transformed cells**.

Bacterial cells that release DNA fragment are called **donor cells**. If one of the released DNA fragment contacts a cell of a species of bacteria that is capable of transformation, the DNA fragment may bound to the recipient and take inside.

Mutations and Genetic Recombinations 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 genetic recombination or mutations. Mutations come from errors made during the replication of DNA or from exposure to mutagens.

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 either random mutation during replication or "stress-directed mutation", where genes involved in a particular growth-limiting process have an increased mutation rate.

Skills: Performing and Recording

- **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	180 minutes	1000
Stationary phase	180 to 360 minutes	3000
Death Phase	360 to 1800 minutes	300

6.7 IMPORTANCE OF BACTERIA

Bacteria are useful as recyclers of nature and they have also ecological importance.

BACTERIA: Recyclers of Nature

Bacteria are vital in recycling nutrients. Many important steps in nutrient cycles depend on bacteria. e.g. nitrogen cycle. Nitrogen fixing bacilli bacteria, genus *Rhizobium*, that live in root nodule of legume convert nitrogen gas to ammonium. Saprotrophic soil bacteria, forming ammonia, decompose

the nitrogenous wastes of animals and plants. Chemosynthetic bacteria *Nitrosomonas* and *Nitrobacter* then oxidise ammonia to nitrate, a process called **nitrification**. **Denitrifying** bacteria converts nitrates into nitrogen gas and the process is called **denitrification**. Bacteria recycle both organic matters and inorganic substances e.g. minerals, water, ammonia, carbon dioxide etc. Carbon dioxide is produced by fermentation, which is released in the atmosphere. The green plants fix this carbon.

Ecological Importance of Bacteria

Bacteria and fungi are the only organisms that decompose dead animals and plants. The organic matter of dead organisms is converted into **humus**. It contains nutrients and increases soil fertility for the growth of plants. It also increases the water retaining capacity of the soil.

Economic Importance of Bacteria

Bacteria are both beneficial as well as harmful. Here we will discuss these two aspects of bacteria.

Harmful Bacteria

Parasitic Bacteria attack plants and cause various diseases e.g., fire blight in apple, ring diseases in potatoes, crown gall etc., many human diseases are caused by bacteria e.g. tuberculosis, diphtheria, tetanus, cholera, leprosy, typhoid fever, meningitis, sore throat, whooping cough (pertusis) etc. Bacteria produce acids, which convert wine to vinegar. Bacteria cause decay of wood, leather, fabrics etc. Bacteria spoil the food materials by decomposition.

Beneficial Bacteria

Help in Digestion: Some bacteria in the large and small intestine help to emulsify fats taken as food and thereby promote the digestion and absorption of fats by the host. In cattle, bacteria help in digestion by decomposing cellulose and starch.

Synthesis of Vitamins: Some bacteria can synthesize vitamin K and vitamin B. These bacteria e.g. *Escherichia coli* are grown in culture and produce vitamin B_{12} for commercial purposes.

Bacteria in Industry: Bacteria are widely used in many industrial processes. It is easier and cheaper to use cultured bacteria than to produce the substances by synthetic process. Bacteria are used in the manufacturing of acetic acid (vinegar), acetone, lactic acid, butanol (alcohol), several vitamins, curing cheese and flavouring of tobacco. Bacteria are also used in coffee and leather (tanning) industries.

Bacteria in Food Industry: Dairy products such as yogurt (yoghurt, yoghourt), cheese, butter etc. are produced with the help of bacteria.

Bacteria as Food: The large number of bacterial cells moving with the partially digested plant material through the alimentary canal undergoes digestion too. When they do, they provide the animal with most of its amino acids and vitamins.

Antibiotics: Most of the antibiotics are obtained from various species of actinomycetes group, e.g., Streptomycin, Auromycin, Teramycin etc.

Biogas: Bacteria decompose sawages, garbages, dungs, stool and during the process produce methane gas. It is used as fuel. Biogas plants are used in villages. Biogas is 54-70% methane, whereas the natural gas is about 80% methane.

A Single Cell Protein: A relatively new food source is "single cell protein". Its production began in the late 1960. The term refers to protein obtained from the large scale growth of microorganisms such as bacteria, yeast and other fungi and algae. The protein may be used for human consumption or animals.

Use of Bacteria in Research

Microorganisms e.g.,bacteria, yeast, *Neurospora* etc have been extensively used in research. We owe to bacteria for many of the biological achievement for the benefit of human being. For example 1n 1952 Alfered D. Hershey and Martha Chase used T2 bacteriophage and bacteria to prove that DNA is the hereditary material.

Use of Bacteria in Technology

Biotechnology Products: Free-living organisms in the environment that have a foreign gene inserted into them are called transgenic organisms. Bacteria are used to clone a gene or to mass-produce a product. These products include hormones and similar types of proteins or vaccines e.g., insulin, growth hormones, clotting factor VII for haemophilia etc.

Protection and Enhancement of Plants: Genetically engineered bacteria can be used to promote the health of plants. For example, bacteria that normally live on plants and encourage the formation of ice crystals have been changed from frost-plus to frost- minus bacteria.

Bioremediation: Naturally occurring bacteria that eat oil can be genetically engineered to clean up beaches after oil spills.

Science Titbits

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 interferoms.

Science, Technology and Society Connections

List some biotechnologies utilizing bacteria.

Chemical Production: Organic chemicals are often synthesized by using bacteria to carry out the synthesis. Today it is possible to manipulate the genes that code for these enzymes. For example genetically engineered bacteria are used to produce phenylalanine.

Mineral Processing: Genetic engineering may enhance the ability of bacteria to extract copper, uranium and gold from low-grade sources.

Important Bacterial Diseases In Man

Bacteria cause many diseases in man such as pneumonia, anthrax, tetanus, botulism, diptheria, meningitis, gonorrhea, whooping cough, pneumonia, plague, urinary tract infection, typhoid fever, gastritis, peptic ulcer, cholera, tuberculosis, syphilis, etc. Here we will discuss only cholera, typhoid, tuberculosis and pneumonia.

Science Titbits

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 thousand 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

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

Cholera

Symptoms: Watery diarrhoea in large volume is the hallmark of cholera.

Causative Agent: Cholera is caused by the bacteria *Vibrio cholerae*.

Treatment: It consists of prompt, adequate replacement of water and electrolytes, either orally or intravenously. Antibiotics such as tetracycline are not necessary, but they do shorten the duration of symptoms and reduce the time of excretion of the organisms.

Prevention: It is achieved mainly by public health measures that ensure a clean water supply. The vaccine composed of killed organisms has limited usefulness. A live vaccine is available in certain countries. The uses of tetracycline for prevention are effective. Prompt detection of carriers is important in limiting outbreaks.

Science, Technology and Society Connections

Relate the causes of food poisoning and the sanitation condtions in restaurants.

Typhoid

Symptoms: In typhoid and other enteric (pertaining to intestine) fever infection begins in the small intestine. The onset of illness is slow, with fever and constipation. High fever, delirium, tender abdomen and enlarged spleen occur. "Rosy spots" i.e. rose coloured macules on the abdomen, are associated with typhoid fever but occur rarely.

Causative Agent: It is caused by bacteria *Salmonella typhi*.

Treatment: Antibiotics should be used in patients who are chronic carriers of *S.typhi*.

Prevention: It is prevented mainly by public health and personal hygiene measures. Hand washing prior to food handling, pasteurisation of milk, and proper cooking of poultry, eggs and meat are all-important. Vaccines are available for the prevention of typhoid.

Tuberculosis

There are different types of tuberculosis e.g. meningeal TB, miliary TB, bone TB, skin TB, abdominal TB etc. Here we will discuss only pulmonary TB.

Symptoms: Mild fever lasts for 7-14 days and mild dry cough. Bluish red raised tender cutaneous lesions on the shins and less commonly on the thighs may occur in primary tuberculosis. In secondary tuberculosis there is low-grade intermittent fever usually in the evening, night sweats, weight loss, anorexia, malaise and weakness, dry hacking cough with blood stained sputum, dull ache in the chest due to pleurisy etc.

Causative Agent: *Mycobacterium tuberculosis*.

Treatment: Multiple-drug therapy is used to prevent the emergence of drug resistant mutants during the long 6 to 9 month duration of treatment or DOTS (directly observed treatment short course) of only two months duration.

Prevention: Prevention of the spread of the organism depends largely on the prompt identification and adequate treatment of patients who are coughing up the organism. The use of masks and other respiratory isolation procedures to prevent spread to medical personnel is also important. A vaccine containing a strain of live *Mycobacterium bovis* (Bacillus Calmette-Guerin or BCG) can be used to induce partial resistance to tuberculosis.

Pneumonia

Symptoms: Pneumonia often begins with sudden chill, cough and pleuritic pain. Sputum is red brown "rusty" colour.

Causative Agent: *Streptococcus pneumoniae.*

Treatment: Most pneumococci are susceptible to penicillins and erythromycin.

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.

Science, Technology and Society Connections

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

Important Bacterial Diseases In Plants

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

Leaf spot

Symptoms: The most common symptoms of plant diseases are discrete or spreading type lesion on leaf blade. It is caused by bacterial pathogens through the action of toxins they produce.

Cause: It is cause by *Xanthomonas campestris* on tomato and pepper. *Pseudomonas syringae* on tobacco, *Aplanobacter sepedanium* causes ring disease of potato

Prevention: Prevention of contact between the pathogen and the host, use of disease free seeds.

Blight

Symptoms: When the necrotic symptoms develop very rapidly damage the plant cell wall structure, and effect organ or shoot or even the whole plant soon gets killed. The symptom is termed blight. In some cases blight symptoms appear initially at or near the leaf tip, often at the margin then spread downwards and inwards drying up the leaf and the whole plant may get blighted soon e.g. maize, rice and oat etc.

Cause: *Xanthomonas oryzae* cause blight disease in rice, *Eriwinia anylovora* causes fire blight of pears and apples

Prevention: Disease free seeds, suitable location and removal of diseased plant by physical method.

Soft Rot

Symptoms: When the cells of plant tissue die because of the action of pathogen, produce pectolytic and cellulolytic, rot type symptoms. Rotting may affect any organ of plant including flowers and fruits. When the pathogen produces peptolytic enzyme, plant cell soon separates from one another because of maceration and the affected host tissue loses its coherence and leakage of water takes place from the effected cells, which are killed soon. The necrotised tissue becomes wet to touch and soft inconsistency hence termed soft rot. Such rot is of fast spreading nature and damage plant organs very rapidly.

Cause: *Erwinia atroseptica* in potato, *Corynebacterium* causes ear rot of wheat.

Prevention: Removal of diseased plants by physical method.

Wilting

Symptoms: Interference with the upward transport of water with dissolved nutrients from roots through the stem into the leaves leads to loses of turgidity in the leaf blade, which becomes limp. Such loss of turgidity in the leaf blade increased with time and ultimately leads to wilting of leaf and drying.

Cause: *Pseudomonas solanacaerum* causes wilt disease of potato. *Xanthomonas campestris* causes important wilt diseases.

Prevention: Selection of disease free seeds, selecting proper dates for planting and suitable location and allowing proper spacing between the plants.

Galls

Symptoms: 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. *Pseudomonas savastonoi* cause a small gall in olive plant known as olive knot. *Agrobacterium tumifaciens* causes large galls in many plants. *Xanthomonas campestris* causes galls on cotton.

Prevention: Crop rotation, removal of disease plants and use of disease free seeds.

Fig. 6.12 Root nodules: The bacteria live in these nodules of legumes

Fig. 6.13 Crown gall disease on a tobacco plant caused by *Agrobacterium*

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6.8 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 the 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

Benefits of the Bacterial Flora to Humans

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. However since germ-free animals are well nourished, the normal flora is not essential for proper nutrition.

Critical Thinking

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

6.9 CONTROL OF HARMFUL BACTRERIA

Chemical Methods to Control Bacteria

Antiseptics, disinfectants and chemotherapeutic agents are used as chemical methods for microbial control.

Antiseptics: The chemical substances used on living tissues that inhibit the growth of microorganisms are called antiseptics.

Disinfectants: Oxidizing and reducing agents are important chemical agents for disinfection e.g. 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: These chemicals and antibiotics destroy the natural defence and stop the growth of bacteria and other microbes in the living tissue e.g. sulphonamide, tetracycline, penicillin etc.

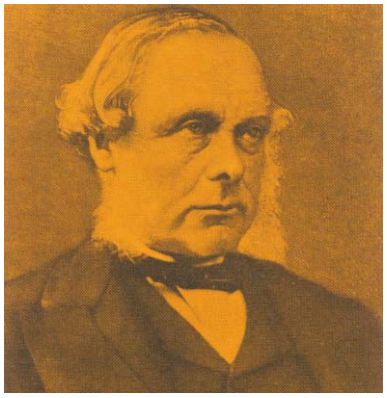

Fig: 6.14 Joseph Lister the first person to use antiseptic.

Science, Technology and Society Connections

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

Physical Methods to Control Bacteria

Sterilization Process: It 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: It is usually used in microbiological labs for control of microbes. Both dry heat and moist heat are effective. Moist heat causes coagulation of proteins and kills the microbes. Dry heat causes oxidation of chemical constituents of microbes and kills them.

Radiations: Certain electromagnetic radiations below 300 nm are effective in killing of microorganisms. Gamma rays are in general use for sterilization process.

Membrane Filter: Heat sensitive compounds like antibiotics, seras, etc can be sterilized by means of membrane filters.

Pasteurization: It is the process to kill microorganisms by heating at temperature enough to kill nonspore forming bacteria e.g. milk is pasteurised by heating at 71°C for 15 seconds and at 62°C for 32 minutes. It does not change the taste of the milk. **Louis Pasteur** introduced pasterization. It minimizes the infector for typhoid and tuberculosis.

Low Temperature: Food can be preserved for several days by keeping it at a temperature between 10° – 15°C e.g. milk, vegetables, cheese and meat.

Freezing: Food can be frozen at –10°C to -18°C for several weeks to several months e.g. meat, vegetables.

Drying: The removal of water is called dehydration. Food is dehydrated so that in dry condition bacteria may not grow e.g. dried milk and dried meat.

Preservatives: 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.

Skills: Initiating and Planning

- Acquire some basic microbiological and safety techniques.

Exercise

SECTION I : MULTIPLE CHOICE QUESTIONS

Select the correct answer

1. Cyanobacteria

A) are poisoned by oxygen B) are not widely distributed

C) have chlorophyll D) have chloroplast

2. Cyanobacteria, unlike other types of bacteria that photosynthesise, do

A) not give off oxygen B) give off oxygen

C) not have chlorophyll D) not have a cell wall

3. Pili are made up of pilin, which is

A) carbohydrates B) lipids

C) protein D) triglycerides

4. 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

5. Chemosynthetic bacteria

A) are autotrophic

B) use the sun rays

C) oxidize inorganic compounds to acquire energy

D) both A and C are correct

6. A bacterium with flagella all around is

A) monotrichous B) lophotrichous

C) amphitrichous D) peritrichous

7. Conjugation is facilitated by

A) capsule B) pili

C) flagella D) both pili and flagella

8. Bacterial membrane differ from eukaryotic membrane in

A) lacking proteins B) lacking lipids

C) lacking polysaccharide D) lacking cholesterol

9. Bacterial membrane also contains enzymes for

   A) respiration B) photosynthesis

   C) protein synthesis D) secretion

10. 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

11. Ancient cyanobacteria found in fossil stromatolites, were very important in the history of life because they

   A) were probably the first living things to exist on Earth

   B) produced oxygen in the atmosphere

   C) are the oldest known archaea

   D) extracted heat from the atmosphere, cooling Earth.

12. The bacteria that cause tetanus can be killed only by prolonged heating at temperatures considerably above boiling. This suggests that tetanus bacteria

   A) are endotoxin B) are autotrophic

   C) produce endospore D) have peptidoglycan

SECTION II : SHORT QUESTIONS

1. Write the pigment composition of cyanobacteria.
2. Do you know the differences between bacteria and archea?
3. What are the morphological forms of bacteria?
4. Give the functions of following in bacteria.

(i)	ribosomes	(ii)	cell membrane	(iii)	nucleoid
(iv)	plasmid	(v)	mesosomes	(vi)	slime capsule
(vii)	flagella	(viii)	cell wall	(ix)	pili

5. How the mechanism of photosynthesis in cyanobacteria is similar and different from that of plants?
6. Draw and label structure of flagellum.
7. How chemosynthetic bacteria are autotrophic in nature?
8. Which chemical methods are, used to control microbes?
9. Give physical methods to control microbes?
10. Name any two bacteria that cause diseases in plants.
11. Name any five diseases caused by bacteria in man.
12. Define the term normal flora.
13. What is chemical composition of cell wall of bacteria?
14. Distinguish between:

    Lysosome and mesosome, Peptidoglycan and muramic acid, Gram positive and Gram negative bacteria, Lytic and lysogenic bacteria, Pathogenic and non-pathogenic bacteria, Autotrophy and heterotrophy, Photosynthetic and chemosynthetic bacteria, Mutation and mutant, Chromosome and a bacteriophage, Bacteria and mitochondria, Prokaryotes and eukaryotes, Cyanobacteria and bacteria.

15. What are plasmids?
16. How do bacteria survive under unfavorable conditions?
17. List five ways in which bacteria are beneficial to man?
18. Why cyanobacteria are considered as the most prominent of the photosynthetic bacteria?
19. What are the benefits of bacterial flora to human?

SECTION III : EXTENSIVE QUESTIONS

1. Discuss taxonomic and phylogenic position of Prokaryotes.
2. Justify occurrence of bacteria in widest range of habitats.
3. Distinguish between conjugation, transformation, transduction in bacteria? What does each accomplish?

4. Describe shape, size, and structure of bacteria
5. Give an account of economic importance of bacteria.
6. Give a detail account of Archaea.
7. Explain the use of bacteria in research and technology.
8. Bacteria exhibit unmatched diversity in methods of obtaining nutrition. Explain?
9. How might life on earth be different if bacteria had not evolved?
10. How prokaryotes are important for biosphere and human society?

ANSWER MCQS

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1. C 2. B 3. C 4. C 5. D 6. D 7. B 8. D 9. A 10. C
11. B 12. C

SUPPLEMENTARY READING MATERIAL

1. Jawetz. E and Levinson W. Medical Microbiology and Immunology. Sixth Edition Lange Madical Books/McDraw-Hill 2001.
2. Audesirk G. and Audesirk T. Biology Life on Earth. Prentice Hall, Upper Saddle River, New Jersy. 1996.
3. Sinha A.K. Fundamentals of Plant Pathology, Kalyani Publishers. New Delhi. 2001.

USEFUL WEBSITES

1) biology.about.com/library/weekly/aa030101a.html
2) biology.about.com/library/weekly/aa022201a.html
3) http://www.accessescellence.org/AB/BC/

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CHAPTER 7

PROTISTS AND FUNGI

Major Concepts:

Number of allotted teaching periods: 11

7.1 Protists – The Evolutionary Relationships (1 Period)

7.2 Major groups of Protists (4 Periods)

7.3 General characteristics of Fungi (1 Period)

7.4 Diversity among Fungi (3 Periods)

7.5 Importance of Fungi (2 Periods)

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. Biologists estimate that there are as many as 200,000 living species of protists—unicellular or simple multicellular organisms that possess a eukaryotic cellular organization. The word **protist**, from the Greek, meaning "the very first," reflects the idea that protists were the first eukaryotes to evolve. Protists are defined by exclusion from other groups.

7.1 PROTISTS – The Evolutionary Relationship

Eukaryotic cells, the unifying feature of protists, are common to complex multicellular organisms from three other kingdoms (fungi, animals, and plants) but clearly separate protists from members of the kingdom Prokaryotae (bacteria). Eukaryotic cells have nuclei and other membrane-bounded organelles such as mitochondria and plastids. There is no universal acceptance among biologists about what comprises a "protist." Many biologists, interpret the protist kingdom broadly to include heterotrophic protists (the protozoa, slime molds, and water molds) and autotrophic protists (the algae).

Polyphyletic Origin

The protist kingdom is a **polyphyletic group** of organisms; that is, protists do not share a single common ancestor. Any eukaryotic organism not considered a fungus, animal, or plant is classified in the protistic kingdom solely for convenience. If a cladist were classifying these organisms into monophyletic kingdoms, **kingdom Protista** would be split into numerous kingdoms-perhaps as many as twenty.

Protists Exibit Ramarkable Variation

The **size** varies considerably within the protist kingdom, from microscopic protozoa to giant kelps, which are brown algae that can reach 60 metres (almost 200 feet) 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 animals, fungi, and plants, multicellular protists have relatively simple body forms without specialized tissues.

Methods of obtaining nutrients differ widely in kingdom protista. The autotrophic protists, e.g. the algae have chlorophyll and photosynthesize as plants do. Some of the heterotrophic protists, 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. The **mode of life** 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 fresh water. They make up a part of the **plankton**.

Reproduction 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.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.

> Protists are divert group of organisms. The manner in which protists are currently divided is artificial.

7.2 MAJOR GROUPS OF PROTISTS

Protists include four major groups: Protozoa, Algae, Myxomycota and Oomycota. We will discuss the **salient features** of major groups of protists.

PROTOZOA: The Animal Like Protists

The name protozoa comes from the Latin word meaning "first animals" (sing, protozoon). The name was first given to animal like organisms that are not multicellular and the term protozoa is used today to designate an informal group of protists that ingest food. Protozoa are polyphyletic group.

Protozoans are mostly aquatic, **fresh water** e.g. *Amoeba*, *Paramecium*, **parasitic** e.g. *Plasmodium, Entamoeba histolytica*. Some are **marine** e.g. Actinipods. Body of the protozoan is a single mass of cytoplasm and consists of one cell containing all the structures of a typical cell. Protozoan show all the features of life e.g. nutrition, respiration, locomotion, homeostasis, reproduction etc. Protozoans have organelles called **vacuoles** to perform special function. Their food is digested inside food vacuoles. Fresh water protozoan have **contractile vacuoles** for the elimination of water. Some protozoans have shell e.g. foraminifera.

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.

Amoebas

They are free-living organisms found in fresh water, marine, soil, and also as parasites of animals. *Amoeba* move and feed with the help of pseudopodia e.g. *Amoeba proteus*, *Entamoeba histolytica*

Zooflagellates

Protozoa that move by means of flagella are called zooflagellates. *Trypanosoma* (fig. 7.2 a) is a human parasitic flagellate. It is transmitted by the bite of tse-tse (se-se) fly and it is the cause of African sleeping sickness.

Choanoflagellate is a marine or fresh water flagellate, is sessile and remains attached by a stalk. Flagellum is surrounded by a delicate collar which resembles the collar cell of sponges (fig. 7.2 b).

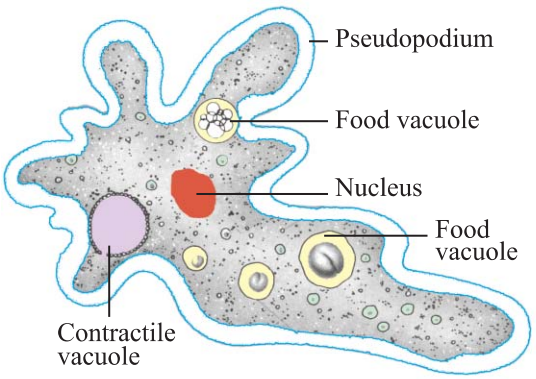
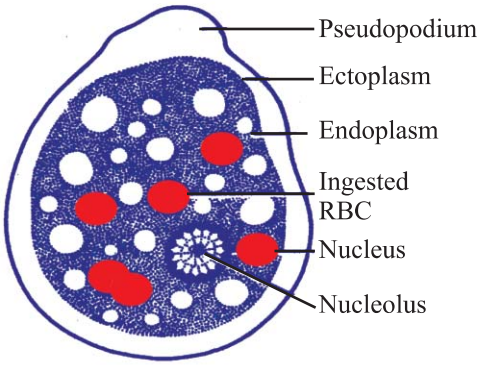


Fig: 7.1 *Amoeba proteus*



Entamoeba histolytica

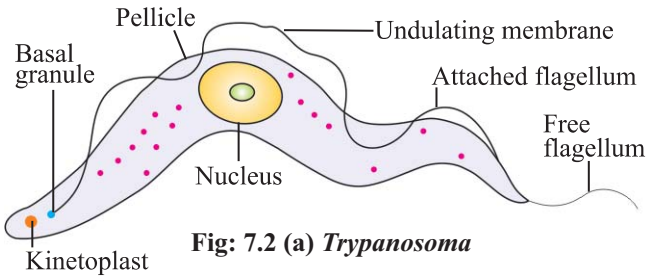


Fig: 7.2 (a) *Trypanosoma*

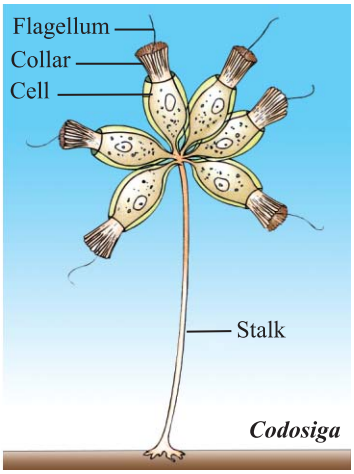


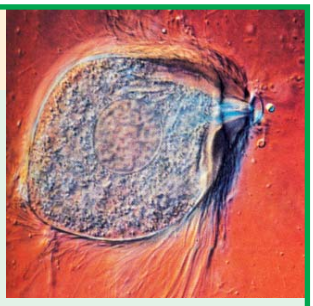
Fig: 7.2 (b) Zooflagellates A colonial Choanoflagellate

Ciliates

Ciliates get their name from a Latin word meaning "eyelash", a name that is description of the fact that all parts of these cells are covered with hair like extensions called **cilia** e.g. *Paramecium, Stentor* and *Vorticella*.

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

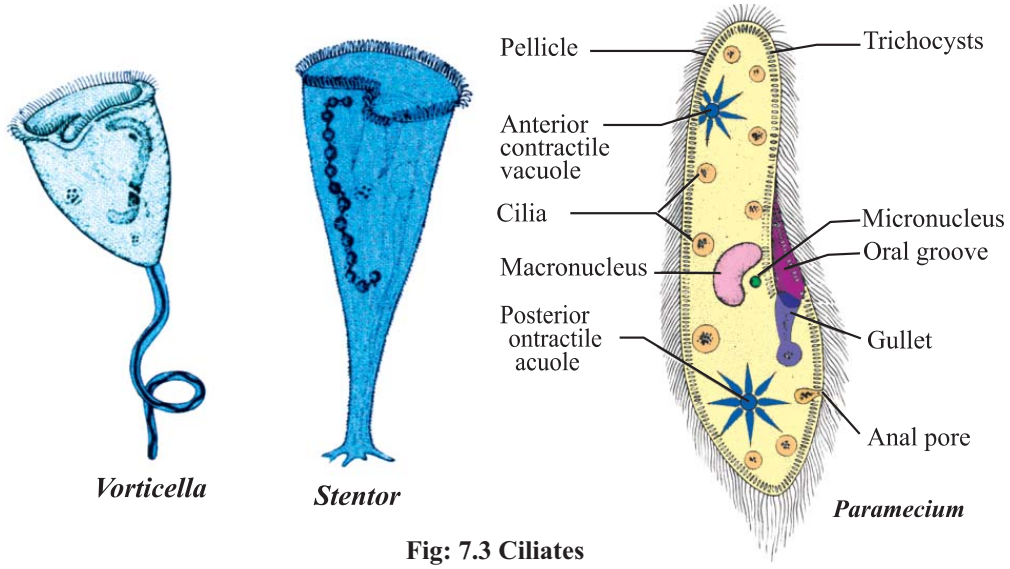


Fig: 7.3 Ciliates

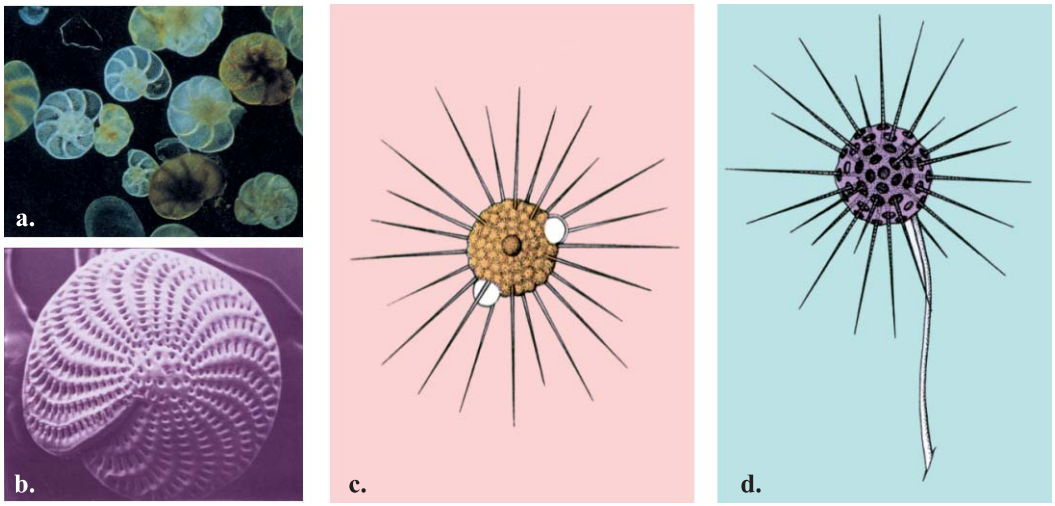


Fig: 7.4 (a, b) Foraminifera (c, d) Actinopods

Foraminifera and Actinopods

These are marine protozoans. They produce tests or shells. In foraminifera (commonly called forams) shells are made up of calcium. In actinopods shells are made up of silica.

Apicomplexans

This is a large group of parasitic protozoa. Some cause diseases in man e.g. *Plasmodium* (malarial parasite).

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. 50 to 60% photosynthesis is carried out by algae. Algae may be unicellular, filamentous or multicellular. Filaments are composed of multicellular structures, which lack cross-walls (coenocytes) or distinct cells. In multicellular algae e.g. sea weeds, the body is branched or leaflike called **thallus**. A thallus has no root, stem, leaves and vascular tissues. The photosynthetic pigments found in algae are chlorophyll "a", yellow and orange carotenoids, xanthophyll and phycoerythrin. Algal life cycle shows extreme variations. All algae except the red algae (Phylum 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. **Alga**e is classified into six phyla. The basic features and examples of each phylum are being discussed here.

Euglenoids: These are small fresh-water organisms. They are plant like in their pigments. One third of all genera have chloroplasts, the rest do not. Those which lack chloroplasts ingest or absorb their food. e.g *Euglena* (fig. 7.5)

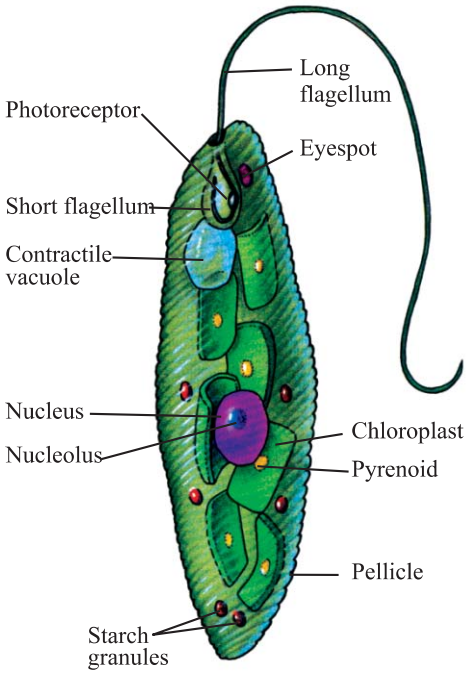


Fig: 7.5 *Euglena*

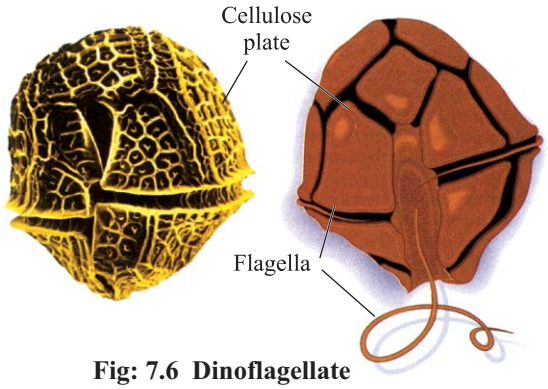


Fig: 7.6 Dinoflagellate

Science Titbits

Most dinoflagellates are unicellular and are extremely numerous and have occasional population bloom. These blooms frequently colour the ocean water orange, red or brown and are known as red tides.

Dinoflagellates: Many dinoflagellates are bounded by protective cellulose plates impregnated with silica. Most have two flagella. They vary in colour from yellow, green to brown (fig. 7.6).

Diatoms: Diatoms (fig. 7.7) are the most numerous unicellular algae in the oceans. They are also plentiful in fresh water. The structure of a diatom is often compared to a box because the cell wall has two halves, with the larger halves acting as a "lid" for the smaller half.

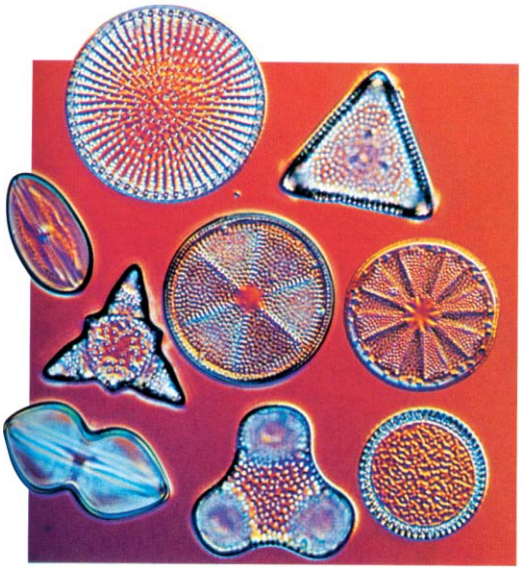


Fig: 7.7 Diatoms.

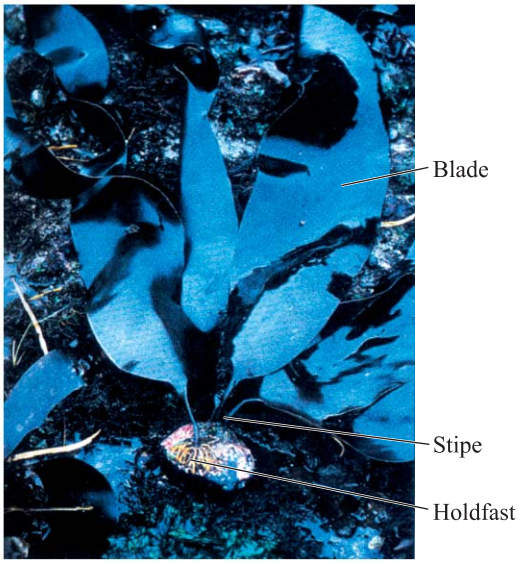


Fig: 7.8 Brown algae Laminaria

Brown Algae: Brown algae 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 are called **kelps**

Red Algae: Red algae are 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 (fig. 7.9).

Fig: 7.9 Red Algae

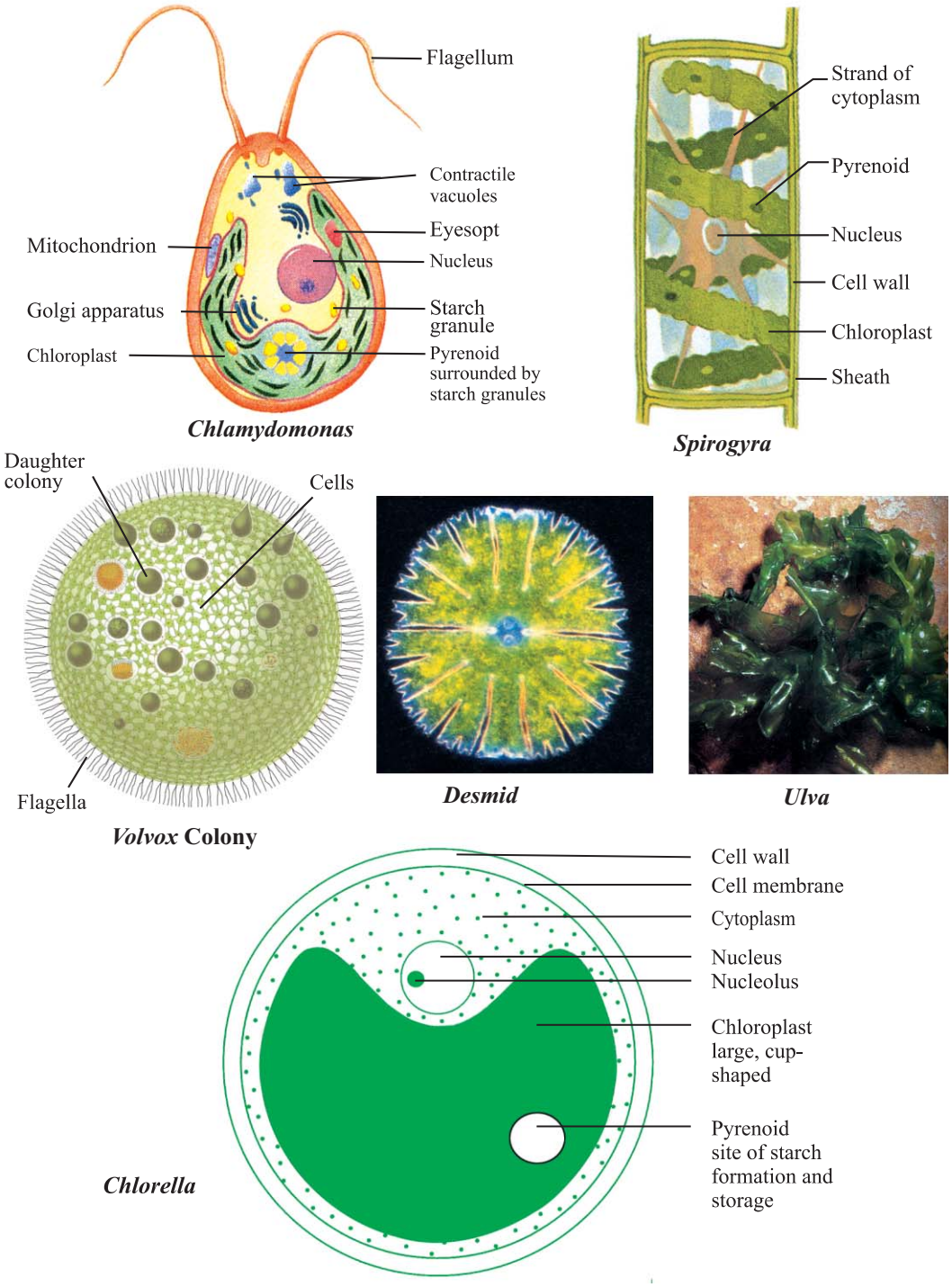


Fig: 7.10 Green Algae

Green Algae

Green algae live in the ocean but are more likely found in fresh water and can even be found on land e.g. *Chlamydomonas*, *Spirogyra*, *Volvox*, *Chlorella*, *Ulva*.

Science Titbits

Green algae are believed to be closely related to the first plants because both of these groups: Have a cell wall that contains cellulose. Possess chlorophyll **a** and **b**. Store reserve food as starch inside the chloroplast.

Fungi Like Protists: Myxomycota and Oomycota

MYXOMYCOTA: Slime Molds

Usually **plasmodial slime molds** exist as a **plasmodium**. It is a diploid multinucleated cytoplasmic mass enveloped by slime sheath. At times unfavourable to growth, such as during drought the Plasmodium develops many sporangia. A sporangium (Gk. *spora*, seed, and *angeion*, vessel) is a reproductive structure that produces spores by meiosis. In **plasmodial slime**, spores release a haploid flagellated cell or an **amoeboid cell**. Eventually two of them fuse to form a diploid **zygote** that feeds and grows, producing a

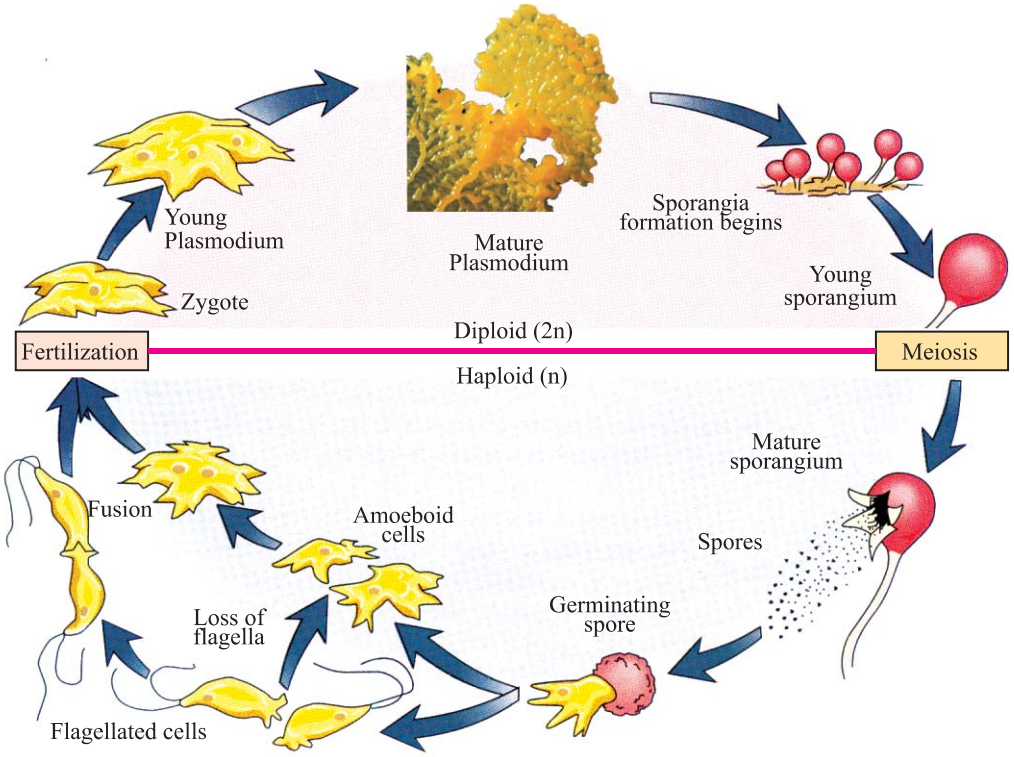


Fig: 7.11 Life Cycle of Plasmodial Slime Mold (*Physarum*)

multinucleated Plasmodium once again. Characteristics of slime molds are interesting to biologists because the life cycle involves many changes in form. These different forms resemble other types of protists.

Science Titbits

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.

OOMYCOTA: The Water Molds

Oomycotes include water molds, white rusts and downy mildews. The characteristics of oomycotes are: All of the members of the group are either parasites or saprotrophs. The cell wall contains cellulose, not chitin like fungi. Their life cycles are characterized by gametic meiosis resulting in a diploid phase. The filamentous structures are called **hyphae** as in fungi. The hyphae are **aseptate** i.e. without intercellular cell wall. Most oomycotes live in fresh water or salt water or in soil. Some are plant parasites. A few aquatic oomycotes are animal parasites. **Zoospores** are motile and have two flagella. Zoospores are produced asexually in sporangium. For sexual reproduction there are two types of

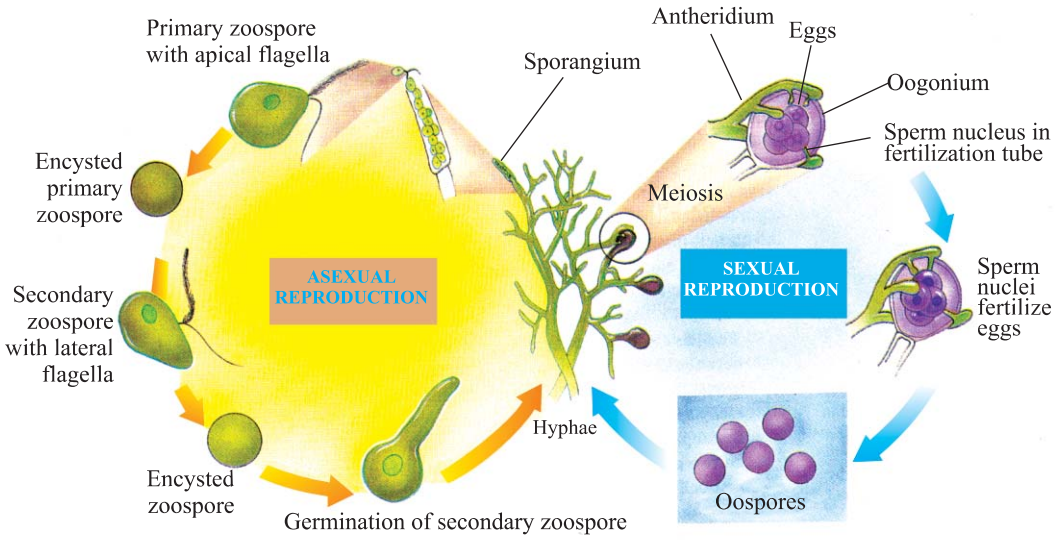


Fig: 7.12 Life cycle of Oomycotes

gametangia. The female gamentagium is called **oogonium** and the male gamentagium is called an **antheridium**. The antheridia contain numerous male nuclei, which are functional male gametes and the oogonia contain from one to eight eggs which are female gametes. 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 is followed by the thickening of the cell wall around the resulting zygote or zygotes. This produces a special kind of thick walled cell called an **oospore**. The structure gives the phylum its name i.e. phylum oomycota e.g. *Phytopthora infestans*.

Importance of Protists to Humans

Some dinoflagellates at times produce a neurotoxin that can kill fish and cause paralytic shell fish, poisoning humans who eat shell fish that have fed on these dinoflagellates and suffer paralysis of the respiratory muscles. Usually the dinoflagellates are an important source of food for small animals in the ocean.

Diatoms are an important source of food and oxygen for heterotroph in both fresh water and marine ecosystem. **Brown algae** not only provides food to organisms, but is also harvested for human food and for fertilizer in several parts of the world.

Red algae are economically important. The mucilaginous material in the cell walls of certain genera of red algae is a source of agar used commercially to make capsules for vitamins and drugs, as a material for making dental impression and a base for cosmetics. In laboratory agar is a culture medium for bacteria.

Green algae are important producers. *Chlorella* has been used as an experimental organism in research in photosynthesis. A relatively new food source is single cell protein (SCP). In Japan and Taiwan dried *Chlorella* is sold as 'health food.'

Malaria caused by *Plasmodium*, is one of the world's most common serious infectious disease. According to world health organization about one to two million people die each year from malaria.

Other important protozoans are *Entamoeba histolytica* causes amoebic dysentery, *Trypanosoma* causes sleeping sickness. Some amoeba like *Acanthamoeba* usually free living but can produce opportunist infections such as eye infections in contact lens users. In oceans, fresh water lakes and ponds, are **zooplanktons** that feed on phytoplanktans, and are important as primary consumers in the food chain.

Potato plants infected with *Phytopthora infestans* show individual leaflets, with small, brown, dead and blighted areas. It obtains its nourishment from the mesophyll cell by short specialized branches known as **haustoria** (singular, *haustorium*) which penetrate them. Some sporangia may fall to the ground and infects tubers. As a result the whole plant is killed. It can be prevented by not planting infected tubers. All diseased parts of the infected plant should be destroyed before lifting tubers.

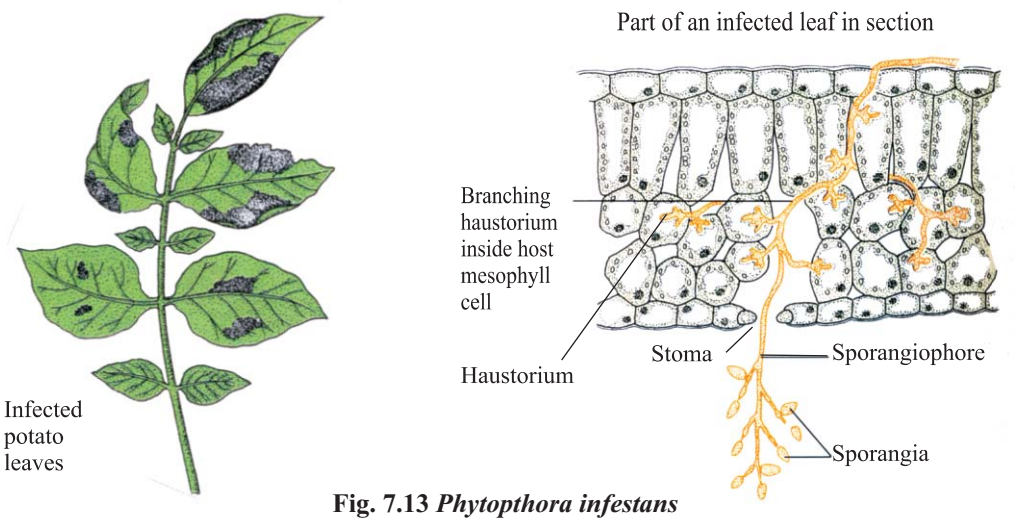


Fig. 7.13 ***Phytopthora infestans***

Science, Technology and Society Connections

Explain what clues protists provide with respect to the evolution of the three kingdoms of eukaryotes.

7.3 GENERAL CHARACTRERISTICS OF FUNGI

Fungi do not have root stem or leaves. Fungi (singular, fungus) can live in darkness and also in light. The study of fungi is called **mycology**. The person who studies fungi is called **mycologist**.

Fungi occupy a wide range of **habitats**, aquatic, terrestrial and as parasites on plants and animals. The **mode of life** shows that fungi can be parasites, saprotrophs or mutualists. Fungi range in **size** from the unicellular yeasts to the large toadstool. Fungi lack chlorophyll, so they are nonphotosynthetic. Thus **mode of nutrition** is heterotrophic. Digestion takes place outside the body and nutrients are absorbed directly. **Cell walls** are rigid containing chitin as fibrillar material. If carbohydrate is stored, it is usually as glycogen and not starch. The thallus or the body of most fungi is a

multicellular structure known as **mycelium**. A mycelium (Gk: *mycelium*, fungus filaments) (pl. mycelia) is a network of filaments called **hyphae** (Gk: *hyphae*, web). Hyphae give the mycelium quite a large surface area per volume of cytoplasm, and this facilitates absorption of nutrients into body of the fungus. The hyphae may be nonseptate (aseptate) or septate. Nonseptate (*L. septum*, wall) hyphae have no cross walls, are multinucleated i.e. they have many nuclei in the cytoplasm, such hyphae are called coenocytic hyphae. e.g. *Rhizopus*. Septate fungi have cross wall e.g. *Penicillium*. 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. A fungus reproduces both asexually and sexually.

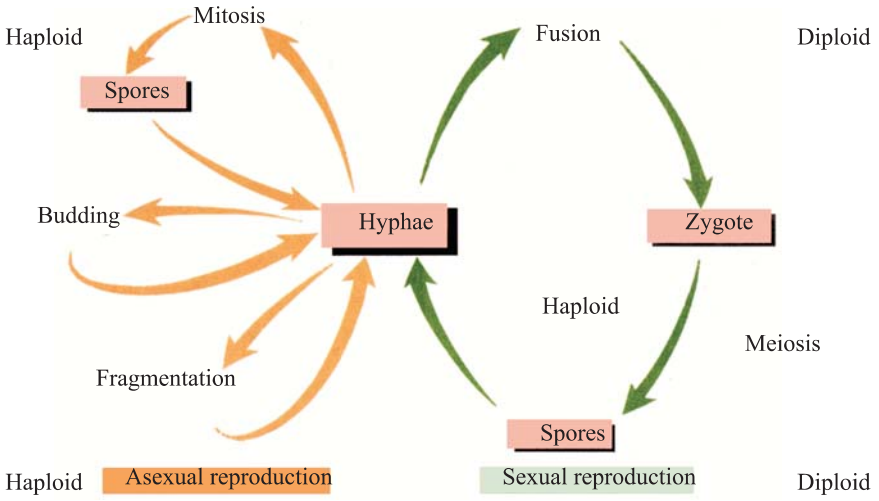


Fig. 14 (a) A Generalised life cycle for Fungi. Fungi alternate between sexual and asexual reproductive stages

Why Fungi are Classified as Separate Kingdom?

According to five kingdom system of classification, 'Fungi' is now a separate kingdom. Fungi have resemblance with plants in: (1) having cell wall (2) lack centriole (3) are non-motile (4) produce spore and sporangium. Fungi different from plants as : (1) fungi have no cholorophyll (2) fungi never have flagella (2) fungi are saprotrophs.

Fungi resemble animals. Both: (a) are heterotrophs (b) lack cellulose in their cell wall and contain chitin so it is thought that fungi and animals arise from common ancestors. Fungi are different from animals. Fungi: (i) have cell wall (ii) are absorptive heterotrophs (iii) are non-motile.

So fungi are neither plants nor animals. They show "nuclear mitosis". During nuclear mitosis nuclear envelope does not break, instead the mitotic spindle forms within the nucleus and the nuclear membrane constricts between the two clusters of daughter chromosomes. In some fungi nuclear envelope dismantles late.

Fungi were originally classified in the plant kingdom, but biologists today recognize that they are not plants. Interestingly, recent studies suggest that fungi are more closely related to animals than to plants. Because fungi are distinct from plants, animals and other eukaryotes in many ways, they are assigned to a separate kingdom-fungi.

7.4 DIVERSITY AMONG FUNGI

The kingdom fungi are diverse group of more than 100000 known species most of which are terrestrial. The ancestry of fungi which evolved about 570 millions 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. Fungi are mostly multicellular eukaryotes of varied structure that share a common mode of nutrition.

Classification of Fungi

Classification of fungi into four main groups is based primarily on the type of their sexual reproductive structures and methods of reproduction. However, these groups also differ in the type of hyphae and some other characters.

Zygomycota (Conjugating Fungi)

The phylum or division zygomycota are called zygospore fungi, and mainly 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 reproductions** takes place by conidia or spores. e.g. *Rhizopus nigricans*. It is known as black or bread molds. It is a mass of mycelium. Asexual reproduction in *Rhizopus* takes place by the sporangia containing spores.

Sexual reproduction takes place by **conjugation**. Conjugation occurs only between a member of a plus (+) strain and one of a minus (-) strain. 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

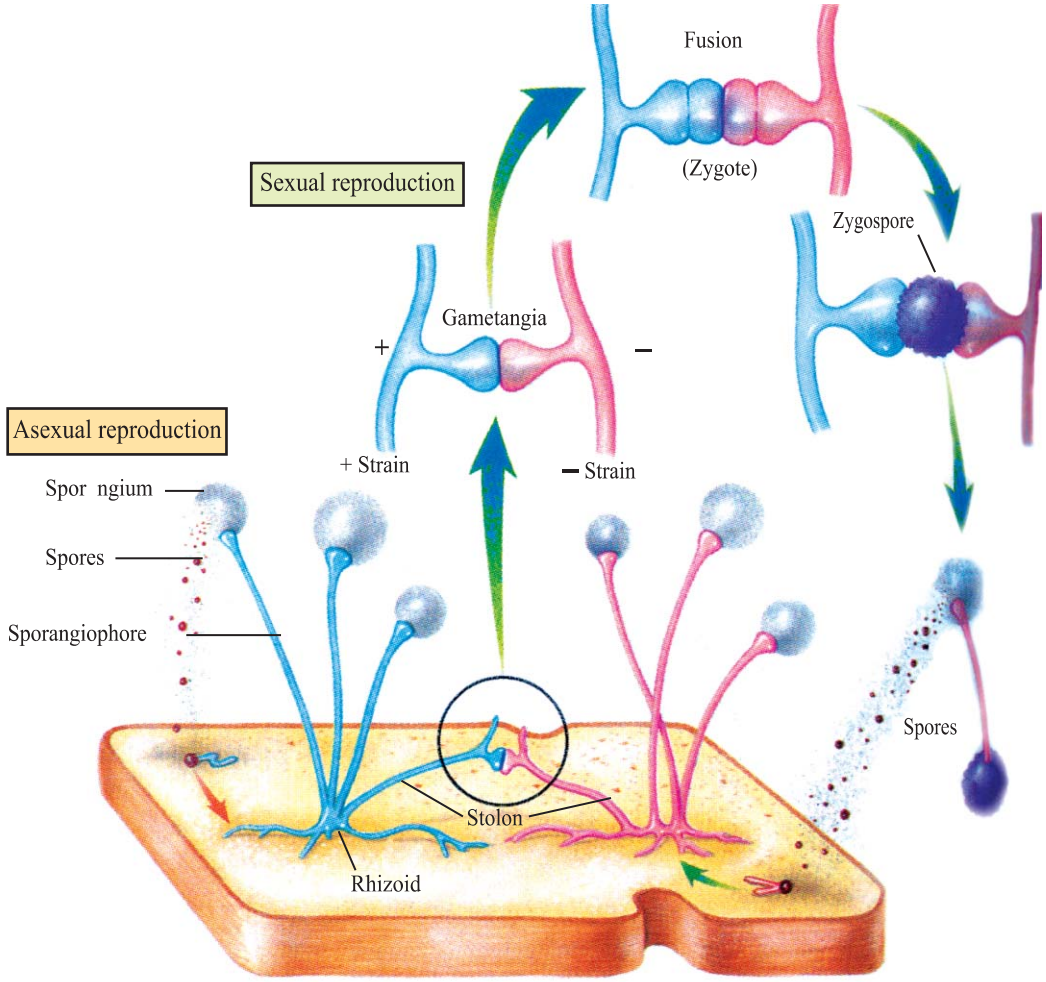


Fig: 7.15 Reproduction in *Rhizopus*

the mycelium by the formation of **septa**. Plus and minus nuclei then fuse to form a diploid nucleus, the **zygote**. The zygote develops into a **zygospore**. The wall of the zygospore is thick and resistant to unfavourable conditions. 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 hyphae 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. Thus the life cycle of *Rhizopus* is continued.

Q. What is the purpose of sporangiophores?

Ascomycota (Sac Fungi)

Ascomycotes are the members of phylum or division ascomycota. It is a large group. Ascomycotes are also known as **sac fungi** because their sexual spores are produced in little sacs called **asci** (sing: *ascus*). Their hyphae usually have septa but the cross walls are perforated so that cytoplasm can move from one compartment to other. Ascomycotes reproduce both asexually and sexually.

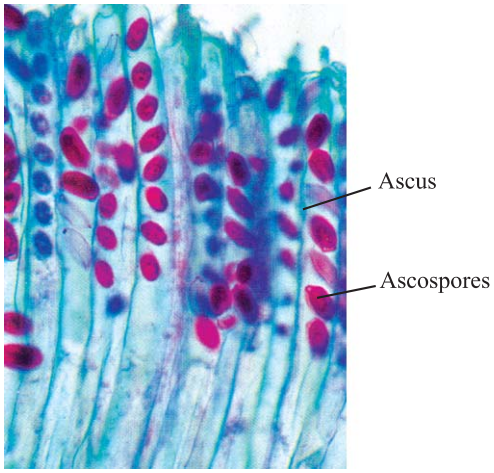


Fig: 7.16 Asci and Ascospore

Asexual reproduction involves production of spores called **conidia** (singular: *conidium*) or **conidiospores** (Gk: *konis*, dust, and *spora*, seed). Conidia vary in shape, size and may be multicellular. There are no sporangia in Ascomycotes.

Fig: 7.17 Conidia

The conidia develop directly on the tips of modified aerial hyphae called **conidiophores**. When released conidia are wind blown. Conidia occur in various shapes, sizes and colours in different species. 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**. In this process a small protuberance (bud) grows and eventually separates from the parent cell. Each bud can grow into a new yeast cell. Yeast also reproduces asexually by fission.

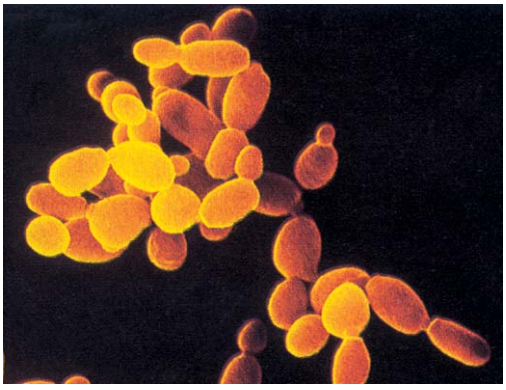


Fig: 7.18 Budding in Yeast

Sexual reproduction takes place after two hyphae grow together and their cytoplasm mingles. Within

this fused structure, 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 n + n hyphae form a fruiting body known as **ascocarp**.

The **asci** develop in the ascocarp. The asci are usually surrounded by sterile hyphae. An ascocarp is a **fruiting body**. It is a reproductive structure where spores are produced and released. 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**.

So there are usually eight haploid ascospores within the ascus. In most ascomycotes the asci become swollen as they mature and then they burst liberating the ascospores, which are then wind blown if lands in a suitable location and germinates to form a new mycelium. e.g. in Yeasts, *Neurospora* etc. Sac fungi produce sexual conidiospores. During sexual reproduction, asci within a fruiting body produce conidiospores. The examples of sac fungi are Yeasts, *Neurospora*, Morels,Truffles.

Basidiomycota (Club-Fungi)

Basidiomycotes are included in the phylum **Basidiomycota**. Included in this phylum are mushrooms, bracket fungi, rust, smut and puffballs. These structures are all fruiting bodies called **basidiocarps**. Basidiocarp contains the basidia. Each **basidium** is a club shaped structure. It is a hyphal cell on the tip of which develops four **basidiospores**, from which this phylum takes its name. Each individual fungus produces millions of basidiospores and each basidiospore has the potential to give rise to a new primary mycelium. Hyphae of primary mycelium are composed of monokaryotic (n) cells. The mycelium of a basidiomycote e.g. *Agaricus* (Mushroom), consists of mass of white, branched, thread like hyphae that occur mostly below ground. The hyphae are divided into cells by septa. The **septa** are perforated and allow cytoplasmic streaming between cells.

Although club fungi occasionally do produce conidiospores asexually, they usually **reproduce** sexually. 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 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** grows and forms 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 more formally referred to as **basidiocarp**. Each basidiocarp actually consists of interwined hyphae that are matted together.

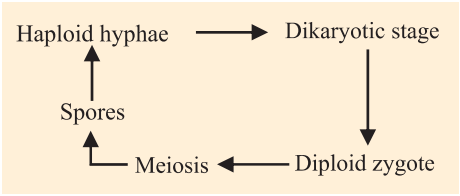


Fig. 7.19 Main Steps of Life Cycle of a Mushroom

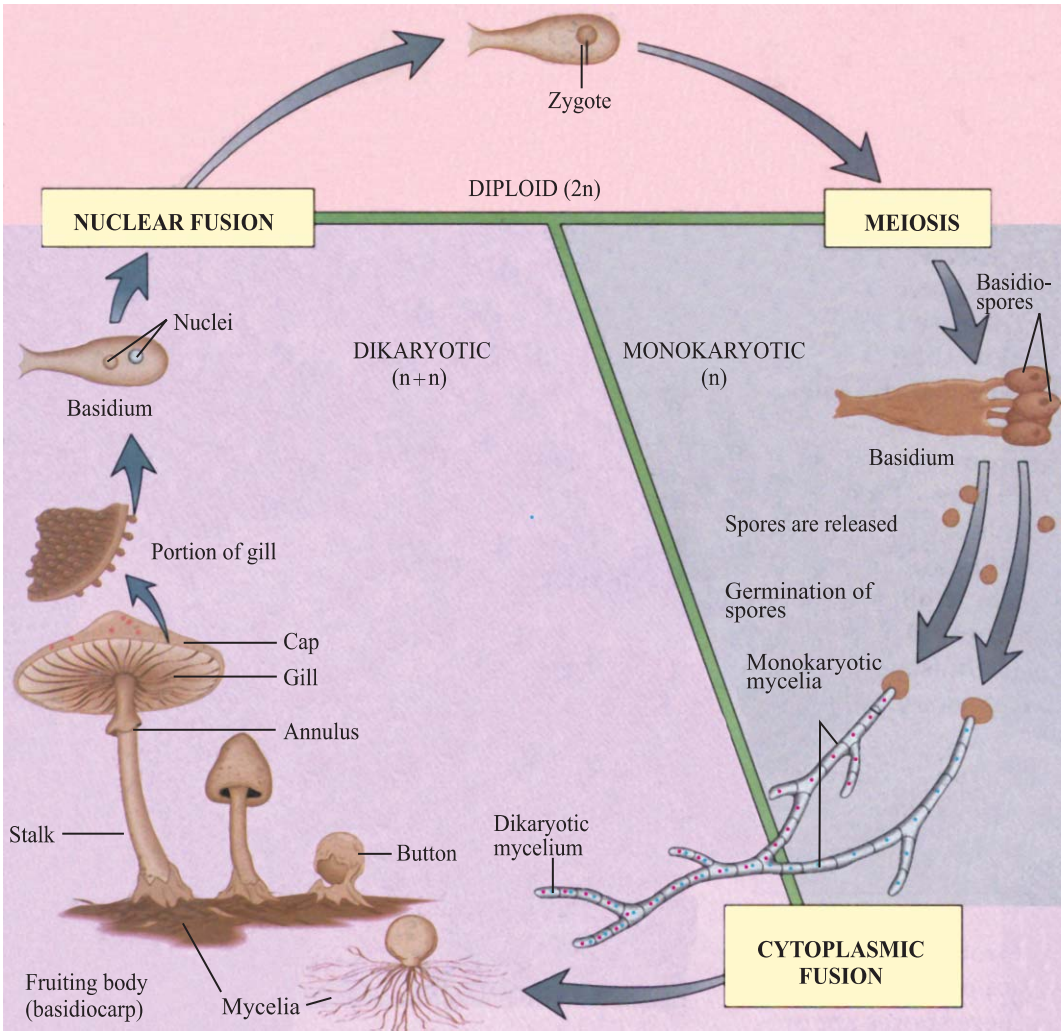


Fig: 7.20 Life Cycle of a Mushroom

The walled off ends of the tightly packed hyphae become the club shaped basidia. 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 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.

Deuteromycota (Imperfect Fungi)

These fungi are called "imperfect" fungi because of the absence of the sexual stage in their life cycle. Imperfect fungi always reproduce asexually by forming conidiospores.

Usually cellular morphology and biochemistry indicate that these fungi are sac fungi which have lost the ability to reproduce sexually. These fungi live either saprophytically or parasitically on plants. Several imperfect fungi have economic importance. The examples of imperfect fungi are: *Penicillium*, *Aspergillus*, *Alternaria* and *Fusarium*.

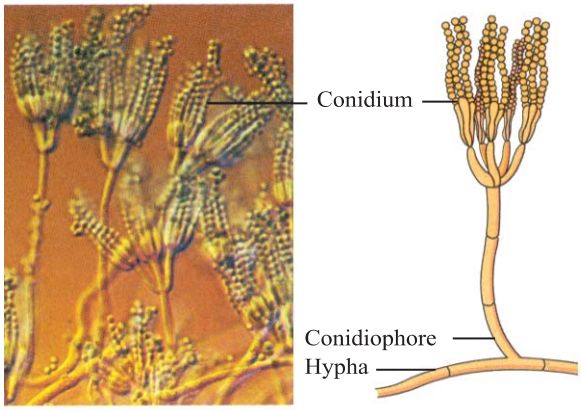
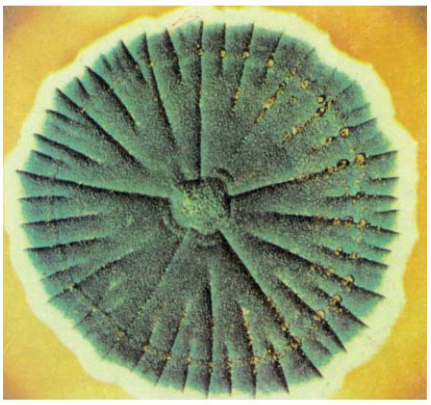


Fig. 7. 21(a) *Penicillium*



(b) *Penicillium* **Colony**

Science Titbits

Despite absence of sexual reproduction, imperfect fungi show special kind of genetic recombination, called parasexuality, in which portions of chromosomes of two nuclei lying in the same hypha are exchanged.

7.5 IMPORTANCE OF FUNGI

Fungi cause economic gains as well as losses. People eat them and grow them to make various chemicals. Fungi cause diseases in humans, other animals and plants. Their activities cost billions of dollars in agricultural damage yearly.

Importance of Yeast

The ability of yeasts to produce ethyl alcohol and carbon dioxide from sugars such as glucose by fermentation is utilized to make wine, beer and other fermented beverages and also to make bread.

Brewing: Wine is produced when yeasts ferment fruit sugars and beer results when yeasts ferment sugars derived from starch in grains (usually barley).

Baking: During the process of making bread, carbon dioxide produced by yeast becomes trapped in dough as bubbles, causing the dough to rise; this is what gives leavened bread its light texture. Both the carbon dioxide and the alcohol produced by the yeast evaporate during baking.

Genetic Research: Yeasts are used in biological research especially in the genetic research. For example yeasts have been used to study mutation, genetic recombination and laws of segregations and effect of many chemicals and medicine.

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 some time 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.

Science, Technology and Society Connections

Describe how helpful fungi have been for us as source of antibiotics and other useful chemicals.

Table: 7.6 Antibiotics Obtained From Fungi			
Name of Fungus		Anitibiotics	
1	*Aspergillus fumigatus*	1	Fumigatin
2	*Cephalosporin acremonium*	2	Cephalosporin
3	*Penicillium chrysogenum*	3	Penicillin
4	*Penicillium nigricans*	4	Grisofulvin
5	*Tolypocladium inflatum*	5	Cyclosporins

MUTULISM: Lichen and Mycorrhizae

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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

Lichens are an association between a fungus (mostly Ascomycotes and imperfect fungi and a few basidiomycotes), a cyanobacterium or green alga. The body of a 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.

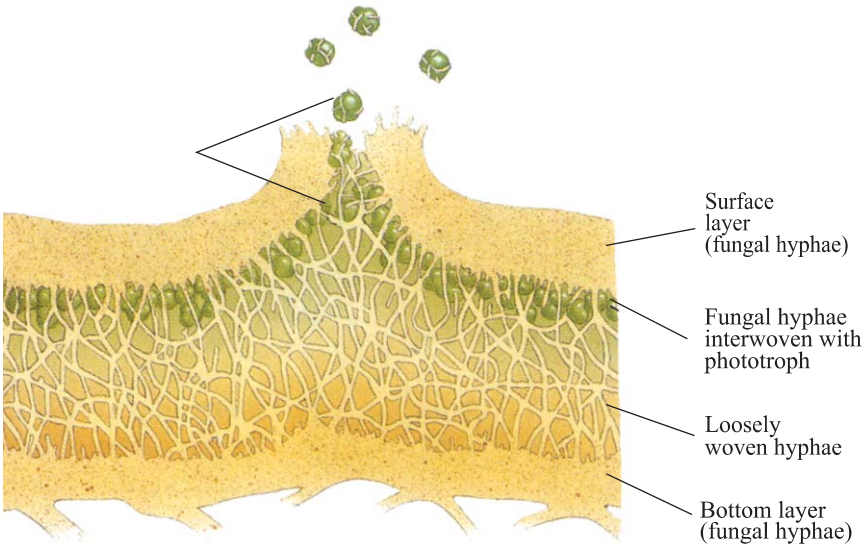

Fig: 7.22 A Cross Section of Lichen

In past lichens were assumed to have mutualistic relationships in which the fungus received nutrients from the algae cells and the algae cells were protected from dessication by the fungus. Actually lichens might involve a controlled form of parasitism of the algae cells by the fungus.

Mycorrhizae

Mycorrhizae are mutualistic relationships between soil fungi and the roots of most plants. This association occurs in 95% of all families of higher plants. Fungal hyphae increases the amount of soil contact and total surface area for absorption. 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 mycelium extends far out into the soil.

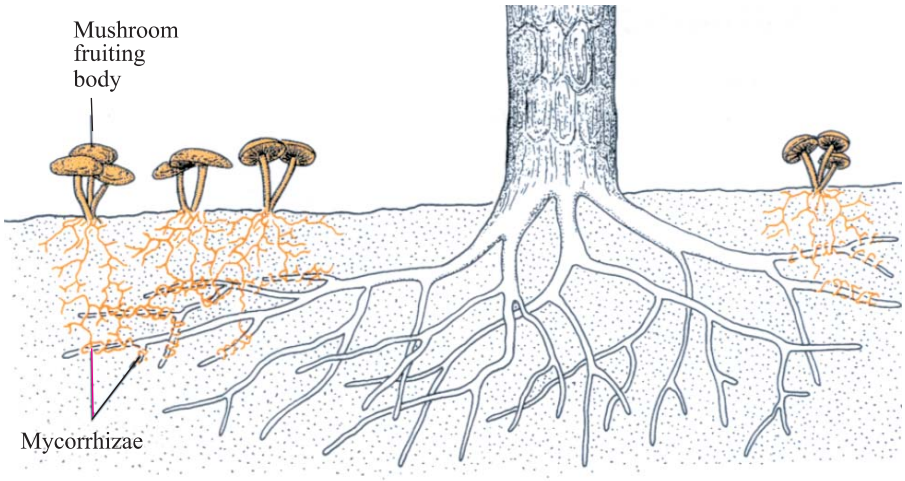

Fig: 7.23 Mycorrhizae

Endomycorrhizae

These penetrate only into the outer cells of plant root forming coils, swellings and minute branches and also extend out into surrounding soil.

Ectomycorrhizae

These form a mantle that is exterior to the root, and they grow between cell walls. These are mostly formed with pines, firs etc.

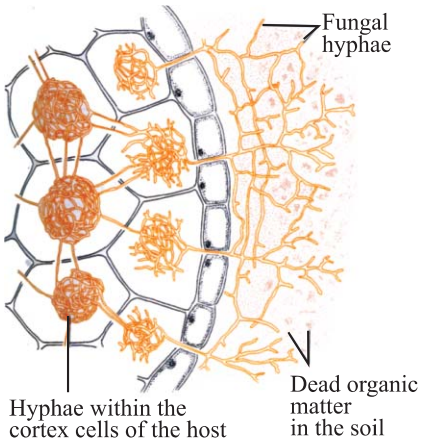

Fig: 7.24 Endomycorrhizae

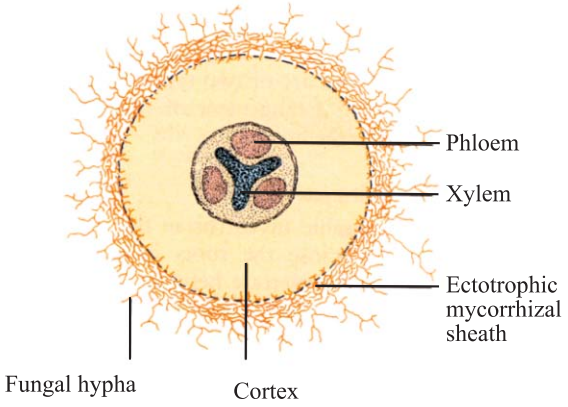

Fig: 7.25 Ectomycorrhizae

Edible Fungi

Aspergillus tamarii and other imperfect fungi are used in the Orient to produce soy sauce by fermenting soy beans. Among the basidiomyco tes, there are some 200 kinds of edible mushrooms (*Agaricus*) and about 70 species of **poisonous** ones, sometimes called **toadstools**. Some edible mushrooms are cultivated commercially. (*Morchella esculenta*), which superficially resemble mushrooms and **truffles**, which produce underground fruiting bodies, are ascomycotes.

Fig: 7. 26 Truffel Fungi

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 he 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 in toxication and hallucinations.

Fig: 7.27 Amanita

Fig: 7.28 Jack-o lantern

Ecological Impact of Fungi

Fungi make important contributions to the ecological balance of our world. Like bacteria, most fungi are saprotrophs, decomposes and absorb nutrients from organic wastes and dead organisms. In this way fungi help in maintaining the nutrient balance in nature. It is done in three ways.

Removal of organic debris: The organic waste is removed from the environment by the activity of saprotrophic fungi and bacteria. In the absence of it, the Earth would be covered by organic waste, which will make life difficult.

Liberation of Carbon dioxide: 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.

Humus: It is an important constituent of soil and essential for the proper growth of plants. It is found from the organic waste material through the activities of fungi and bacteria.

Pathogenic Role of Fungi

Fungi cause many important diseases in plants and also in animals including human beings.

Fungi Cause 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 casued by basidiomycotes include smuts and rusts that attack various plants - for example the cereal crops of corn, wheat, oats etc.

Fig: 7.29 Brown Rot of Peaches *(Monilinia fruticola* an ascomycote)

Fig: 7.30 Ergot Infection of rye, *(Claviceps purpurea,* sac fungi)

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.

Rusts

Powdery mildews on grapes, roses and wheat, ergot of rye, red rot of sugar, potato wilt, cotton root rot, apple scab, brown rot of peaches, plums, apricots and cherries etc are common plant diseases caused by fungi.

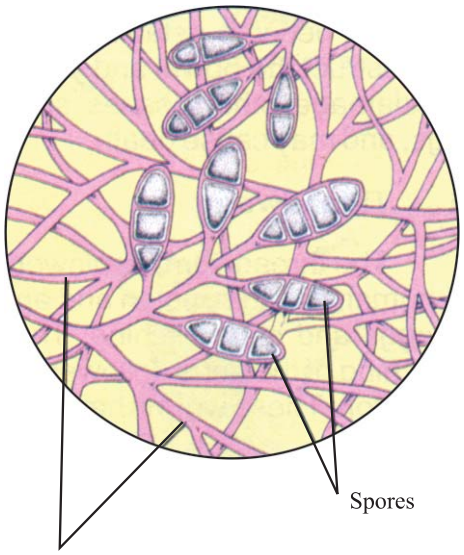

Fig: 7.31 Ringworm (*Microsporium audouni*)

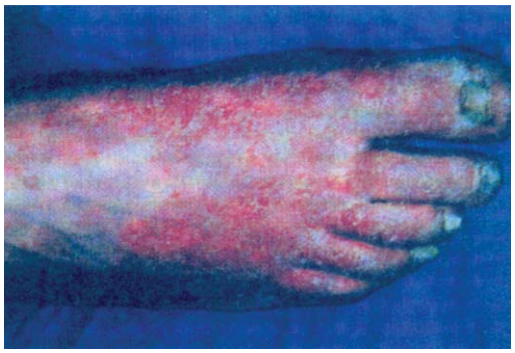

Fig: 7.32 Athlete's foot

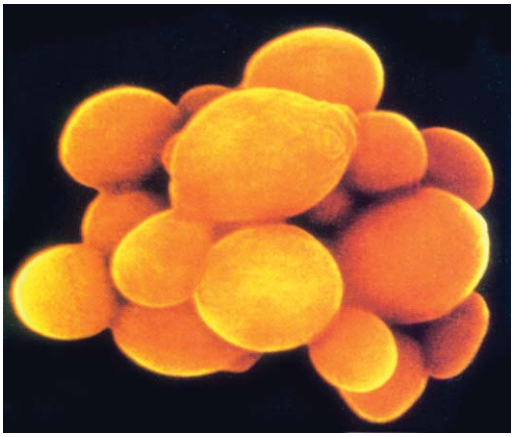

Fig: 7.33 *Candida* (Candidiasis)

Fungi Cause Animal Diseases

Some fungi cause superficial infections in which only the skin, hair, or nails are infected. Ringworm (*Microsporium audouni*) and athlete's foot (*Tinea pedis*) are examples of superficial fungal infections; both are caused by imperfect fungi. **Candidiasis**, a yeast infection of mucous membranes of the mouth or vagina, is among the most common fungal infections.

Other fungi cause systemic infections that infect internal tissues and organs and may spread through many regions of the body. **Histoplasmosis**, for example, is a serious infection of the lungs caused by inhaling spores of a soil fungus.

Aspergillus fumigatus causes **aspergillosis** which may cause death to persons with defective immune system. Some strains of *Aspergillus flavus* produce **aflatoxin**, a cancer causing mycotoxins in improperly stored grains of peanut, corn etc. **Ergotism** is caused by purple ergot rye. It causes nervous spasm, convulsion, psychotic delusion and even gangrene.

Exercise

SECTION I : MULTIPLE CHOICE QUESTIONS

Select the correct answer

1. 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
2. The cell wall consists of two over lapping shells in
   A) euglenoids B) diatoms
   C) dinoflagellates D) brown algae
3. Which of the following structure would you expect to find in the corn smut fungus?
   A) ascospores B) basidiospores
   C) zoospores D) zygosopres
4. The feeding stage of a slime mold is called
   A) hyphae B) plasmodium
   C) rhizoids D) mycelium
5. Which is found in slime molds but not in fungi?
   A) non-motile spores B) amoeboid adult
   C) zygote formation D) photosynthesis
6. Fungi resemble animals because they are
   A) saprotrophs B) autotrophs
   C) heterotrophs D) heterosporous

7. Fungi cell walls contain chitin, which is also found in exoskeleton of

   A) arthropods B) molluscs

   C) echinoderms D) chordates

8. Poisonous mushrooms are called

   A) toadstools B) morels

   C) truffles D) tuber

9. Which of the following is associated with asexual reproduction in fungi

   A) zygospores B) ascospores

   C) basidiospores D) conidia

10. Imperfect fungi are called imperfect because

   A) they have no zygospores

   B) they cause diseases

   C) they form conidiospores

   D) sexual reproduction has not been observed

SECTION II : SHORT QUESTIONS

1. Name the three eukaryotic kingdoms.
2. How do ciliates differ from other protozoans?
3. How do algae differ from plants?
4. What are diatoms?
5. Write two characteristics of:

   (a) Protozoa (b) Dianoflagelles (c) Diatoms

   (d) Slime mold (e) Oomycotes

6. How fungi resemble plants?
7. Define coenocytic hyphae.
8. How fungi get their nutrition?
9. Name the fungal mutualistic associations.

10. List the methods of asexual reproduction in fungi.
11. What is zygospore and how it is formed?
12. Where basidiospores are produced?
13. What do you mean by imperfect fungi. Why they are given this name?
14. What is histoplasmosis?
15. Write one difference between: (a) Fungi and Plants. (b) Fungi and Animals. (c) Zygomycota and Basidiomycota. (d) Sporangium and Conidium. (e) Ascus and Basidium. (f) Diakaryotic and Diploid. (g) Ascocarp, Ascus and Ascospores. (h) Basidiocarp, Basidium and Basidiosopres. (i) Endomycorrhizae and Ectomycorrhizae.
16. List some fungi that attack crops. In what division is each found?
17. List the differences between bacteria and fungi.
18. Why are fungi and plants are classified in different kingdom?
19. What ecological consequences would occur if all fungi on Earth were destroyed by human using a new and deadly fungisides?

SECTION III : EXTENSIVE QUESTIONS

1. What are the important features of protists.
2. Write the reasons for a separate kingdom, protista.
3. Explain the importance of protists.
4. Discuss general characteristics of algae.
5. Describe structure and reproduction of slime mold.
6. Write features that distinguish oomycotes from fungi.
7. Give some important features of Basidiomycotes.
8. Write general characteristics of fungi.
9. Discuss taxonomic status of fungi.
10. List the major divisions of fungi, describe the feature that gives each of its name, and give one example of each.

11. Give an account of beneficial fungi and harmful fungi.

12. Discuss pathogenic role of fungi.

13. Explain the term club fungi. Draw and explain a diagram of the life cycle of a typical mushroom.

ANSWER MCQS

1. C 2. B 3. B 4.B 5. B 6. C 7. A 8. A 9. D 10. D

SUPPLEMENTARY READING MATERIAL

1. Lewis, R. "A New Place for Fungi?" Bioscience 44:6, June 1994

USEFUL WEBSITES

1. www.prenhall.com/~audesirk
2. www.scigenics.com/index.html
3. www.newsscientist.com/
4. www.prairiepublic.org/features/healthworks/antibiotics/

www.learningall.com

CHAPTER 8

DIVERSITY AMONG PLANTS

Major Concepts:

Number of allotted teaching periods: 20

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. These range in size from minute, almost microscopic duckweeds, to massive giant sequolas, some of them are the largest organisms that has ever lived.

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. Plants are thought to have descended from a common protistan ancestor, an ancient freshwater alga. Because of their common ancestory the living green algae and plants share a number of features.

Both contain the same photosynthetic pigments: **chlorophylls** a and b, **carotenes** and **xanthophylls**. Both store **carbohydrates** as starch inside

chloroplast. Both have cellulose in cell wall. Both types of organisms form a cell plate during cytokinesis. Plants and some algae have a two-generation life cycle called **alternation of generation** that involves sporic meiosis.

Diagnostic Features of Plants

The diagnostic features of plants are :

(1) Plants are multicellular eukaryotes with well-developed tissue and have autotrophic nutrition.

(2) Plants are well protected from being dried up in air by their cuticle, formed from a waxy substance called **cutin**.

(3) The plant body has root, stems and leaves having vascular tissue xylem, phloem and **cellulose** rich **cell walls**,

(4) 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.

(5) The plants are oogamous; the gametes are eggs and sperms.

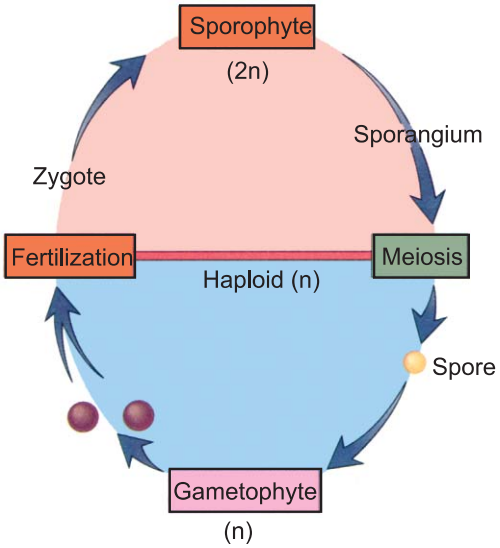

Fig: 8.1 Alternation of Generation

Four major groups of plants are living today. These are: (a) Bryophytes, (b) Seedless vascular plants, (c) Gymnosperms, (d) Angiosperms.

Bryophytes are small plants that lack vascular tissues and reproduce by spores. The other three groups of plants have vascular tissues xylem and phloem. Seedless vascular plants reproduce by spores like bryophytes. Gymnosperms are vascular plants and reproduce by forming seeds, borne exposed on a stem or cone. Angiosperms are vascular plants, which reproduce by forming seeds enclosed within a fruit.

8.2 NON-VASCULAR PLANTS

Plants are currently divided into two main groups: the nonvascular and the vascular plants. The nonvascular plants consist of three groups: hornworts (division Anthocerotophyta), liverworts (division Hepatophyta), and mosses (division Bryophyta).

The nonvascular plants lack vascular tissues specialized means of transporting water and organic nutrients. Although they often have a "leafy" appearance, these plants do not have true roots, stems, and leaves—which by definition must contain true vascular tissue. Therefore, the nonvascular plants are said to have rootlike, stemlike, and leaflike structures.

General Characteristics of Bryophytes

Bryophytes is considered as a phylum and also as a group or division. The bryophyta is a group of plants comprising of liverworts, hornworts and mosses are the only nonvascular plants. 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 evident 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.

The four 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.

Fig: 8.2 Mosses Covering Several Rocks

(4) Their life cycles are similar to seed plants. Bryophytes are also called **amphibious plants** because they need water for development, existence and reproduction.

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** *(ar-keh-gonium)*. 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.

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 is called thallus and is multicellular e.g. *Marchantia* (*Mar-kan-shia*). The **thallus** consists of hundreds of cells. 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

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.

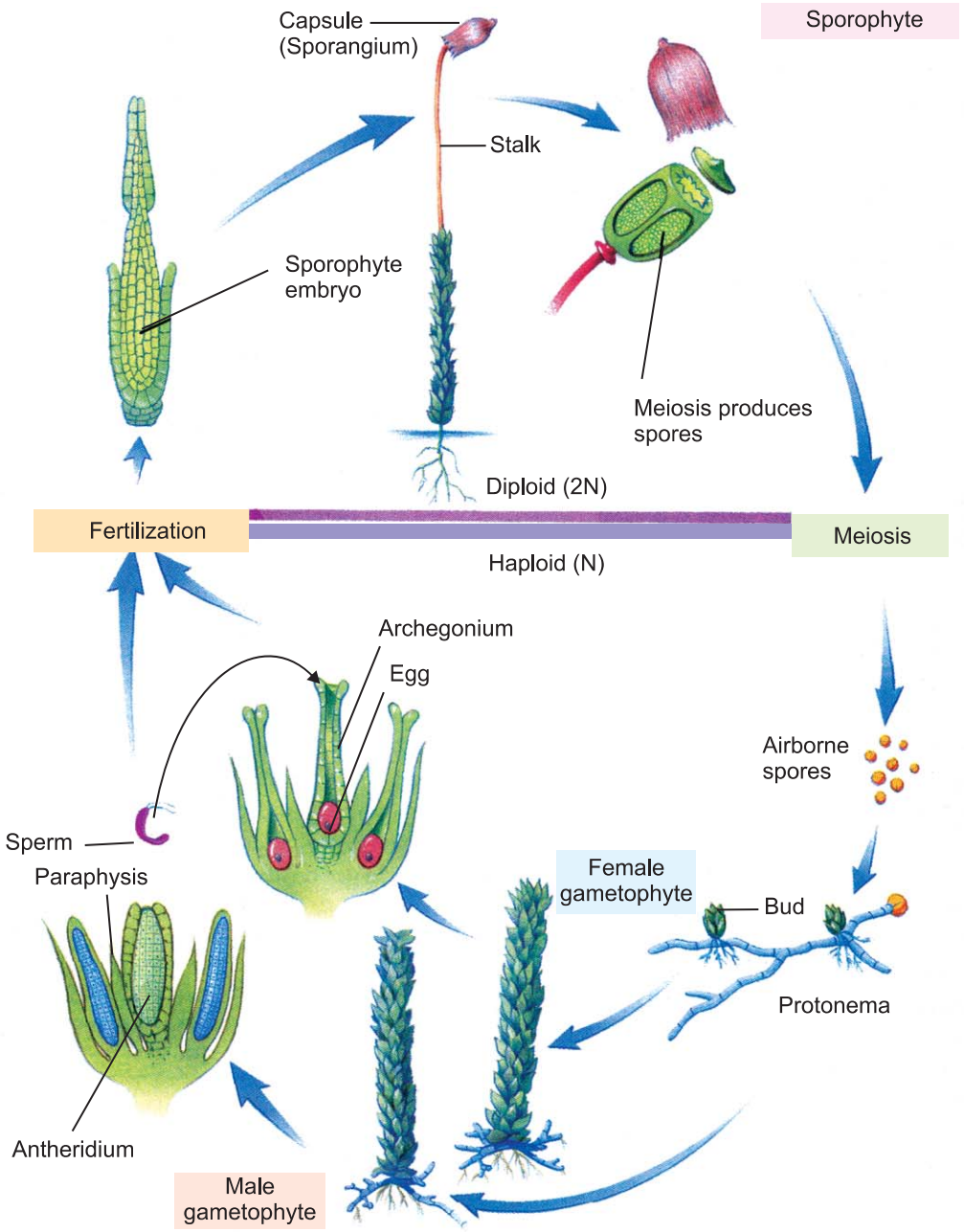

Fig: 8.3 Life Cycle of Moss (*Funaria*)

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**.

(2) Absorption of Carbon Dioxide: The upper epidermis in *Marchantia* has many **pores**. The pores 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.

Fig: 8.4 Marchantia Thallus

(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.

(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 wedutus for reaching egg. The **egg** is large and nonmotile. It contains large amount of food. The food 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 and are thus called **amphibious plants**.

(5) Protection of Reproductive Cells: The moss, *Marchantia* etc. can be distinguished as male and female plants. The sex organs are multicellular, (whereas in algae the sex organs are unicellular). In the moss plants the sex organs are at the tip of the green shoot. The male sex organ is called **antheridium** and it produces sperms. The female sex organ is called **archegonium** (ar-keh-gonium). It produces eggs. The sex organs 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.

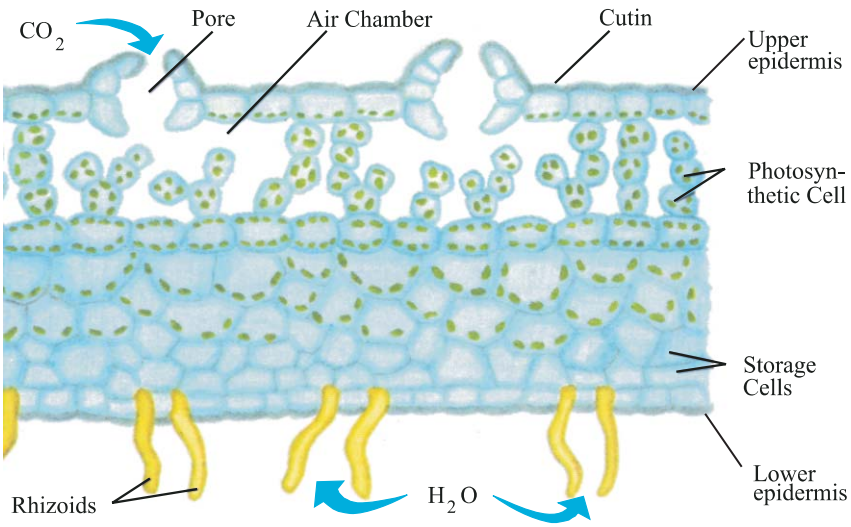

Fig: 8.5 Transverse Section of Marchantia Thallus

(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.

Fig. 8.6 Disk shaped structures that bear antherida

Umbrella shaped structures that bear archegonia

(7) Alternation of Generations: The mosses and liverworts have a life cycle with alternating gametophyte and sporophyte generations. It increases the chances of survival of the plants on land.

Q. Where will you find bryophytes in Pakistan?

Uses 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 and are beneficial as a soil conditioner. When added to sandy soils peat moss helps to hold and retain moisture.

8.3 SEEDLESS VASCULAR PLANTS

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).

General Characteristics of Vascular Plants

Vascular plants (L. *vasculum*, dim. of *vas*, vessel) include ferns and their allies, gymnosperms, and angiosperms. Vascular tissue in these plants consists of **xylem** (Gk. *xylon*, wood), and **phloem** (Gk. *phloios*, bark). 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 fully covered by a waxy **cuticle** except where it is interrupted by **stomata.** The **sporophyte generation** is diploid and dominant in vascular plants. The vascular plants are complex, extremely varied, and widely distributed.

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 sperm** are released by **antheridia** and swim in a film of external water to the **archegonia**, where fertilization occurs.

In **seed plants**, there is a separate **microgametophyte** (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 ovule becomes **embryo**, which is retained within the body of the sporophyte, becomes a **seed**. Seed dispersal occurs by wind and water or by animals to a new location.

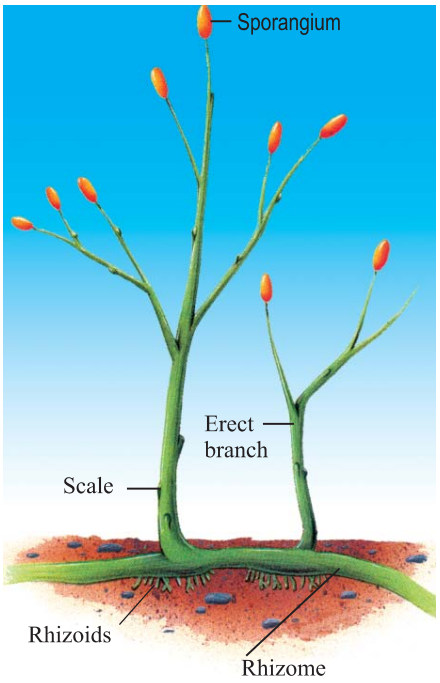

Fig : 8.7 *Rhynia*

Characteristics of Seedless Vascular Plants

Psilopsida—Whisk ferns

The group psilopsida (division or phylum Psilotophyta/Psilophyta) 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

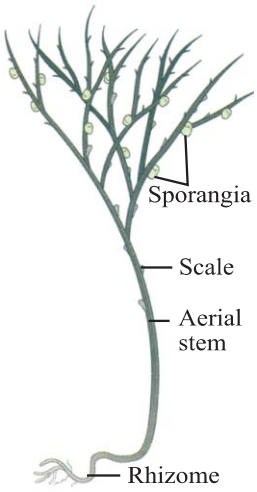

Fig : 8.8 Whisk Fern, *Psilotum*

this group are extinct and these fossil plants are known collectively as **psilophytes**. Examples of extinct group are *Rhynia*, *Psilophyton* and *Cooksonia*. *Psilotum* is the most common living genus. Another living genus is *Tmesipteris*.

Lycopsida – Club Mosses

Lycopsida or Lycodophyta includes the **club mosses**, **spike mosses** and **quillwort**. 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 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** (sing. strobilus) which are club shaped. They are only living plants to have microphylls. The familiar members of this group belong to genera *Lycopodium* and *Selaginella*.

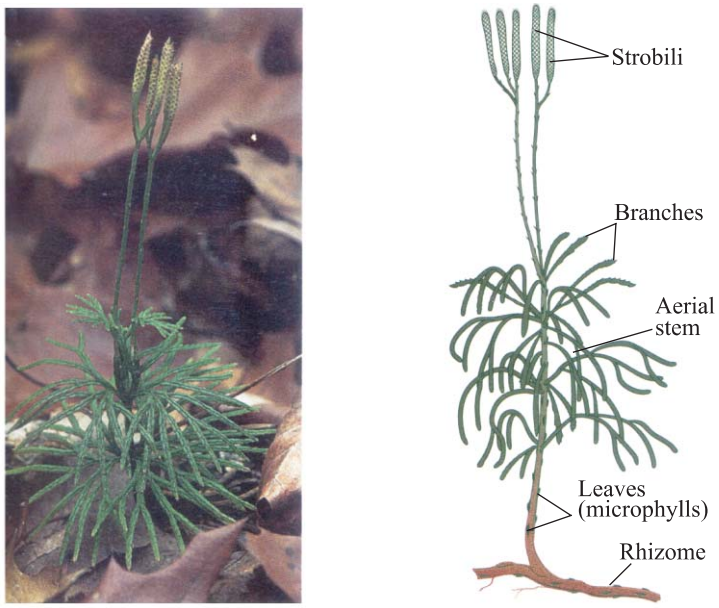

Fig : 8.9 Club Moss, *Lycopodium*

Sphenopsida - Horsetails

Sphenopsida (Equisetophyta or Sphenophyta) commonly known as horsetail, are found in waste and wet places round 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 strobili at the tips of the stem.

Q. Why *Equisetum* is called Horse tail?

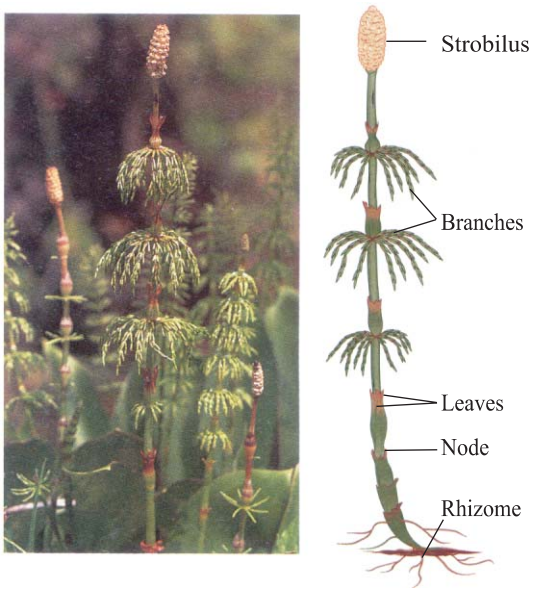

Fig : 8.10 Horsetail, *Equisetum*

Pteropsida - Ferns

Ferns belong to the group pteropsida (division pterophyta/ pteridophyta), subgroup or class **filicinae**, which are most abundant group of seedless vascular plants. Ferns a wide-spread group of plants, are much more abundant 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 long. All but a few ferns are **homosporous**. Sporophyte generation is much larger, more conspicuous, and more complex than the

Fig : 8.11 Ferns

gametophyte. Sporophyte is completely independent. Sporangia is 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.

The moss *Sphagnum* grows in bogy places that is low lowing, 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*

Science, Technology and Society Connections

Describe the formation and importance of peat bogs.

8.3.1 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) One veined leaves. (b) Many veined leaves.

One 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.

Evolution of Single Veined Leaves

There is no fossil record showing the evolution of microphyllous leaves. However two hypotheses (singular; hypothesis) have been proposed to explain their origin: (a) outgrowth hypothesis (b) reduction hypothesis.

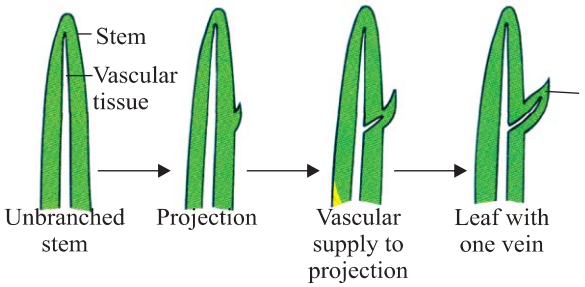

Fig: 8.12 Evolution of Single Veined Leaf, Outgrowth Hypothesis

Out-growth hypothesis: According to this 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.

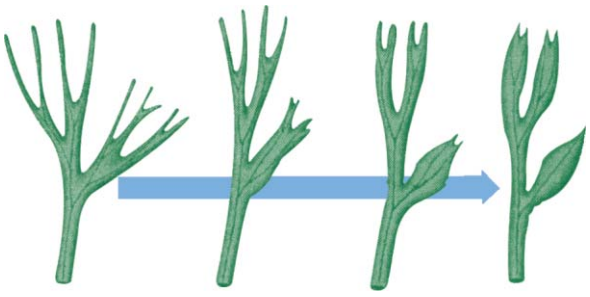

Fig: 8.13 Evolution of Single Veined Leaf, Reduction Hypothesis

Reduction Hypothesis: 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 microphyllous leaves were evolved.

Evolution of Many Veined Leaf

It is evident from fossil record that these leaves have evolved through

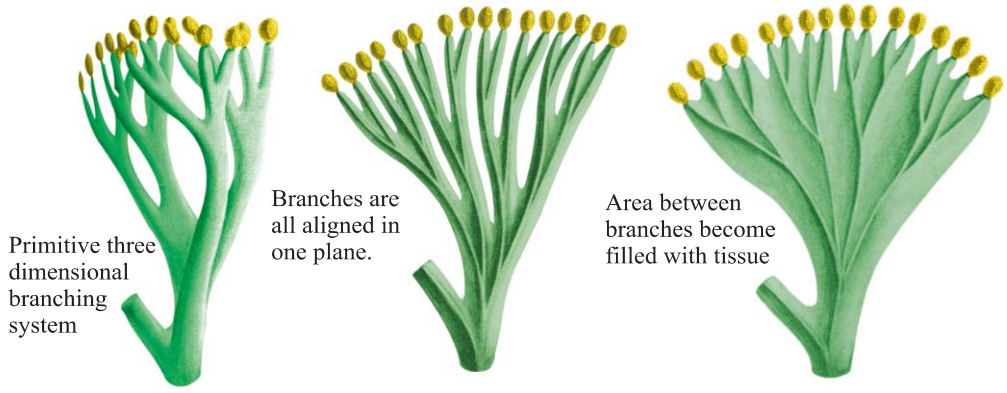

Fig: 8.14 Evolution of Many Veined Leaf

modification of the forked branches found in early vascular plants e.g. *Rhynia*. According to this view the following three steps have taken place.

Plannation: The forked branches were changed to a single plane.

Flattening: The branches became flat.

Webbing: The spaces between the bundles and branches of vascular tissues became filled with photosynthetic tissues. The structure resembles superficially to the webbed foot of the duck and thus a many veined leaf evolved.

Life Cycle of Fern

The life cycle of *Adiantum* (Maidenhair fern) shows heteromorphic alternation of generation. The gametophyte is small reduced, haploid and independent. It bears antheridia and archegonia which produce antherozoids (sperms) and eggs (ova) respectively.

Fertilization leads to zygote formation which develops into an embryo within the archegonium. Embryo develops into an independent **sporophyte**. The sporophyte is dominant, diploid plant body and produces on the underside of the leaflets of compound leaves (frond), number of sori. Each **sorus** contains a cluster of sporangia, producing **haploid spores**. The spores are dispersed by wind. When a spore falls on a moist soil it germinates under favourable conditions forming haploid gametophyte.

The fern life cycle differs from that of a moss primarily in the much greater development, independence and dominance of the fern's sporophyte. In addition, the fern's sporophyte is more complex than that of moss having vascular tissue and well differentiated roots, stem and leaves.

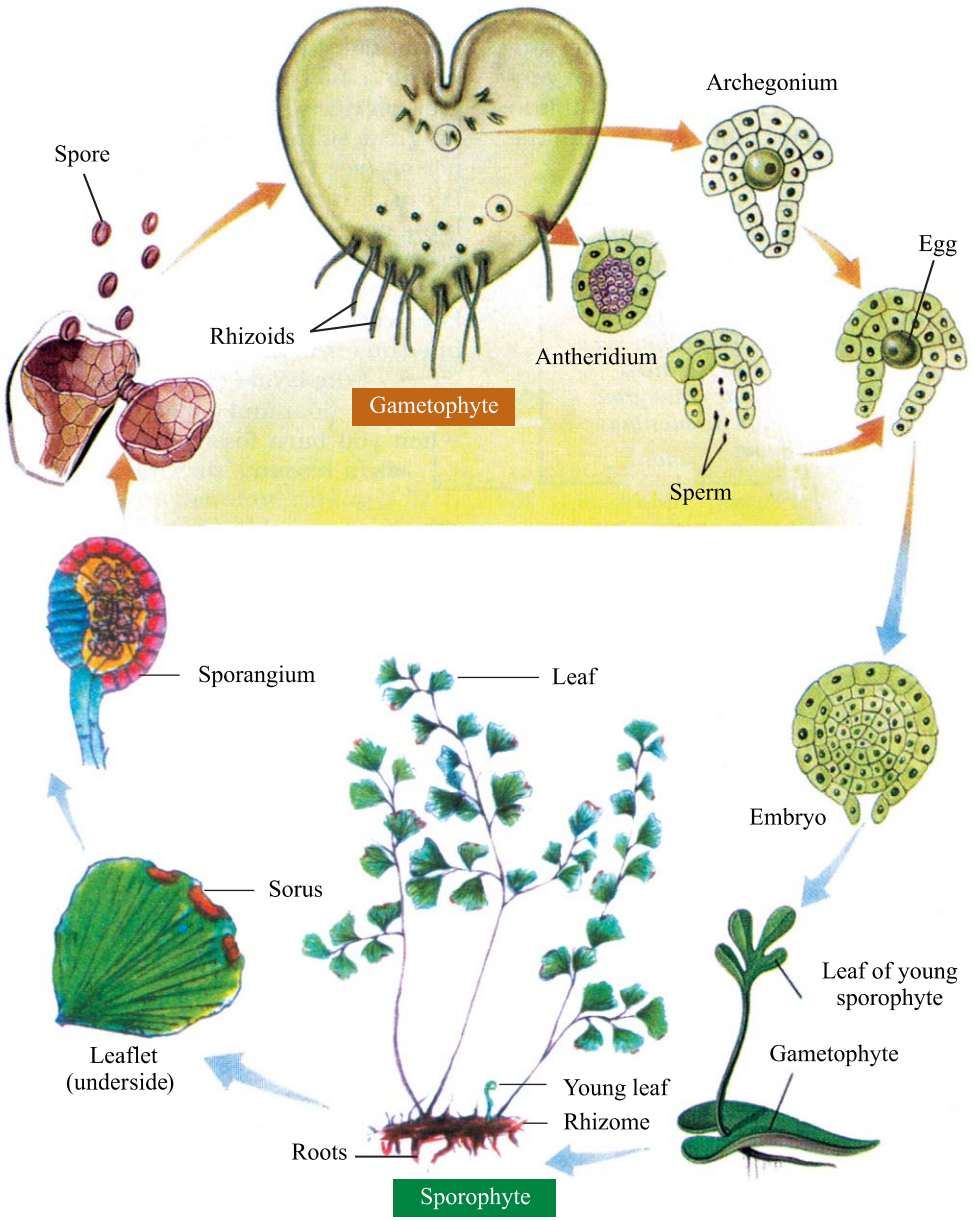

Fig : 8.15 Life Cycle of Fern (*Adiantum*)

VASCULAR PLANTS - Successful Land Plants

The three groups of vascular plants i.e. seedless ferns, naked seeded gymnosperm and covered seeded angiosperms show many adaptations to become the successful group of land plants.

Adaptations of Ferns: (a) Have true roots, stems and leaves. (b) Leaves are green photosynthetic. (c) Gametophyte lacks vascular tissue. (d) Gametophyte is separated from sporophyte. (e) Flagellated sperms require outside source of water for fertilization. (f) Some ferns e.g. bracken fern (*Petridium aquilinum*) can spread into drier areas by means of vegetative (asexual) reproduction. (g) Fern also spreads by means of rhizome.

Adaptations of Gymnosperms: Gymnosperms have well developed roots and stem. Many are tall trees that can withstand heat, dryness and cold. **Pollen grains** are transferred by wind, and the growth of the pollen tube delivers a sperm to an egg. Enclosure of the dependent **megagametophyte** in an ovule protects it during its development and shelters the developing zygote as well. Finally the **embryo** is protected within the seed. All these factors increase the chance for reproductive success on land.

Adaptations of Angiosperms: The evolutionary adaptations of flowering plants account for their success in terms of ecological dominance and large number of species. Angiosperms have true roots, stems and leaves. Roots are often modified for storage e.g. food or water. The vascular tissue is well developed. **Xylem tissue** in angiosperms is different from that of virtually all other vascular plant groups because it 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 sorts of habitats and some have even returned to water. The reproductive organs are in the **flowers**, which attract animal pollinators. Flowers are modified in wind pollinated plants.

Seeds are reproductively superior to spores for three main reasons. First a seed contains a multicellular, well-developed young plant with embryonic root, stem and leaves already formed, whereas a spore is a single cell. Second, a seed contains a food supply. After germination, the plant embryo is nourished by food stored in the seed until it becomes self-sufficient. Because a spore is a single cell, few food reserves exist for the plant that develops from a spore. Third a seed is protected by a well resistant seed coat, as compared to the thick wall of the spore. Along with primary growth **secondary growth** has also helped the survival of angiosperm (also gymnosperms) on land.

Importance of Seedless Vascular Plants

The seedless vascular plants are of economic importance. *Lycopodium* and *Selaginella* are chiefly grown as **ornamental plants** and are utilized in the preparation of christmas wreathes. Spores and stems of *Lycopodium* have got some medicinal importance. Ducks and other aquatic animals feed upon the corm of *Isoetes*.

The **ferns** are mostly ornamental plants of gardens and greenhouses. Some of them are used in the preparation of bouquets and are also placed in the buttonholes. In some tropical countries stems and leaves of tree ferns are used for **building purposes**, because the wood of the ferns resists decay particularly by termites. Some genera, like *Pteris*, *Ceratopteris* and *Marsilea*, are edible. The rhizome of the male fern yields a drug, which is utilized for removing the intestinal parasites. The maidenhair fern are the source of expectorant. 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 seed 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

Botanists now generally agree that seed plants were derived from a single common ancestor. From ecological and evolutionary perspective seed represents an important evolutionary advancement. A seed may be considered as a fertilized **megasporanguim**. It has integument around the embryo. The seed is found in higher vascular plants i.e. gymnosperms and angiosperms. During evolution the seed has passed through the following stages.

Development of Heterospory

All seed plants are heterosporous produce microspore and megaspore. Microspores are formed in microsporangia and megaspores are formed in megasporangia. 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.

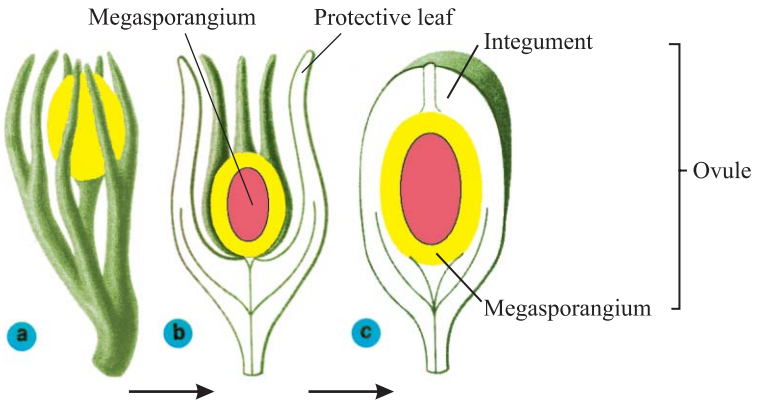

Fig: 8.16 Evolution of Seed

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 (geological period 280-350 millions years ago), 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

General Characteristics: The plant body 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 *Cycus*, which is rarely branched. There are two types of leaves. The foliage leaveas and the scalar leaves. Foliage leaves may be simple or compound. The leaves are evergreen with thick cuicle. 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 with exceptions of Gnetales. Companion cell are absent in phloem. Cones are unisexual. Male and female sporophylls are arranged on straight axis. Gymnosperms are heterosprous i.e produce microspores and megaspores. There is alternation of generation i.e sporopohytic and gametophytic generation. Polyembryony is of common occurrence, but finally a single embryo matures.

Conifers*: Pinus*

Cycus

Ginkgo

Gnetophytes*: (a) Ephedra*

(b) Welwitschia

Fig: 8.17 Gymnosperms

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. *Cycas circinalis*, which grows as 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.

8.4.3 ANGIOSPERMS

Angiosperms are the flowering plants. Their seeds are enclosed by fruits. The term angiosperms literary means "enclosed seed" (*angio*: closed, *sperm* seed). The leaves bearing ovules are folded and joined at the margins to form

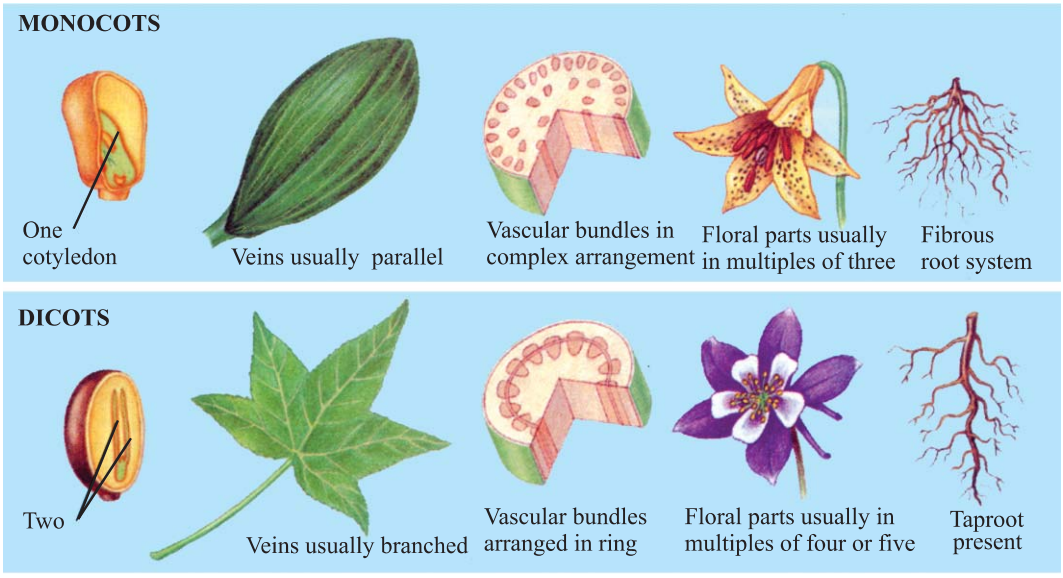

Fig: 8.18 Comparison: Monocots and Dicots

ovaries. The ovary after fertilization is changed into fruit. This is exceptionally a large and successful group of plants. Angiosperms live in all sorts of habitats, from fresh water to desert and from frigid north to the torrid tropics. Angiosperms have well developed vascular and supporting tissue. The xylem tissue consists of tracheids and vessels. Gametophyte generation is very small and inconspicuous. Pollen and ovules are produced in flowers. Sporophyte is the dominant generation. They vary in size e.g. *Eucalyptus* about 100 meters high and *Wolffia* (Duckweed) about 1 mm in length. Dicots and monocots have common characters, like, vascular tissues, differentiated plant body, flower, fruits, and seeds. The two groups may be differentiated as shown in table 8.1.

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 bundles 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.

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.

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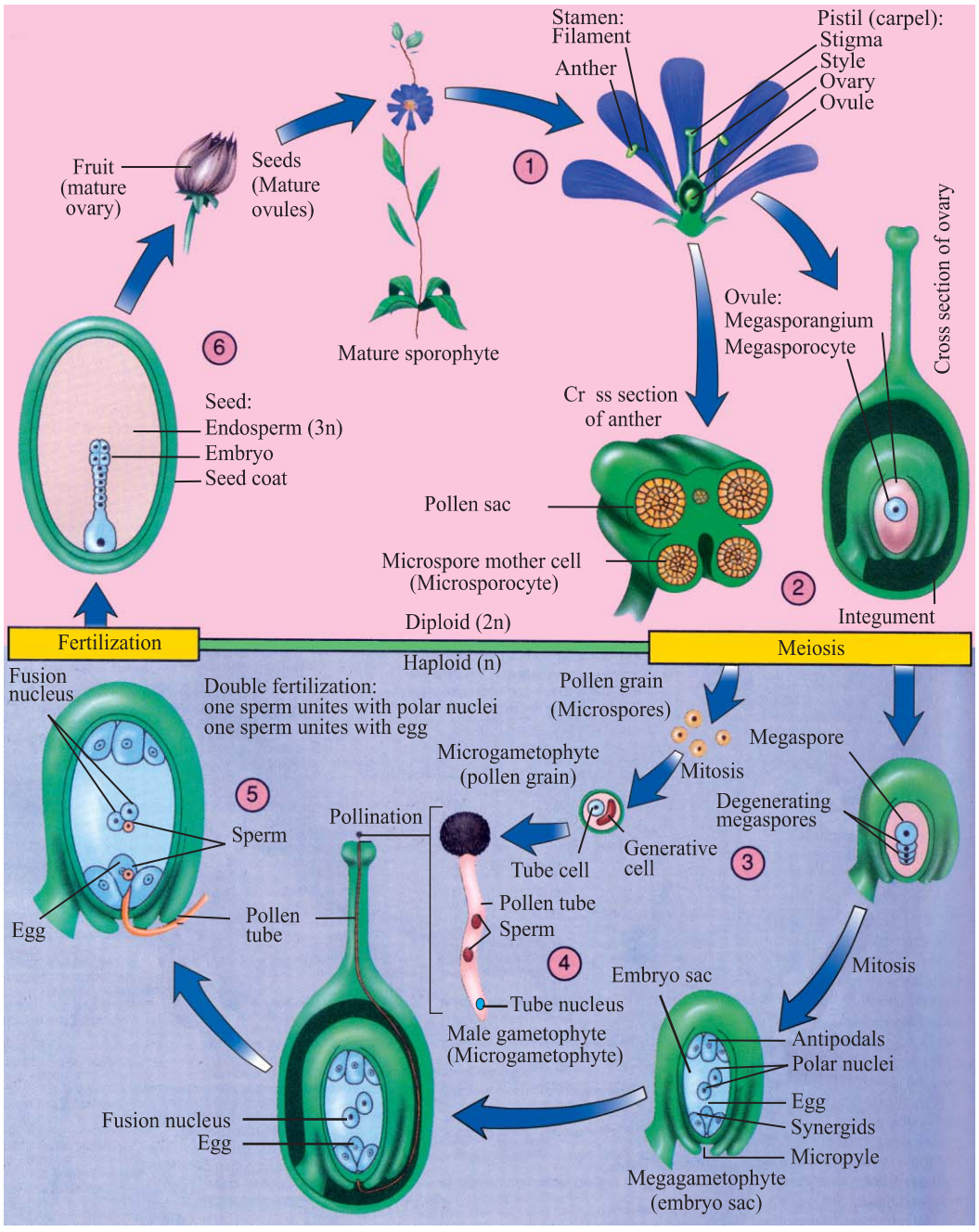


Fig: 8.19 Life Cycle of Angiosperm

Sporophyte

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.

Male Gametophyte

The anther when fully developed contains 2 to 4 elongated sacs called **pollen sacs**. The pollen sacs contain pollen grains.

Formation of Pollen Grains: When the anther is developing, mitotic divisions produce local masses called **microspore mother cells** (microsporocyte). Following meiosis in a diploid mother cell, four haploid microspores are produced. A **microspore** divides mitotically into a two celled, **pollen grain** (microspore). A tough wall develops around the pollen grain, which protects the contents of the pollen grain from drying out.

Pollen Tube: 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.

Tube Nucleus: 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** (microgametophyte).

Q. Why is pollen tube called male gametophyte?

Female 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 thousand of ovules. The ovule has an opening called **micropyle**. Certain cells (megasporocyte) of the ovule undergo meiosis to produce four monoploid (haploid) cells. Only one of these cells survives. The surviving cell is called the **megaspore**, which means large spore. The megaspore nucleus divides by mitosis to form two haploid nuclei. Each of these nuclei divides two more times to produce a total of eight haploid nuclei. At the centre of

the ovule is the microscopic structure called **embryo sac** having all these eight nuclei. Wall formation takes place and these nuclei are converted into cells.

The cells of embryo sac are: (a) Antipodal cells – 3 (b) Polar nuclei – 2 (c) Synergids – 2 (d) Egg - 1

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.

Seed and Fruit Formation

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 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 **cotyledons** become enlarge and store food for the development of the embryo. Such plants are called **nonendospermic** e.g. bean. In some plants the endosperm tissue continues to grow as the ovule matures into a seed. These plants are known as **endospermic** e.g. corn, castor, rice and wheat. The

ovule matures into a seed. The protective covering (integument) of the ovule is transformed into seed coat. Seed coats of some seeds are tough and protect the embryonic plant from injury and dessication. The ovary wall enlarges and ripens to become the fruit.

The Life Cycle Demonstrates an Adaptation of Angiosperms on Land

Fertilization takes place through pollen tube independent of external water. Double fertilization increase 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.

Critical Thinking

How do the life cycles of seedless plants and seed plants differ? In what fundamental way are they alike?

Inflorescence

Flowers are borne either singly or in clusters. A flower is said to be **solitary** when occurring singly. e.g. *Hibiscus rosasinensis*.

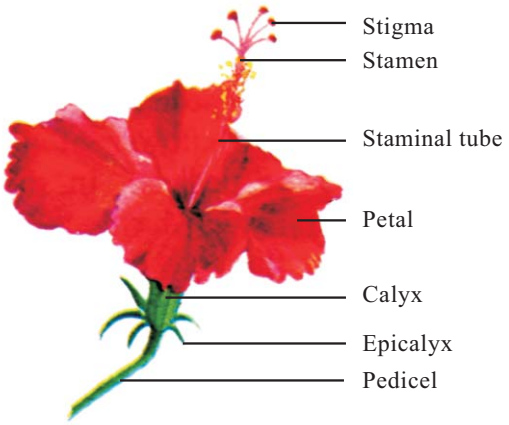


Fig: 8.20 A Solitary Flower, China-rose (*Hibiscus rosasinensis*)

Flowers borne in clusters along with the stem and associated whorls constitute **inflorescence**. The advantages of the aggregation of flowers in an inflorescence are: Makes the flowers in more conspicuous to attract insects for pollination. Many flowers get pollinated by a single insect. Inflorescence combines economy with greater chances of pollination and surety of abundant seed production. Depending upon the arrangement of flowers, inflorescence is classified as:

(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. Some of the main types are as follows.

Fig: 8.21 Raceme of Mustard

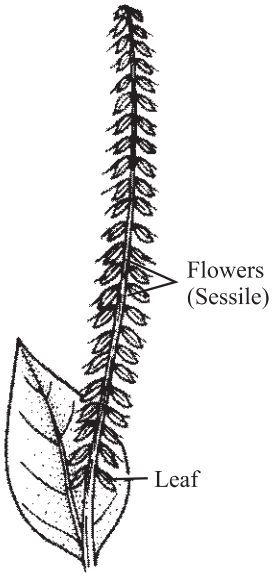


Fig: 8.22 Spike of *Achyranthes*

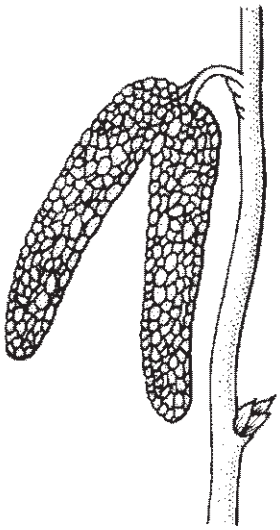


Fig: 8.23 Catkin of Mulberry (*Morus*)

Raceme: The main axis is elongated and bears flowers laterally. The flowers are stalked and arranged in acropetal succession, e.g., radish and mustard.

Catkin: It is also a spike with a long and pendulous axis. It bears unisexual sessile flowers, e.g., mulberry (*Morus*).

Spike: Here also the main axis is elongated but the flowers are sessile and arranged in acropetal succession, e.g., *Amaranthus*, *Achyranthes*.

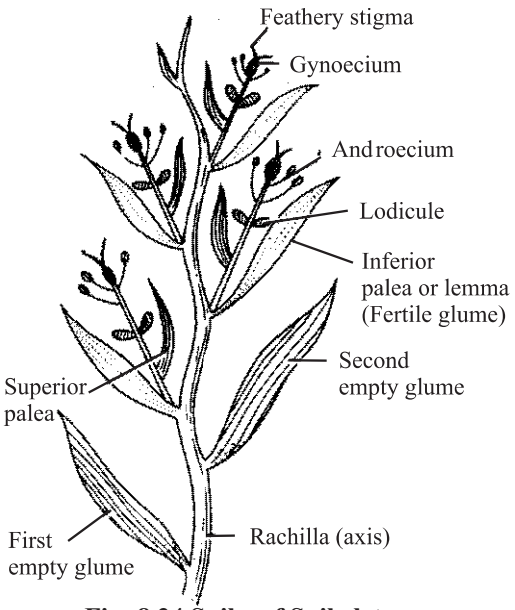


Fig: 8.24 Spike of Spikelets

Spikelet : This is a very small spike with reduced axis, hence called spikelet. It bears one or a few small flowers. The spikelets arise in a racemose manner on the main axis, e.g., wheat, sugarcane, paddy, etc.

Corymb: In this case the main axis is comparatively short and the flowers are pedicellate. The lower flowers have longer pedicels than the upper ones so that all the flowers lie more or less at one level, e.g., Candytuft (*Iberis*), *Cassia*.

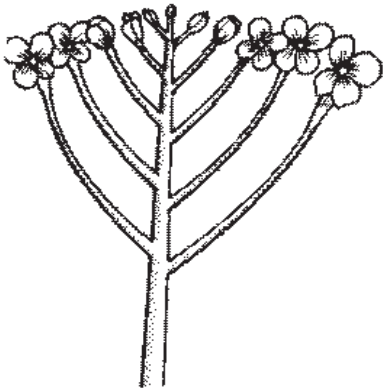


Fig. 8.25 Corymb of Iberis,

Head or Capitulum: Here the main axis is highly suppressed and becomes flattened forming a disc-like structure. It bears small sessile flowers of two types the **ray florets** and the **disc florets**. The ray florets are situated at the periphery and have a flat tongue-shaped corolla. The disc florets are situated at the disc or the receptacle. The florets are surrounded by a whorl of bracts called **involucre**. Sunflower and marigold are the common examples of this type.

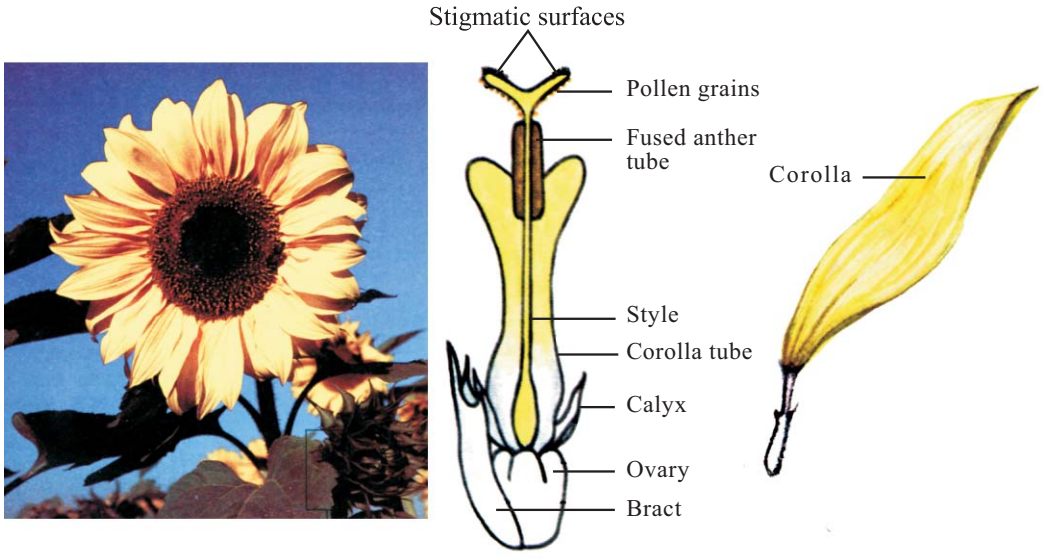


Fig: 8.26 Capitulum of Sunflower

Cymose Inflorescence

Here the primary axis terminates in a flower but the growth continues through the lateral buds. These buds give rise to lateral branches which bear flowers. The flowers are arranged in basipetal succession, i.e., the outer or basal flowers are younger and the upper flowers are older.

Compound Inflorescence

In a compound inflorescence the peduncle or 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. Goldmohur (*Delonix regia*), Amaltas (*Cassia fistula*),. *Yucca*, etc. Compound Spike e.g. Wheat (*Triticum aestivuni*), rice (*Oryza sativa*).

Significance of Angiosperms to Humans

Food: Cereals constitute the staple food of man. Major cereals are wheat rice, maize, barley, oat, etc.

Pulses: These are seeds of leguminous plants. These are rich in proteins. Common pulses are lentil, arhar, urd, pea, gram, green gram, soyabean, black gram.

Vegetables and Fruits: The main vegetables obtained from angiosperms include carrot, radish, cabbage, cauliflower, potato, tomato, okra. The fruits are mango, apple, banana, guava, grapes, melon, mulberry, pears, etc. Nuts consumed as dry fruits are cashewnut, almonds, walnut, etc.

Edible Oils: Edible oils used for cooking are obtained from groundnut, mustard, cotton seeds, coconut and sunflower.

Spices: These include cinnamon, (vern. dalchini), cloves, (vern. laung), chillies, black pepper (vern. kali mirch), caraway (vern. zeera), coriander (vern. dhania), fennel (vern. saunf).

Beverages: Tea, Coffee and Cocoa are important beverages obtained from flowering plants.

Sugar: It is obtained from sugarcane and beet roots.

Fodder: Many plants yield fodder for the cattle. Important fodder giving plants are *Trifolium* (barseem), *Melilotus* (senji), etc.

Medicines: A large number of drugs are obtained from flowering plants. Some of the drugs are aconite, belladona, quinine, malathi, santonin, digitalis, asgandh, etc.

Timber: It is mostly obtained from dicotyledonous plants. The wood

Science, Technology and Society Connections

Justify plants as a medical treasure.

is called hard wood in contrast to soft wood of gymnosperms. Important timber yielding plants are teak, sal, oak and sisso (vern. sheeshum). Commercial cork is obtained from oak.

Fibres: 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 and sunn hemp, etc. Jute fibres are obtained from the husk of unripe fruits of coconut.

Ornamental Plants: A large number of flowering plants are grown in gardens and houses as ornamental plants. Common among them are bougainvilleas, roses, petunias, chrysanthemums, crotons, coleus, etc.

Exercise

SECTION I : MULTIPLE CHOICE QUESTIONS

Select the correct answer

1. Plants are thought to have descended from a common protistan ancestor ancient

   A) freshwater algae B) archaea

   C) cyanobacteria D) brown alga

2. Gametophyte in bryophytes is

   A) haploid B) diploid

   C) triploid D) pentaploid

3. Whisk ferns belong to the group

   A) pteropsida B) lycopsida

   C) psilopsida D) annelida

4. Sago grains are obtained from

   A) cycus B) pinus

   C) moss D) fern

5. These are highly evolved of all the plants on the earth

A) bryophytes B) pteridophytes

C) gymnosperms D) angiosperms

6. Moss plants develop from

A) oospore B) protonema

C) antherozoids D) diploid spores

7. Fern plant is

A) diploid sporophyte B) diploid gametophyte

C) haploid sporophyte D) haploid gametohyte

8. Gymnosperms are characterised by

A) multiflagellate sperms B) naked seeds

C) winged seeds D) seeds inside fruits

9. Seed habit originated in some

A) bryophytes B) ferns

C) gymnosperms D) angiosperms

10. Gametophyte generation is dominant in

A) pterideophytes B) gymnosperms

C) bryophytes D) angiospersms

SECTION II : SHORT QUESTIONS

1. How are cones and flowers are alike? How they are different?
2. What is the importance of alternation of generation, pollen tube and seed?
3. Write three main features of bryophytes.
4. Name the land adaptation features of bryophytes.
5. Write any four features of vascular plants.
6. Give one example of: Whisk ferns, club mosses, horsetails and ferns
7. What is the importance of seedless vascular plants?
8. Write any six features of gymnosperms.

9. Write any four uses of bryophytes and gymnosperms.
10. Define: angiosperms, inflorescence, and alternation of generation.
11. The majority of all plants are seed plants. What is the advantage of the seed?
12. What do monocots and dicots have in common? How do they differ?

SECTION III : EXTENSIVE QUESTIONS

1. Write the evolutionary origin of plants.
2. List the diagnostic features shared by all plants with the emphasis on alternation of generation.
3. Explain the land adaptations of bryophytes.
4. Describe the general characteristics of vascular plants.
5. Write the characteristics of seedless vascular plants and summarize their importance.
6. Explain the evolution of leaf in vascular plants.
7. Describe vascular plants as successful land plants.
8. Describe the evolution of seed.
9. Write the general characteristics and uses of gymnosperms.
10. Describe major types of inflorescence.
11. Write the significance of angiosperms to humans

ANSWER MCQS

1. A 2. A 3. C 4. A 5. D 6. B 7. A 8. B 9. B 10. C

SUPPLEMENTARY READING MATERIAL

3. Mauseth, J.D. Botany: An Introduction to Plant Biology. 2nd edition Saunders Collage Publishing, Philadelphia. 1995.

USEFUL WEBSITES

1. www.mhhe.com/sciencemath/biology/mader/ (click on biology).
2. www.prenhall.com/~audesirk

www.learningall.com

CHAPTER 9

DIVERSITY AMONG ANIMALS

Major Concepts:

Number of allotted teaching periods: 18

9.1 Characteristics of Animals (1 Period)

9.2 Criteria of Animal Classification (3 Periods)

9.3 Diversity in Animals

9.3.1 Invertebrates (8 Periods)

9.3.2 Chordates (6 Periods)

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? We can define animal very generally that animals are eukaryotic, multicellular heterotrophs that lack cell walls. We will have a glance at the characteristics of animals.

9.1 CHARACTERISTICS OF ANIMALS

Animals may be free living and motile, sessile or a parasite. Animals are found almost in all types of habitat. They range in **size** from worms only seen with a microscope to blue whales, which weigh up to 150 tons. Animals are multicellular eukaryotes.

Most animals have cells specialized to form tissue and organs. Body may be soft or hard, radial symmetry or bilateral symmetry, diploblastic or triploblastic segmented. Body may be covered by shell, chitin, scales, furs. Animals may be acoelomate, pseudcoelomatc and coelomate. All animals are **heterotroph** and usually acquire food by ingestion followed by digestion. Animals may have no **definite digestive** system e.g. sponges, it is a saclike

gastrovascular cavity e.g., *Hydra*, or it may be rudimentary e.g. tapeworm. **Digestive system** may have one opening e.g. planaria. Tube like digestive system have two openings e.g. nematodes to mammals. **Excretory system** may be absent in sponges, cnidarians. It is like branching tubes in flatworms. Excretory system is present in nematodes to mammals. There is no definite **nervous system** in sponges, and cnidarians. Nervous system is present in nematodes to chordates. Most animals have sense organs. All animals respire but a **respiratory system** is absent in sponges, cnidarians, flatworms, nematodes (roundworms) and annelids. Respiratory system is present in arthropods to chordates.

Skeleton is present is all animals. Spicules are present in sponges. Hydroskeleton is present in worms and annelids. Skeleton may be exoskeleton in arthropods, molluscs (mollusks), and chordates or it may be endoskeleton in mollusks (sepia), echinoderms, chordates and highly developed in vertebrates. Most animals are capable of locomotion at sometime during their life cycle.

Circulatory System is absent in sponges, cnidarians, roundworms and flatworm. It is present in annelids to chordates. Reproductive cells; organs or **reproductive system** is present in all the animals. Asexual reproduction is seen in sponges, cnidarians, sexual reproduction takes place in all other groups of animals and produce an embryo that undergoes specific stages of development. Animals have a **life cycle** in which the adult is always diploid. The life cycle may have larval stages e.g. sponges, annelids, arthropods, molluscs, echinoderms and amphibians. **Regeneration** is exhibited by sponges, some cnidarians, annelids and echinoderms.

Thus we have a number of characteristics that answer the question, what is an animal? What characteristics animals have common?

First, being **eukaryotic**, unites animals with protists, fungi and plants and separates them from all prokaryotes. Secondly being **multicellular** separates animals from fungi, plants and most **protists**, which are unicellular. Third being **heterotrophic** separates animals and fungi from plants and plantlike protists (the algae), which are photosynthetic. Finally **lacking cell walls** distinguishes animals from plants, algae and fungi, so we have four features that taken together distinguish animals from other organisms.

9.2 CRITERIA FOR ANIMAL CLASSIFICATION

Classification of animals is based on presence or absence of tissues, number of tissue layers, type of symmetry and type of coelom.

Animals can be Classified According to Presence or Absence of Tissues

The animal kingdom has been divided into two subkingdoms on the basis of presence or absence of tissues: subkingdom – **Parazoa** and subkingdom – **Eumatozoa**. Parazoa includes the simplest metazoans or multicellular animals that show the cellular grade of organization in which cells demonstrate division of labour but are not strongly associated to perform a specific collective function. They are asymmetrical. It includes all the sponges.

In **Eumatozoa** – similar cells are grouped together and perform their common functions as a highly coordinated unit called **tissue**. The tissues are assembled into larger functional unit called **organs**. Most metazoa have an additional level of complexity in which different organs operate together as organ system. Eleven different kinds of organ systems are observed in Eumetazoa: skeletal, muscular, integumentary, digestive, respiratory, circulatory, excretory, nervous, endocrine, immune and reproductive.

Animals can be Classified According to Number of Tissue Layers

Animals may be classified as diploblastic and triploblastic animals.

Diploblastic Organization

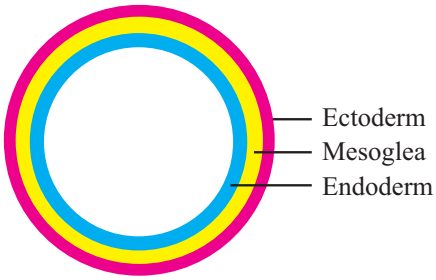


Fig: 9.1 Diploblastic Organization

One of the main events during the development of the animals is the establishment of **germ layers** from which all other structure is derived. The body of **diploblastic animals** consists of two germ layers of cells, the **ectoderm** and **endoderm**. Such animals have tissue level of organisation. There is a jelly like **mesoglea**, which in most cases is non-cellular between the two germ layers. There are no specialized organs, no special transport system and no central nervous system in diploblastic animals. A neuron net is present. There is only one cavity called **gastrovascular cavity** (9.9) with only one opening. This is known as sac like digestive system. These animals are radial symmetry. The examples of diploblastic organization are animals of phylum Cnidaria.

Triploblastic Organization

The body of the **triploblastic animals** consists of three germ layers i.e. ectoderm, mesoderm and endoderm (9.3a). 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. Animals with three germ layers have an organ level of organization. The animals have specialized cells, organs and organ systems. The **ectoderm** gives rise to integumentary and nervous system. **Mesoderm** gives rise to muscular, skeletal, blood vascular and reproductive systems. **Endoderm** forms the lining of digestive tract and the glands of digestive system. The digestive system is of a tube type having two openings the mouth and the anus. The body of the animals has bilateral symmetry. Triploblastic animals may be acoelomate, pseudocoelomate or coelomate.

Animals can be Classified According to Body Symmetry

The subkingdoms Eumatozoa 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 belong to phylum Cnidaria. The body of a sea anemone can be cut in two equal halves vertically in any plane. All the animals included in grade radiata are also diploblastic. Radial symmetry is considered an adaptation for a sessile life.

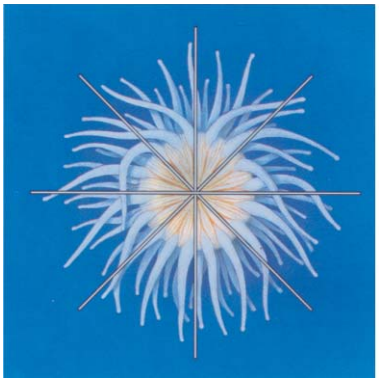


Fig: 9.2a Radial Symmetry

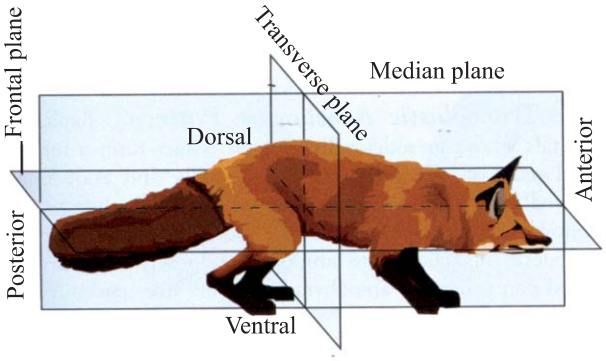


Fig: 9.2b Bilateral Symmetry

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. The animals belonging to phyla Platyhelminthes, Aschelminthes, Annelida, Mollusca, Arthropoda, Echinodermata, Hemichordata and Chordata are included in this grade. In Echinoderms the larval stages show bilateral symmetry and the adult secondarily develops radial symmetry. All the animals included in grade Bilateria are triploblastic. These may be acoelomate, pseudocoelomate or coelomate. Bilateral symmetry is considered an adaptation to motility.

Animals can be Grouped According to Type of Body Cavity

A widely held system for grouping animal phyla is based on the presence and type of body cavity or **coelom**, a fluid filled space between the other body wall and the digestive tube.

Acoelomate

In platyhelminthes the body is essentially a double walled sac surrounding a digestive cavity with a single opening to the outside, the mouth. There is no body cavity so these animals are called **acoelomate**. There are cellular tissues called **mesenchyma** which fills the spaces between ectoderm and mesoderm. It forms a packing around the internal organs of the animals to support and protect them.

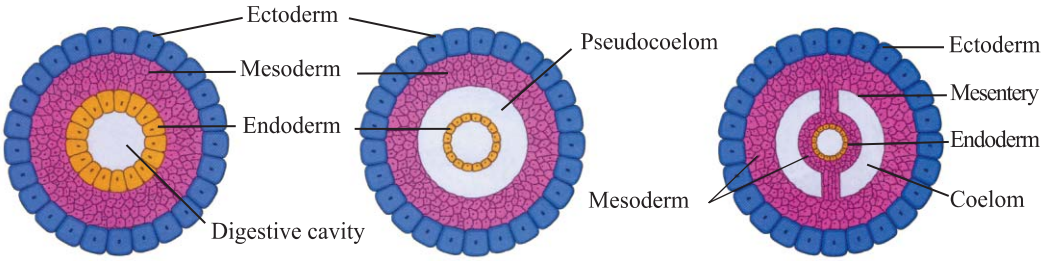


Fig: 9.3 Acoelomate, Pseudocoelomate, and Coelomate Comparison

Pseudocoelomates

Complex animals usually have a tube within a tube plan. The inner tube, the digestive tract, is lined with tissue derived from the endoderm and open at each end. Between the two tubes is a second cavity the body cavity. 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**. In coelomates gut is more complex and neurosensory, excretory, circulatory respiratory and reproductive systems are well developed. Animals from annelids to chordates are coelomate.

Coelomate Can be Classified as Protostomes or Deuterostomes

Animals with a true coelom 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 and opening called the **blastopore**. In most of the mollusks, annelids and arthropods, this opening develops into the mouth. These animals are **protostomes** (from Greek words meaning "first, the mouth").

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").

Another difference in the development of protostomes and deuterostomes is the pattern of **cleavage**, the first several cell divisions of the embryo. In many protostomes, the early cell divisions are diagonal to the polar axis (the long axis of the egg), resulting in a somewhat spiral arrangement of cells; any one cell is located between the two cells above or below it (fig 9.4). This pattern of division is known as **spiral cleavage**. In **radial cleavage**, characteristics of the deuterostomes, the early divisions are either parallel or at right angles to the polar axis; the cells are located directly above or below one another.

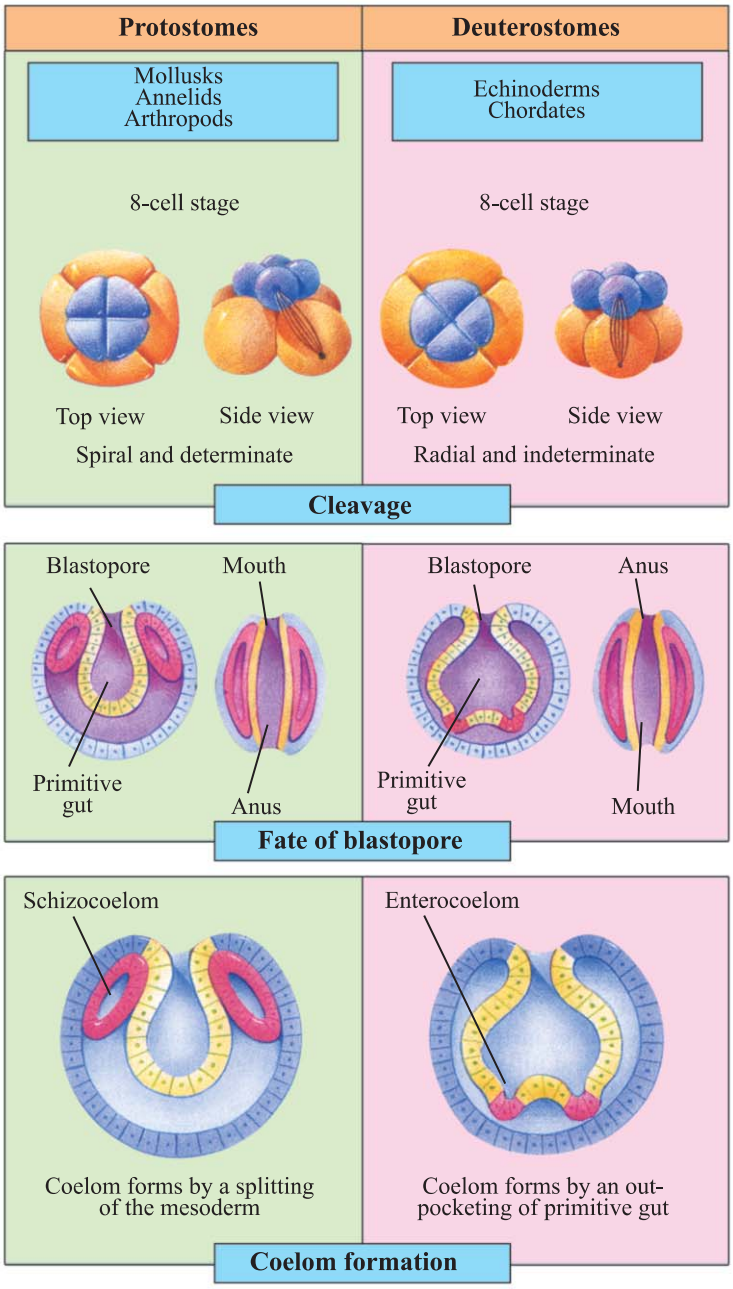


Fig: 9.4 Protostomes versus Deuterostomes

In the protostomes, the fate of each embryonic cell is often fixed very early. For example, if the first four cells of an annelid embryo are separated, each cell develops into only a fixed quarter of the larva; this is known as

determinate cleavage. In deuterostomes, cleavage is usually **indeterminate**. If the first four cells of a sea star embryo, for instance, are separated, each cell is capable of forming a complete, though small, larva.

Still another difference between protostome and deuterostome development is the manner in which the coelom is formed. In protostomes, the mesoderm splits and the split widens into a cavity that becomes the coelom. This method of coelom formation is known as **schizocoely** and for this reason the protostomes are sometimes called **schizocoelomates**. In many deuterostomes, the mesoderm forms as "outpocketings" of the developing gut. These outpocketings eventually separate and form pouches; the cavity within the pouches becomes the coelom. This type of coelom formation is called **enterocoely** and these animals are sometimes referred to a **enterocoelomates**.

Table 9.1 Comparison of Protostomes and Deutrostomes

PROTOSTOMES	DEUTEROSTOMES
Cleavage mostly spiral	Cleavage mostly radial
Endomesoderm usually from a particular blastomere.	Endomesoderm from enterocoeluos pouching (except chordates)
In coelomate protostomes the coelom forms as a split in mesodermal bands (schizocoelous)	All coelomate, coelom from fusion of enterocoelous pouches (except chordates, which are shizocoelous)
Mouth form, at or near blastopore; anus a new formation.	Anus form, at or near blastopore; anus a new formation
Embryology mostly determinate (mosaic)	Embryology usually intermediate (regulative)
Blastopore develops into mouth	Blastopore develops into anus
Includes phyla Platyhelminthes, Aschelminthes, Annelida, Mollusca, minor phyla.	Includes phyla Echinodermata, Hemichordata, Chordata

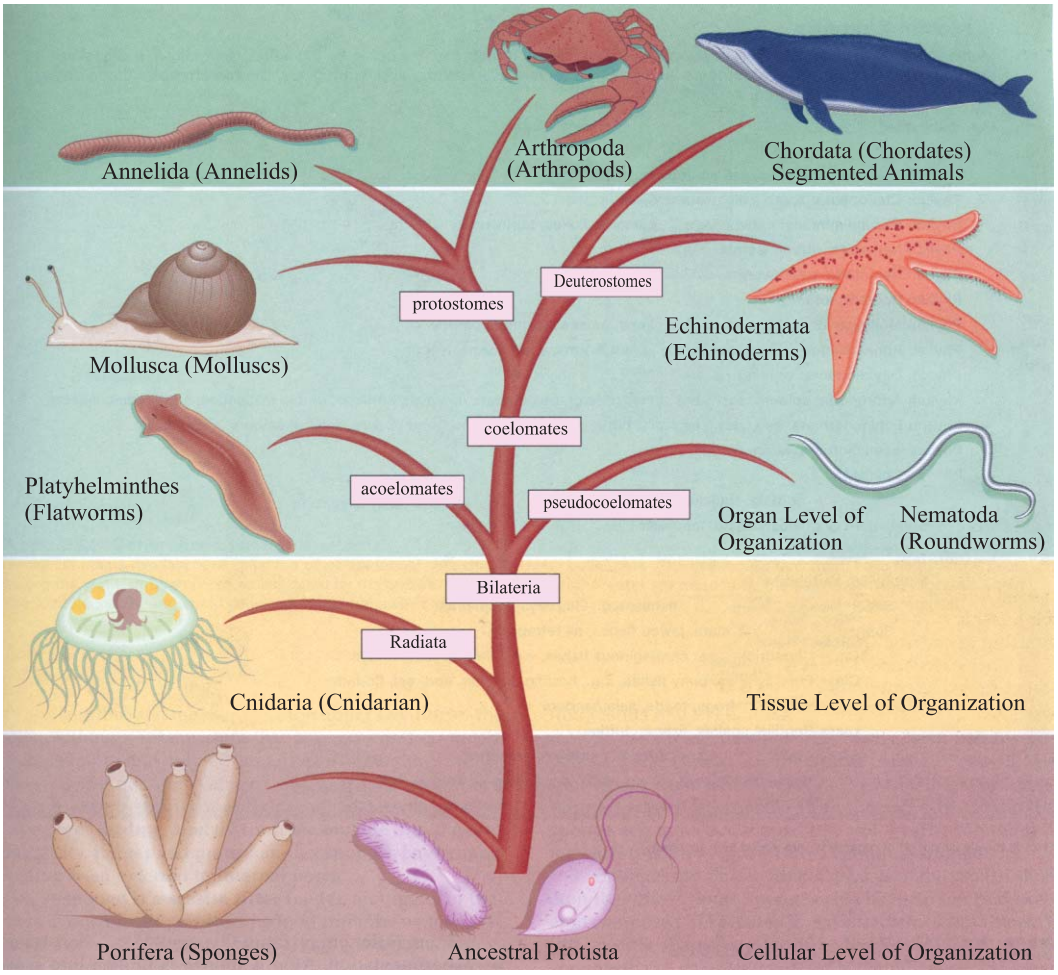


Fig: 9.5 Phylogenetic Tree of the Animal Kingdom

Science, Technology and Society Connections

Trace the position in the phylogeny of major groups of animals.

Skills: Interpreting and Communication

- Draw the evolutionary tree of sponges, butterfly and monkey.

1. Ancestral Protista – Choanoflagelates – Sponges (Porifera),
2. Ancestral Protista – Bilateria – Coelomets – Prostotomes, Butterfly (Arthropods) –
3. Ancestral Protista – Bilateria – Coelomets – Deuterostomes – Monkey (Chordates)

9.3 DIVERSITY IN ANIMALS

Animals are incredibly diverse in structure. Despite the vast differences in structural complexity of organisms ranging form the simplest sponges to humans, all share an intrinsic material design and fundamental functional design.

9.3.1 INVERTEBRATES

When we think of animals we tend to imagine birds, dogs, fishes, and squirrel etc. However most animal species are those that lack a backbone and are commonly known as invertebrates. The invertebrates have been divided into eight major phyla: porifera, cnidaria, platyhelminthes, aschelminthes, mollusca, annelida, arthropoda, echinodermata. The chordates may be grouped as invertebrate chordates (Phylum Hemichordata, sub phylum Urochordata and subphylum cephalochordata) and vertebrates (subphylum vertebrata).

1. PHYLUM PORIFERA

The General Characteristics of phylum porifera (Latin *porus*, pore, *ferra*, to bear) are: Sponges are sessile, attached to the rocks at the bottom of water. Larvae are motile. Sponges are all aquatic, mostly marine, some found

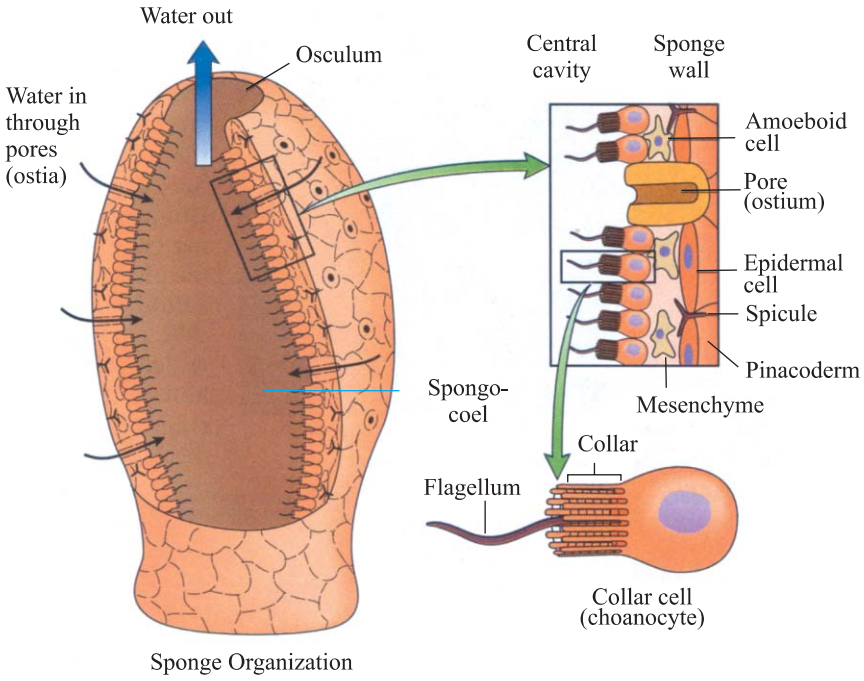


Fig: 9.6 Generalized Sponge Anatomy

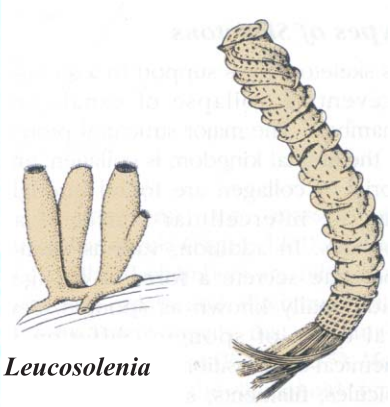
in fresh water. They range in size from a few millimetre wide to more than a metre long. Body is multicellular and not organized as tissue or organs. Body lacks symmetry. The sponges consist of outer dermal layer called **pinacoderm**, and inner layer **choanoderm** made of flagellated cells called choanocytes. 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. There is no definite nervous system. Various shapes of spicules form the skeleton. These are needle like and may be calcarious or siliceous. The bath sponge has spongin fibre.

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 choanoflagelates. The examples of Sponges are: *Sycon, Leucosolenia, Euplectella, Spongilla*.

Yellow sponges



Leucosolenia

Euplectella

Fig: 9.7 Examples of Sponges

Q. Justify the classification of sponges as animals.

Evolutionary Adaptations in Sponges

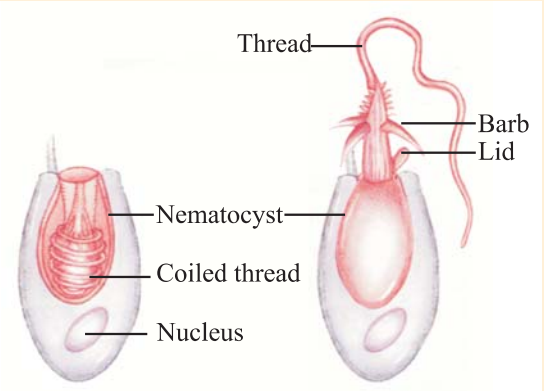
Digestion is completely intracellular and occurs in food vacuoles within choanocytes. **Respiration** is aerobic. All the cells of the dermal and gastral layers are in contact with water. There are no special organelles for respiration. Transportation takes place through water current and diffusion. The water current system has greatly enlarged area for the feeding and gaseous exchange. **Excretion** takes place through diffusion and outgoing water-current. The individual cells react as independent effectors. A sponge lacks nervous system. Sensory cells probably seem to coordinate the flow of water. Sponges are the only animals with **collar cells** (choanocytes). In the sense that they apparently did not give rise to any other animal group, sponges seem to represent a dead end in evolution.

Economic 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

The name Cnidaria as this group of animals have special cells called cnidocytes. These cells give rise to nematocyst the stinging cells characteristics of this group.



The General characteristics of phylum Cnidaria (Greek, *Knide*, nettle, + L. *aria*, connected with) are: Most of the species are sessile, e.g. *Hydra*, free living and motile e.g. Jelly fish, colonial e.g. *Obelia*. Cnidarians are entirely aquatic, mainly marine, few found in fresh water, e.g. *Hydra*.

They range in size from microscopic (*Hydra*) to two metres in length (**hydrozoan polyp**). Body is 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**. Nervous system consists of nerve net and some sense

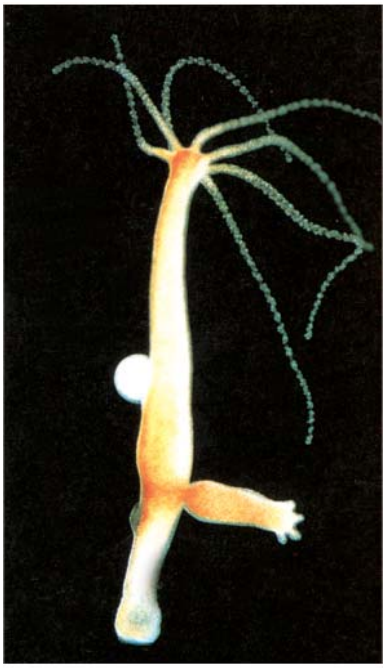


Fig: 9.8 *Hydra*

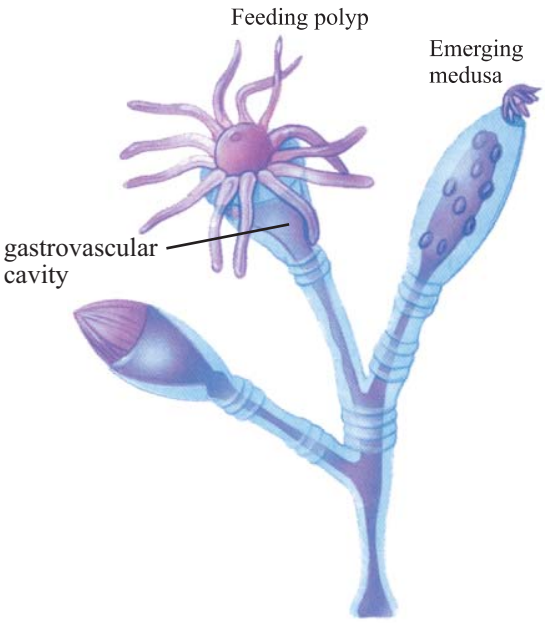
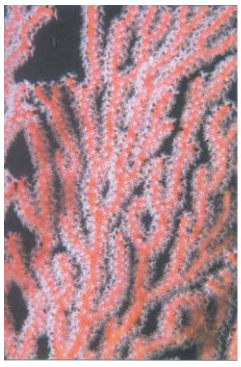


Fig: 9.9 *Obelia*

Science Titbits

Alternation of Generation: Polyp reproduces asexually by budding to form medusae. In turn medusae reproduce sexually to form polyp. It is called alternation of generation. Both the generations are diploid, often the two generations consist of one free living and one attached stage. e.g. *Obelia*. Some do not show any alternation of generation e.g. *Hydra*.



Red gorgonian

Sea fan

Red whip coral

Jelly fish

Fig 9.10 Cnidarians

organs. 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. **Hydroids** or **polyps** which are feeding zooids and **Medusae** are reproductive zooids, for sexual reproduction.

Evolutionary Adaptations in Cnidarians

In cnidaria, both the polyp and medusa are constructed on the same scheme. The colonial form of life shows alternation of generation and polymorphism. Occurrence of different types of zooids in the same organism is called polymorphism. Some colonies grow to a great size e.g. corals. Gastro vascular cavity is often branched or divided with septa with a single opening. Nerve net is present. Transportation and excretion take place through diffusion. There is no respiratory and excretory system.

Economic 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. Large jelly fish and sea anemone are even more dangerous. Jellyfish is common at seashore in Karachi and stings many persons every year.

Coral Reefs: 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.

3. PHYLUM PLATYHELMINTHES

The general characteristics of phylum platyhelminthes (flatworms) are: The flat worms are free living e.g. *Planaria*, or parasite e.g. Tapeworm. They are found in fresh water, 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. Digestive system is incomplete and is of gastrovascular type and it is absent in some flatworms.

Excretory system consists of two lateral canals with branches bearing **flame cells** (protonephridia). Nervous system consists of a pair of anterior ganglia to which longitudinal nerve cords are connected by transverse nerves

and are located in the mesenchyme. Cells, organs are simple and 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.

Development is direct in free-swimming forms and with those with a single host in the life cycle. Indirect development takes place in internal parasites in which there may be a complicated life cycle involving several hosts. The examples of flatworms are: *Dugesia* (planaria), *Fasciola* (liver fluke), *Taenia* (tapeworm).

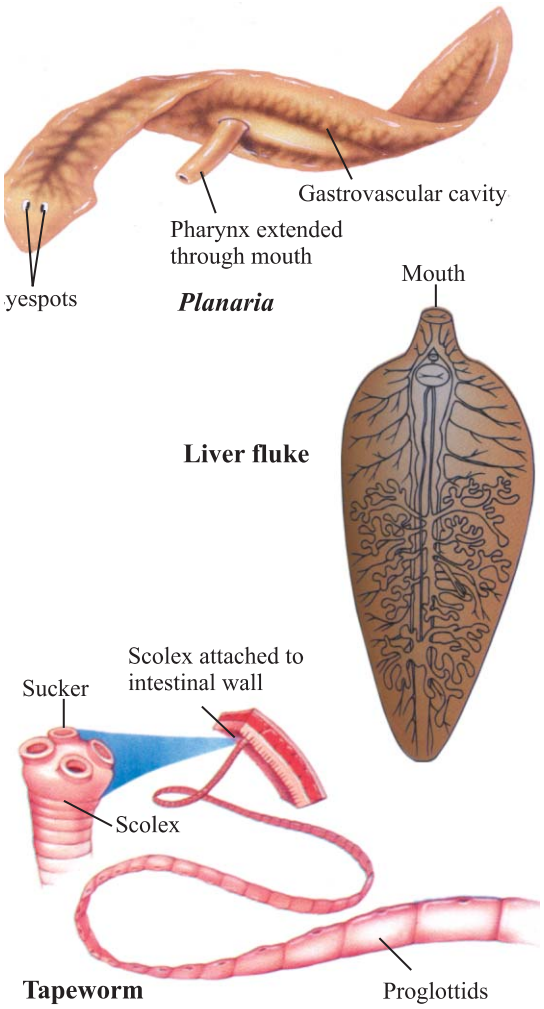


Fig: 9.11 Flatworms

Evolutionary Adaptations in Platyhelminthes

Digestive system is incomplete i.e. gastrovascular type, having only one opening to the exterior, the mouth. Respiratory and transport systems are absent, exchange of gases take place through diffusion. Excretory system of two lateral canals with branches bearing flame cells (protonephridia). Nervous system consisting of a pair of anterior ganglia with longitudinal nerve cord.

Economic 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.

4. PHYLUM ASCHELMINTHES

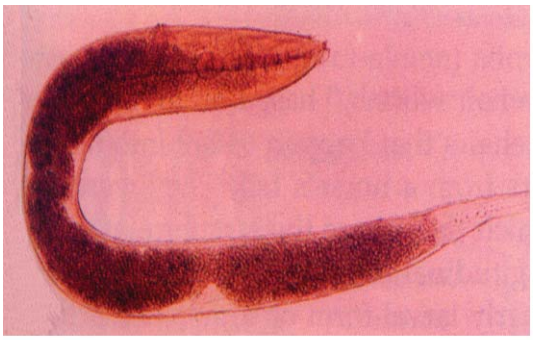
The phylum is also known as Nematoda (Gr, *nematos*, thread). The general characteristics of Phylum Aschelminthes (roundworms) are: The roundworms are free living or parasites, and live in soil, roots, human and animal intestine and muscles. Most roundworms are less than five cm long and many are microscopic but some parasitic roundworms are more than one metre in length.

The worms are symmetry bilateral, having three germ layers. Body is cylindrical, tapering at both ends. **Digestive** tract is complete. It is a straight tube with mouth and anus at opposite ends of the body. Muscular layer is not continuous. It is divided into four longitudinal quadrants: two - dorsolateral, two - ventrolateral.

The body cavity is pseudocoelom. The excretory system consists of a pair of longitudinal excretory canals and excretory pore. Nervous System consists of a nerve ring around oesophagus (pharynx), from which nerve cord and fibres extend in various directions. Most nematodes are dioecious. Fertilization is internal. Most animals are unisexual. The circulatory and respiratory organs are absent.

Evolutionary Adaptations in Aschelminthes

Aschelminthes have been able to adapt to almost every habitat available to animal life. Their basic pseudocoelomate body plans with the



Pinworms *Enterobius vermicularis* (Female)

Ascaris

Fig: 9.12 Nematodes

cuticle hydrostatic skeleton and longitudinal muscles have proved generalized and plastic enough to adapt to an enormous variety of physical conditions and virtually all potential host have been exploited. All types of life cycle occur from the simple and direct to the complex with intermediate hosts from normal dioecious reproduction to parthenogenesis, hermaphroditism and alternation of free living and parasitic generation. Aschelminthes have extraordinary capacity to survive conditions suboptimal for viability.

Digestive System is complete with mouth and anus. Pharynx is muscular well-developed tube within a tube arrangement. Circulatory and respiratory organs are absent. Excretory system consists of canals and protonephridea. Nervous system consists of a ring of nerve tissue and ganglia around the pharynx with longitudinal nerve cords connected by transverse nerve.

Economics Importance - Parasitic Diseases

Aschelminthes is important from the point of view of its parasites which has a great variety causing some very serious diseases in man and plants. *Ascaris lumbericoides* is an intestinal parasite of man. The genus *Rhabditis* contains numerous species normally found in soil, organic matter, water and faeces of man and animals. *Enterobius vermicularis* commonly known as pinworm is cosmopolitan but more common in Europe and America. Pinworms are parasites in the human caecum, colon and appendix. Their movement causes intense itching of anus, inflammation of mucous membrane of colon and appendix resulting in insomnia and loss of appetite.

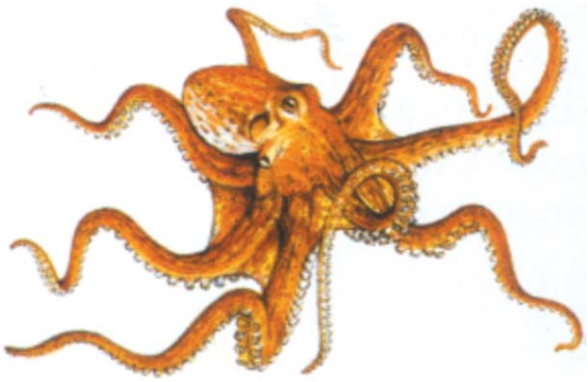
5. PHYLUM MOLLUSCA

The general characteristics of Phylum Mollusca (Latin; *Moallis*, soft) are: They are free living or sessile, and live in fresh water, marine and land (in moist places). The molluscs are bilateral symmetry, triploblastic, coelomate, soft and unsegmented animals. Body is divided into; head ventral muscular foot dorsal visceral region containing most of the internal organs. The whole animal is covered in an envelope of glandular epithelial tissue 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**, provided with horny teeth e.g. Cuttle fish, snail. Respiration takes place by gills, lungs mantle or by body surface, which is richly provided with blood vessels. Circulatory System is of open type except for the Cephalopods e.g. Squids. Coelom is divided into **haemocoelic channels** or sinuses. The excretory system consists of one or two metanephridia. Nervous System consists of three pairs of interconnected ganglia in the head, foot and visceral

mass. There is a collection of ganglia in the head region forming a ganglionic mass. e.g. Squids. Sexes may be separate e.g. *Unio* or united e.g. *Helix*. The development takes place through **trochophore larvae**.

The molluscs are classified into six classes. The three major classes are: (1) Gastropoda e.g. *Helix aspera* (gardan snail), *Limax* (slug) (2) Bivalvia (Pelecypoda) e.g. *Mytillus* (marine mussel) , *Ostrea* (Oyster), *Anodonta* (fresh water mussel) (3) Cephalopoda e.g. *Loligo* (squid), *Sepia* (cuttlefish), Octopus.

Nautilus



Octopus

Snail

Fresh Water Mussel

Fig: 9.13 Molluscs

Evolutionary Adaptation in Molluscs

Most of the diversity among molluscs is related to their adaptation to different habitats and modes of life and to a wide variety of feeding method ranging from sedentary filter feeding to active predation. Digestive system is complex having rasping organ radula and anus usually emptying into mantle cavity. Gaseous exchange by gills, lungs mantle or body surface. Open

circulatory system consists of heart and blood vessels. In cephalopods mostly closed circulatory system is present. There are one or two metanephridia, which open into the pericardial cavity. The nervous system consists of paired cerebral, pleural, pedal and visceral ganglia with nerve cords.

Economic Importance in Molluscs

Beneficial molluscs: Shell of fresh water mussels are used in button industry. Shells of oyster are mixed with tar for making roads in America. Shells in certain parts of the world are also used for making ornaments. Some oysters make valuable pearls e.g. pearl oyster. Calms, oyster, mussels are source of food in Far East, Europe, and America.

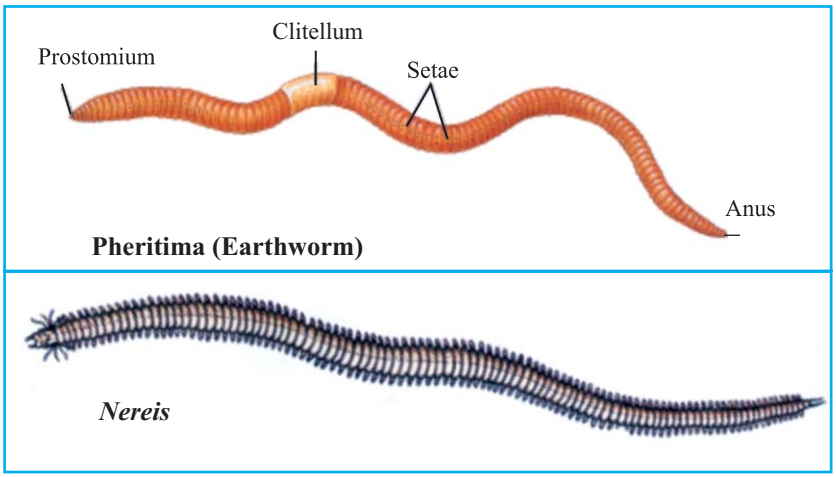
Harmful molluscs: Slugs are injurious in garden and cultivation. Toredo a shipworm damages wooden parts in ships.

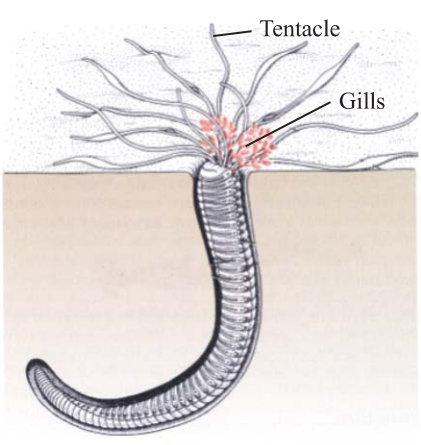
6. PHYLUM ANNELIDA

The annelids are called segmented worms. The general characteristics of Phylum Annelida (Latin - *Annelus* = little ring) are: They are free living (Earthworm) or ectoparasite e.g. (*Stylaria*, *Hirudo*). They are found in soil, freshwater and marine (*Nereis*). Body is metamerically segmented i.e. the body is divided into segments both internally and externally by transverse septa. Circulatory, nervous and digestive system extend throughout the body. Coelom is a true coelom. It is separated into compartments. Due to spaces around alimentary canal, the adjacent coelomic chambers communicate with each other. Thus coelomic fluid of the adjacent chamber is mixed. The coelomic fluid serves as a hydrostatic skeleton also. Digestive system is in the form of a alimentary canal. It is divided into distinct parts each performing a specific function. It has two openings the mouth and anus. The mouth is surrounded by a lobed structure the prostomium. The digestive system is poorly developed in parasitic species. Annelids are the first group in the animal kingdom having definite **closed blood vascular system**. Excretion takes place by **nephridia**. These are ciliated organs present in each segment of the body. Central nervous system is present. It consists of a pair of dorsal ganglia and a solid double, longitudinal ventral nerve cord. Nerves arise in each segment from the nerve cord. Respiratory system is absent and respiration takes place through the moist skin. The body wall contains circular and longitudinal muscles which help in locomotion. The locomotion takes place by the interaction of muscles and hydrostatic skeleton. The organs of locomotion in the annelids are chitinous **chaetae** or **setae**. It is embedded in sacs in earthworm. **Parapodia** is present in the body wall of *Nereis*. The

chaetae are absent in leech. 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 **trochopore larvae**. Regeneration is common in annelids.

Phylum Annelida consists of three classes: 1. Class Polychaeta e.g. *Nereis*, 2. Class Oligochaeta e.g. *Pheritima posthuma* (Earthworm). 3. Class Hirudinea e.g *Hirudo* (Leech).





Amphitrite *Leech*

Fig: 9.14 Annelids

Evolutionary Adaptations in Annelids

A basic adaptive feature in evolution of annelids is their septal arrangement resulting in fluid filled coelomic compartments. Fluid pressure in those compartments is used as a **hydrostatic skeleton** for movement.

Powerful circular and longitudinal muscles have been adapted for flexing shortening and lengthening of the body. There is a wide variation in feeding adaptations from the sucking pharynx of the oligochaetes and the chitinous jaws of carnivorous polychaetes to the specialized tentacles and cirri of the ciliary feeders. In Polychaetes the parapodia have been adapted in many ways and for many functions, chiefly locomotion and respiration.

Economic Importance of Annelids

Polychaetes form an important food item for many edible fish. Polychaetes that build calcarious tubes greatly contribute to reef formation. Earthworms help in soil improvement. Leech is an ectoparsite to man and cattle.

7. PHYLUM ARTHROPODA

The arthropods are called joint footed animals. The general characteristics of Phylum Arthropoda (*Arthros*, joined *pods*, feet) are: They are free living or parasites and are found in all types of habitat. The body is segmented. The segments are attached to each other by a modified portion of the cuticle which is thin and flexible. Arthropods vary in structure. 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.

There are several pairs of appendages. Each pair of appendages with many joints is used for movement in various directions, often modified for specialized functions. 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.

Arthropods have complex digestive system. Alimentary canal has two openings, the mouth and anus. Each part is modified for specific function. Mouthparts are modified from appendages and are adapted for different methods of feeding. Arthropods feed on small plants, plant juices, animals etc. 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. A pair of compound eyes and antennae form the sensory organ. Excretion takes place through paired excretory glands called coxal, antennal or maxillary glands. In insects the excretory organs are called **Malpighian tubules**, and the nitrogenous wastes are excreted in the form of solid uric acid. Respiratory system consists of extensive tracheal system formed by the air tubes called **trachea**. Spiracles are the openings of the main tubes to the exterior. In aquatic arthropods respiration takes place through **gills**.

Circulatory system consists of dorsal contractile heart and haemocoel (blood sinuses). Skeleton is exoskeleton, formed chiefly of chitin. Muscles are attached to exoskeleton for locomotion. Arthropods have active and swift movements. They may swim, crawl or fly as per habitat. The organs of locomotion are paired appendages. Insects have paired wings.

Sexes are separate in arthropodes. 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.

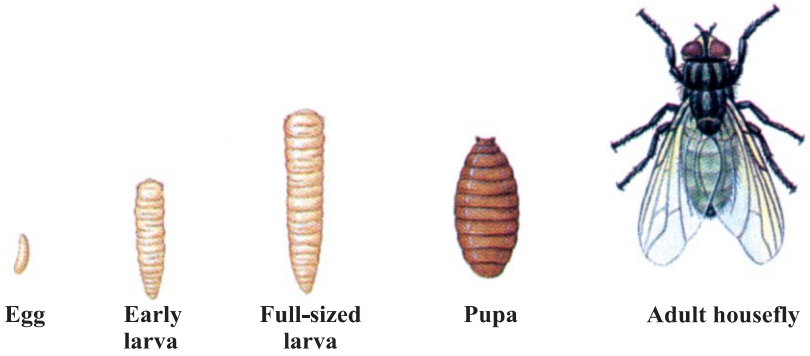


Fig: 9.15 Complete Metamorphosis

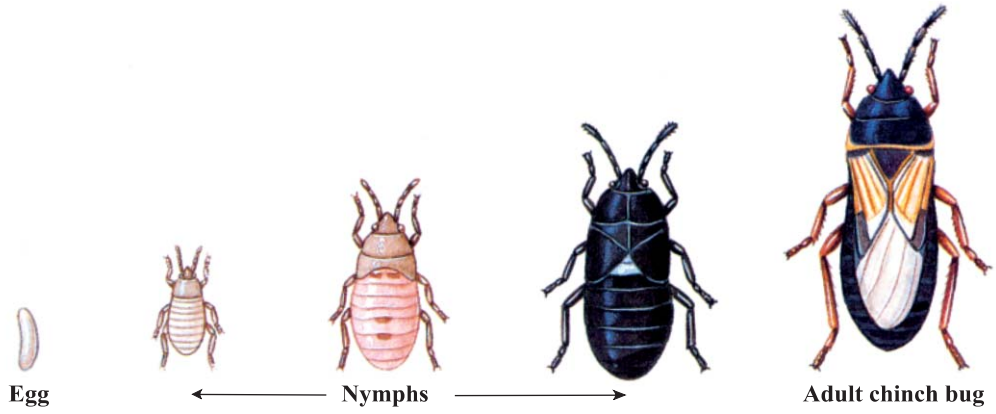


Fig: 9.16 Incomplete Metamorphosis

Development takes place through **metamorphosis**. It is of two types. In **incomplete metamorphosis** only larval stage is present which resembles the adult called nymph e.g. cockroach, chinch bug. In **complete metamorphosis** the life cycle consists of egg, larva, pupa and adult e.g. butterfly, housefly. In the larvae e.g. insects, the chitinous exoskeleton is shed from time to time to allow growth of the larvae. This process of shedding of exoskeleton is called **moulting** or **ecdysis**.

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.

Classification of Arthropods

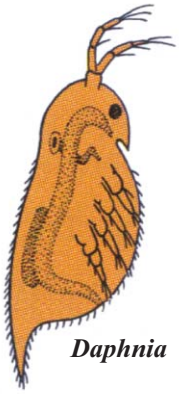
Phylum Arthropoda is a large group. It shows a great diversity. It has been divided into four major classes. (1) Crustacea e.g *Daphnia*, *Cyclops*, Crab, Lobsters, Prawn and Wood louse. (2) Insecta e.g. Dragon fly, mosquitoes, butterflies, moths, wasp and beetles etc. (3) Arachnida e.g. Scorpions, Spiders, Mites and Tick. (4) Myriopoda e.g. Centipede (Scolopendra), Millipedes (Julus).

Evolutionary Adaptations in Arthropods

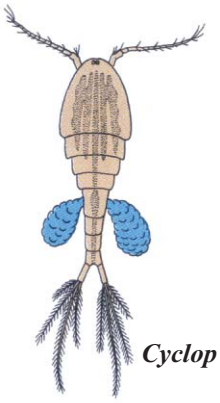
In arthropods there is the strong but flexible exoskeleton composed primarily of chitin. It is hard and nonexpandable so arthropods molt the exosekeleton as they grow larger. Before molting, the body secretes a new larger exoskeleton. Arthropods are segmented but some segments are fused into regions, such as head, thorax and abdomen. In modern arthropods apppendages are specialised for walking, swimming, reproducing, eating and sensory reception. Several arthropod groups, such as insects, arachnids, centipedes, and millipedes, contain species that are adapted to terrestrial life. The head bears various types of sense organs including compound and simple eyes. Arthropods have a variety of respiratory

Science Titbits

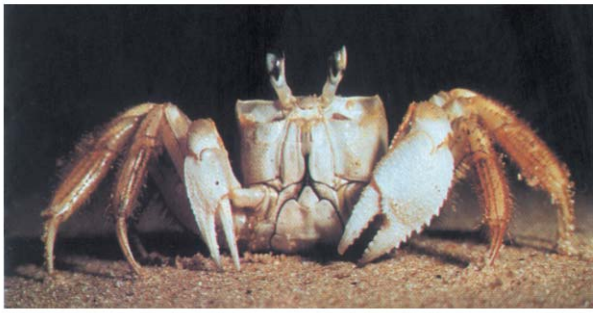
Origin of Arthropods: It is believed that the arthropods and annelids have a common origin, as both have appendages, a segmented body and cuticle.



Daphnia

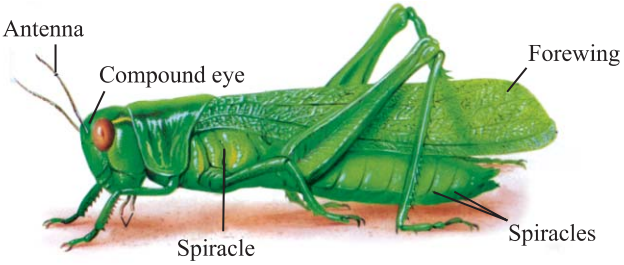


Cyclop



Crab

Fig: 9.17 Crustaceans



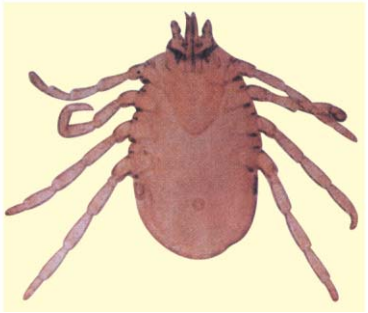
Grasshopper

Butterfly

Wasp

Fig: 9.18 Insects

Spider



Tick

Mite

Fig: 9.19 Arachnids

Scolopendra Julus

Fig: 9.20 Myriapods

organs. Marine forms have gills. Terrestrial forms have book lungs (e.g., spiders) or air tubes called tracheae (L. *trachia*, windpipe).

Digestive system is complete, mouthparts modified from appendages and adapted for different methods of feeding. Open circulatory system with dorsal contractile heart arteries and blood sinuses (homocoel) is present. Paired excretory glands called coxal, antenna or maxillary glands present some with other excretory organs called **Malpighian tubules**. Nervous system with dorsal brain connected by a ring around the gullet to a double nerve chain of ventral ganglia, well developed sensory organs.

Economic Importance of Arthropods

Many arthropods are of great importance, as some are useful and others are harmful to mankind.

Crustacea: Many crustaceans provide human food, directly or indirectly. Lobsters, cray fish and prawns are eaten. Some crustaceans act as intermediate hosts for human parasites, e.g Cyclops carry larvae of a nematode, the Guinea worm.

Insecta: The insects are of very great economic importance. They are beneficial as well as harmful.

Beneficial Insects: They give us many substances of commercial importance, e.g. Honey and bee's wax are produced by the honeybee, silk by silk worms and shellac from a wax is secreted by lac insects. Insects aid in the production of fruits, seeds and vegetables by pollinating the flowers e.g. bees, wasps, ants and butterflies. Insects like grasshoppers, locusts, crickets, and many more are eaten by human beings in certain parts of the world. Insects form food

Fig: 9.21 Lady Bird Beetle

for animals useful to man. Insects act as scavengers. Insects destroy other injurious insects. Dragonflies feed on mosquitoes, ladybird beetles eat up plant lice. Insects destroy weeds by feeding on them. Insects are employed in scientific studies. Fruit fly (*Drosophila*), cockroach, grasshopper are abundantly used as laboratory animals for scientific learning and research.

Harmful Insects: They destroy field crops, fruit trees and timber plants. The more destructive insects are locusts, grasshoppers, beetles, caterpillars, aphids, leafhoppers, scale insects, bugs and weevils. They damage stored grains, e.g. grain weevils and ants. They spoil useful articles in the houses, e.g. Silverfish damages books and white ants destroy furniture. They spread diseases among human beings. The more important disease carriers are housefly, mosquitoes, lice, sand fly, tsetse fly and bugs. They irritate man in various ways. Bees and wasps sting, mosquitoes, lice and fleas bite and suck blood; small insects fall into the eyes.

Arachnida: The arachnids are mainly harmful to man. Scorpions and a few spiders are poisonous and sting. Certain mites damage crops. Spiders and scorpions are beneficial to a certain degree as they feed largely on injurious insects.

Science, Technology and Society Connections

Explain the role of invertebrates in the field of research and daily life.

8. PHYLUM ECHINODERMATA

The echinodermata are called **spiny skinned animals**. The general characteristics of phylum echinodermata (GK. *echinos*, spiny and *derma* skin) are: 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).

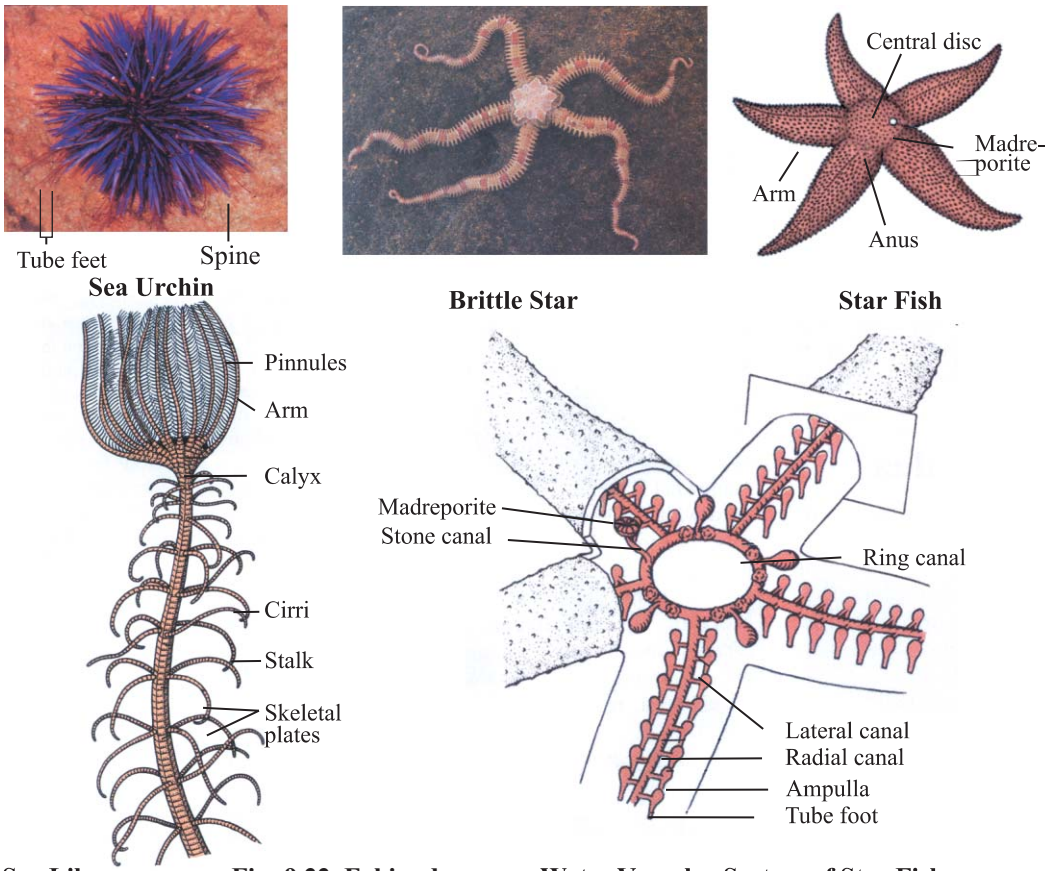


Fig: 9.22 Echinoderms

Coelom consists of canals and spaces. One of which forms water vascular system. It is a complex system of tubes. It consists of stone canal, ring canal, lateral canal, radial canal, ampulla and tube feet. Water circulates through these channels. Water enters through a sieve like plate called madreporite present on the aboral surface. Organs of locomotion are the tube feet. Each foot is a soft structure. These are present along the edges of grooves present in the arms.

There are specialized organs for digestion and reproduction. There are no specialized organs for respiration or excretion. The nervous system is poorly developed. There is no brain, only a nerve ring is present around the pharyngeal region. The circulatory system is poorly organized. The sexes are separate. The fertilization is external. The larvae such as **bipinnaria** and **brachiolaria** are complex and exhibit bilateral symmetry. Autotomy and regeneration are common among 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

The most evolutionary characteristic are: Radial symmetry, the water vascular system and their dermal endoskeleton. If their ancestors had a brain and specialized sense organs these were lost in the adoption of radial symmetry. There are large numbers of echinoderm, which are creeping benthic forms with filter feeding, deposit feeding scavengers and herbivores, comparatively few predators and very large pelagic forms. Digestive system usually complete axial or coiled anus absent in ophiuroids. Respiration by dermal branchiae, tube feet, respiratory tree e.g. see cucumber and bursae e.g spiny brittle star. Blood vascular system is much reduced. Excretory organs are absent. Nervous system includes a circumoral nerve ring and radial nerve-cords. There is no brain.

Economic Importance of Echinoderms

Many echinoderms are used as food e.g. Sea cucumber is used in making soup in China. Gonads of sea urchin are eaten in South America. Eggs of starfish, sea urchin are eaten in West Indies etc. 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. The echinoderms are also harmful. They cause damage to oyster beds. The stinging sea urchins are poisonous.

9.3.2 CHORDATES

Both invertebrate and vertebrate chordates have been divided into two phyla, phylum Hemichordata and phylum chordata.

1. PHYLUM HEMICHORDATA

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*.

The hemichordates are called **acorn worms**. The general characteristics of Phylum Hemichordata (Gr. *Hemi*, half, *Chorda*, string cord) are: 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.

The body wall consists of a single layered epidermis with mucous secreting cells and nerve net. Symmetry is bilateral and hemichordates are **triploblastic**. Body cavity is a **true coelom** with three parts corresponding to the three body divisions. Respiration occurs by one pair to numerous pairs of gill slits forming a dorsal row behind collar.

Circulatory system includes a dorsal heart and two longitudinal vessels, a dorsal and a ventral, interconnected by small lateral vessels. Blood is colourless and without corpuscles. Excretory system comprises of a proboscis gland or glomerulus situated in the proboscis and connected with blood vessels. There are no nephridia. Nervous system is diffused, consisting of an epidermal plexus of nerve cells and nerve fibres. Sexes may be separate or united. Fertilization is external. Developmen may include free swimming larval stage.

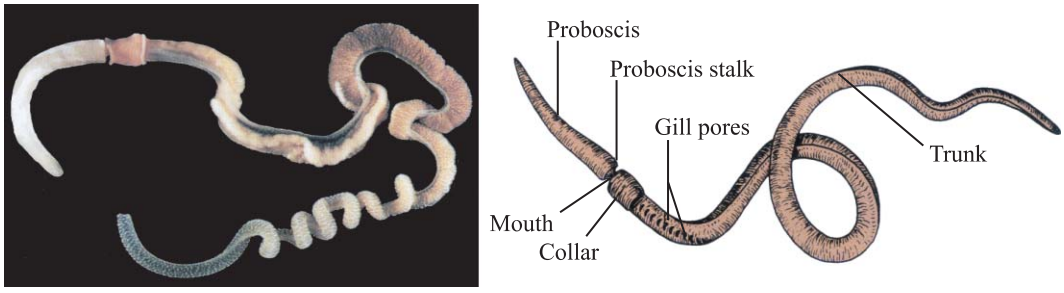


Fig: 9.23 ***Saccoglossus***

Evolutionary Adaptations in Hemichords

(a) The body is long slender having tapering proboscis

(b) Hemichordates live in burrows, foul smell provide safety from the predators

(c) Filter feeding habit suits the sluggish life in burrow

(d) Gonads are multiple

(e) There is a great power of regeneration

(f) Free swimming larva causes dispersal so essential for a sluggish creature.

2. PHYLUM CHORDATA

The representatives of the phylum chordata called the chordates, are the most familiar, adaptable, successful and the most widely distributed animals, showing diversity of form, habitat and habits to an amazing degree. The chordates include the tunicates, lancelets, lampreys, fishes, salamanders, frogs, lizards, snakes, tortoises, turtles, crocodiles, birds and mammals along with man.

Characteristics of Chordates

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.

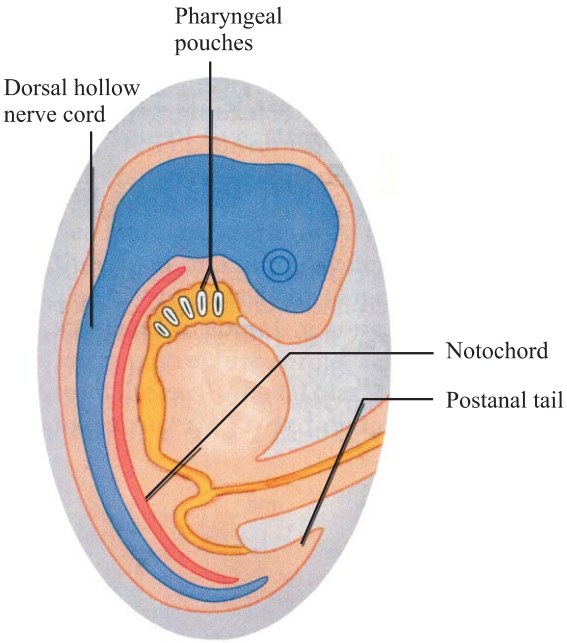


Fig: 9.24 Main Features of the Chordates, as Shown in a Generalized Embryo

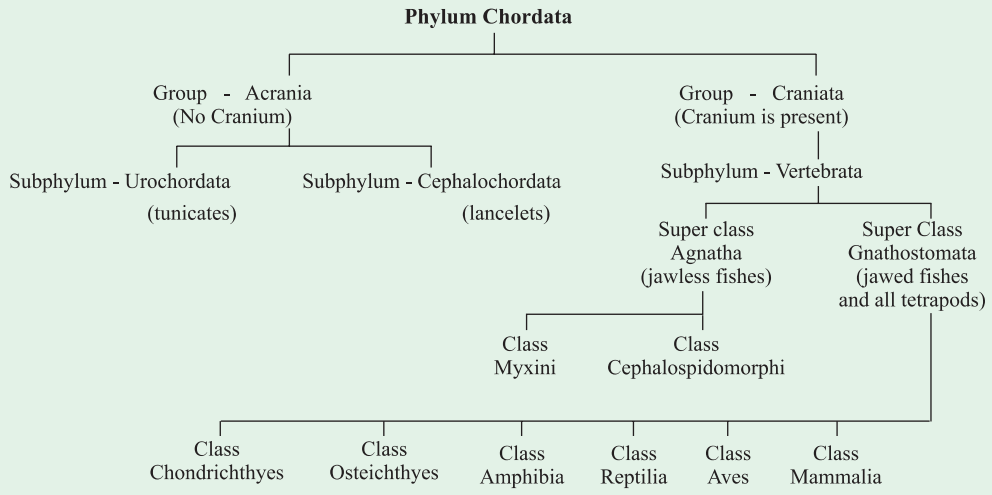
Nervous System: The central nervous system of all the chordates consists of a single, tubular fluid filled, nongangliated nerve cord, situated along the mid dorsal line above the notochord and outside the coelom.

Gill Slits: The gill slits are paired perforations on the lateral sides of the anterior part of the body, leading from the pharynx to exterior.

Classification of Chordates

The phylum chordata has been subdivided into two groups: **Protochordata (Acrania)** in which brain is not enclosed in bony case and **Craniata** in which brain is enclosed in a bony case and notochord has been replaced by vertebral column. Protochordata has been divided into two sub-phyla: (1) Subphylum urochorda, (2) Subphylum cephalochordata.

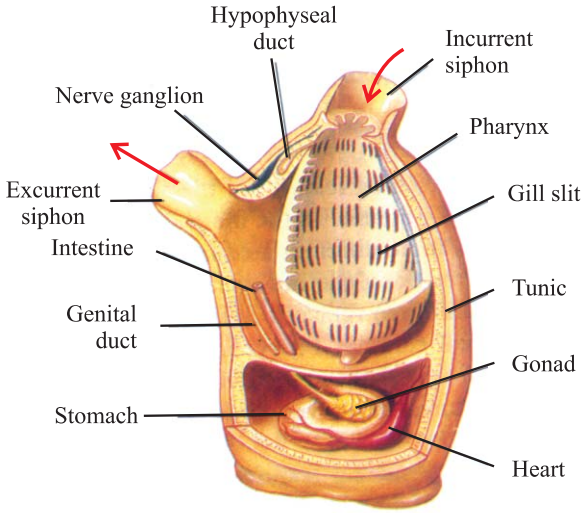
Table 9.1 CLASSIFICATION OF PHYLUM CHORDATA



i. Subphylum Urochordata

The general characteristics of subphylum urochordata are: Body varies considerably in size, form and colour. The body is covered by a covering called **tunic** so they are called **tunicates**. Lining the tunic is an inner membrane, the mantle. 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. The notochord usually disappears during metamorphosis, so that adult has no

Halosymthia



Ascidia

Fig: 9.25 Urochordates

skeleton. Digestive tract is complete. There are two to many gill or pharyngeal slits in the pharyngeal wall. Circulatory system is of open type. Nervous system is represented in the adult by a single **ganglion**. Excretion is carried on by nephrocytes.

Urochordates are hermaphroditic, usually with a single testis and a single ovary in the same animal. Germ cells are carried by the **genital duct** to the arterial cavity and then to surrounding water where fertilization takes place. Asexual reproduction takes place by budding. Larvae are free swimming and have a dorsal hollow nerve cord extending the greater length of the body and a notochord confined to the tail so the group has been named urochordata. The examples of urochordates are *Ascidia*, *Halosymthia*, etc.

Evolutionary Adaptations in Subphylum Urochordata

Adaptation for feeding: Inability to move about in search of food has been overcome by developing ciliary feeding in which food particles are drawn towards the mouth.

Adaptation for survival: Thick leathery test and calcarious spiny spicules keep the predators away. Free-swimming larva brings about dispersal.

ii. Subphylum Cephalochordata

The general characteristics of subphylum cephalochordata are: Body is fish like. It has no head but tail is present. Notochord extends the entire length of the body. Digestive tract is complete. There is no organ for respiration. It takes place through general body surface. Circulatory system is of closed type. Excretory system consists of paired **protonephridia**. Sexes are separate and fertilization is external. Development takes place through a ciliated free-swimming larva. The example of cephalochordata is *Branchiostoma* (*Amphioxus*) (lancelet).

Evolutionary Adaptations in Subphylum – Cephalochordata

Adaptation for Swimming: Streamlined form, expanded caudal fin increases the forward thrust of the body

Adaptation for Burrowing: Stream lined body helps burrowing in sand, mucus acts as lubricant and front end acts as efficient drill during burrowing.

Adaptation for Feeding: Ciliary feeding by the lancelet best suits its nearly sedentary life inside burrows.

Adaptation for Survival: Translucence of the body renders it almost invisible in water. Habit of leaving the burrows at night, free-swimming larvae and high degree of sensitivity also contributes to survival of the animal.

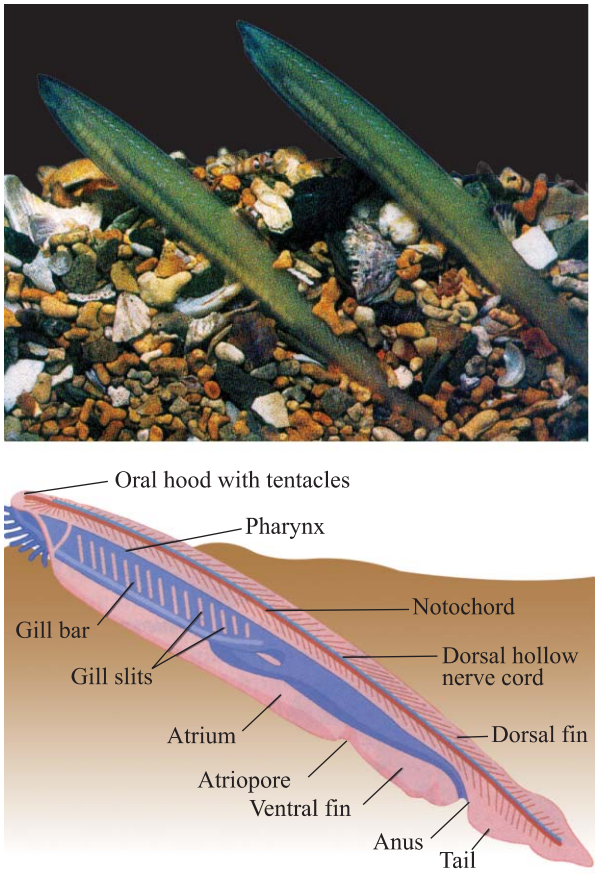


Fig: 9.26 ***Branchiostoma lanceolatum***

iii. Subphylum Vertebrata (Craniata)

The third subphylum of the chordate is the largest and imminently diverse 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. The classification of the subphylum vertebrata is given in the table No. 9.1

Vertebrates may be divided into nonamniotes or those without foetal membrane, include cyclostomata, chondrichthyes, osteichthyes, amphibia and amniota or those with foetal membranes includes reptiles, aves and mammals.

a. SUPER CLASS AGNATHA

The living members of agnatha are divided into two classes; **Mixini** (hagfishes) and **Cephalospidomorphi** (lampreys) members of both groups lack jaws, internal ossification, scales and paired fins and both group share pore like gill openings and an eel-like body form. In other aspects however, the two groups are morphologically very different.

Science Titbits

Vertebrates are distinguished, in particular by, having endoskeleton, closed circulatory system, paired appendages, efficient respiration and excretion, high degree of cephalisation.

The general characteristic of super class Agnatha are: Body slender, eel-like, 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 teeth in Class Myxini and the oral disk is sucker like and tongue with well-developed teeth in class Cephalospidomorphi. There are five to sixteen gills for respiration in class Myxini and seven pairs of gills each with external gill opening in class Cephalospidomorphi. Digestive system is without stomach. Dorsal nerve cord with differentiated brain. Sexes are separate. Fertilization is external and there is no larval stage. The examples of agnatha are Hagfish, and Lamprey.

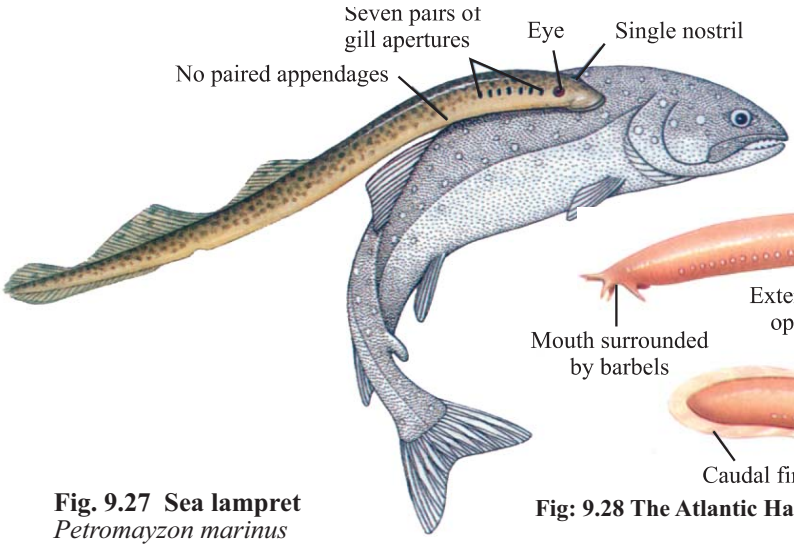


Fig. 9.27 Sea lampret
Petromayzon marinus

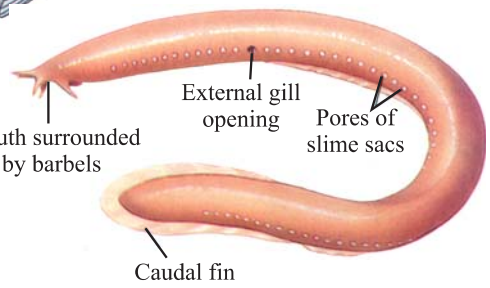


Fig: 9.28 The Atlantic Hagfish *Myxine* glutinosa

Evolutionary Adaptations in Super Class Agnatha

Body is long slender limbless, slimy skin offer minimum resistance to water. Laterally compressed, tail with caudal fin provides greater forward thrust. **Buccal funnel** and toothed tongue form a device for blood sucking in absence of jaws. Ability to draw in and expel out water through the gill slits carries on respiration. Very large numbers of eggs are laid. Burrowing life of the larvae gives them protection against carnivores and filter feeding best suits their nearly sedentary life in burrows.

b. SUPER CLASS GNATHOSTOMATA

It is divided into six classes: Chondrichthyes, Osteichthyes, Amphibia, Reptilia, Aves and Mammalia.

1. CLASS CHONDRICHTHYES

The chondrichthyes are popularly called the cartilaginous fishes. The cartilaginous skeleton is considered as a degenerate character rather than primitive character. It includes the sharks, dogfishes, rays, skates and chimaeras. The general characteristics of class Chondrichthyes are: Body is laterally compressed and spindle (fusiform) shaped. Mouth is ventral. Olfactory sacs are not connected to mouth cavity.

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.

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**. 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. Skates and Rays are bottom dwelling fishes. The pectoral fins of these fishes are much enlarged and are used for swimming like wings. Two members of this group are of special interest are Sting rays and Electric rays. The tail of the sting rays is long and whip like and have sharp spines, which can inflict dangerous wounds. Electric Rays have certain dorsal muscles modified into powerful electric organ which can give severe shock and stun their prey.

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.

Economic Importance of Chondrichthyes

They provide food. Some shark and rays are eaten in many countries. They provide products of commercial value. Oil is obtained from the liver of

many sharks, which is a source of vitamin A and D. Shark skin leather is used for shoes and bags. Pituitary gland of shark yields an extract of medical use. Sharks feed on crustaceans, lobsters, crabs, and other fishes, which form human food.

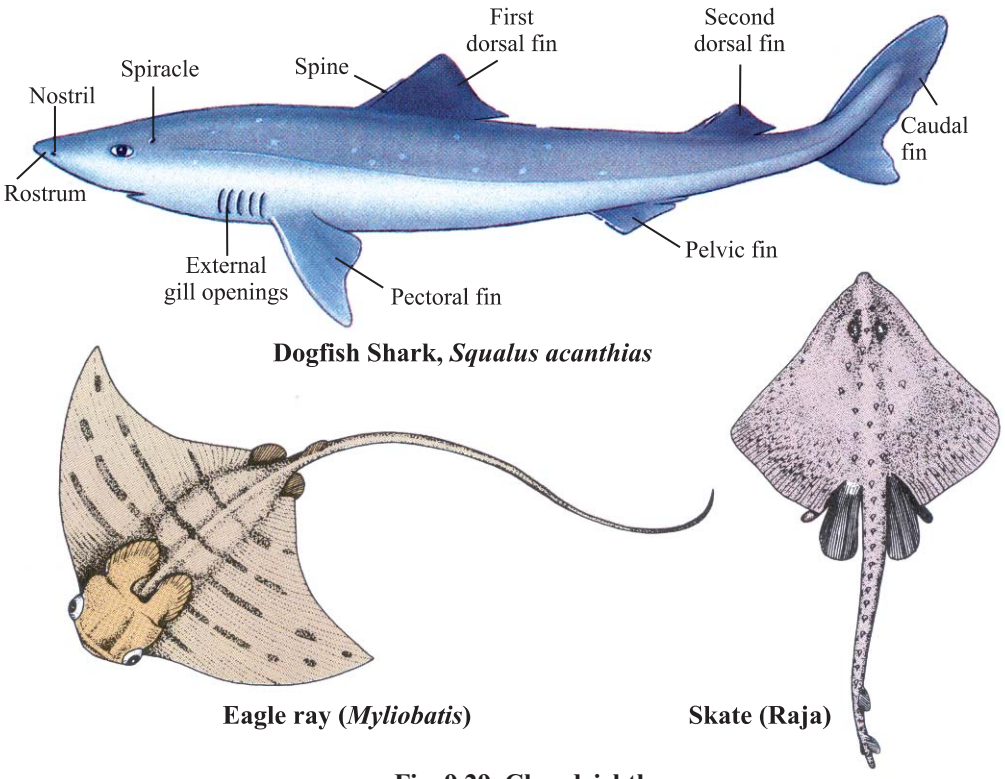


Fig. 9.29 Chondrichthyes

2. CLASS OSTEICHTHYES

The general characteristics of class Osteichthyes (bony fishes) are: Body is usually spindle-shaped and stream lined 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. The scales are **ganoid**, **cycloid** or **ctenoid**. Both median and paired fins are present. These are supported by cartilaginous or bony rays in the distal part. Pelvic and pectoral fins are paired while dorsal fin is single. The caudal fin is **homocercal**. Mouth is usually terminal i.e. anterior end often bears numerous teeth. Jaws are well developed. Anus is present and cloaca is absent.

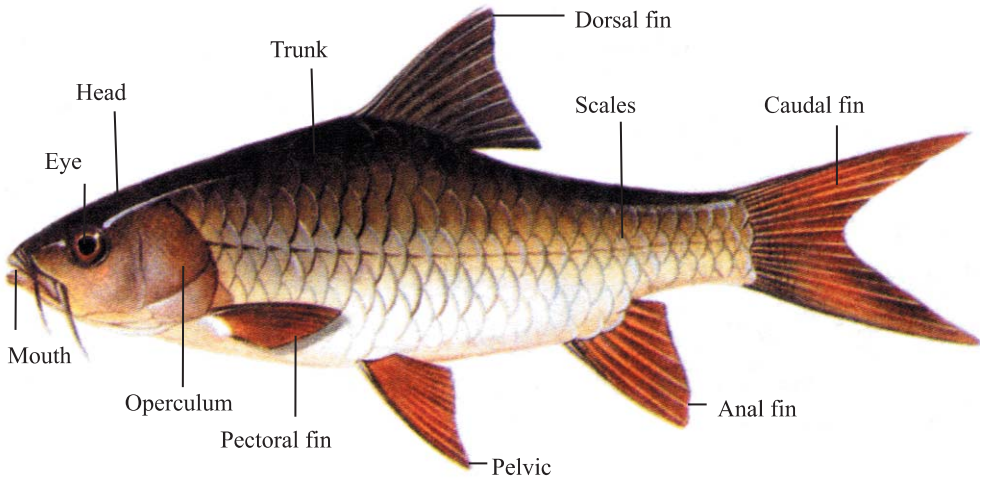


Fig: 9.30 ***Labeo rohita***

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 bouyancy. 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**, some are ovaviviparous or even **viviparous**.

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.

Economic Importance of Osteichtheys

They provide food and important marine food fishes include cod, herring and salmon etc. Popular fresh water food fishes are trout, carp, cat-fish and mullet. They provide products of commercial value. Fish oil, fish meal and liquid glue are important fish products. Liver of cods yield oil, which is a source of vitamins A and D.

Adaptations to Aquatic Life in Fishes

Streamline body offers little resistance to water while fishes are swimming. **Swim bladder** is present in bony fishes, except a few. It may or

may not be connected to pharynx. It helps in bouyancy and with its help fish can float high or sink lower in water. The swim bladder is filled with oxygen, carbon dioxide and nitrogen. The gases may be secreted by the glands in the swim bladder. When the swim bladder is connected to pharynx the bladder may be filled by gulping of air.

Fig: 9.31 Sea Horse

Fins help in swimming. They keep balance of fish in water. Fins are paired and unpaired. Pectoral and pelvic fins are paired. Dorsal, caudal and anal fins are unpaired fins. Heart has two chambers. Afferent and efferent branchial system present. Gills are the respiratory organs having network of blood capillaries. Gills are adapted to receive oxygen dissolved in water and remove carbon dioxide. Kidney is **mesonephros**. It is modified for excretion in the aquatic environment.

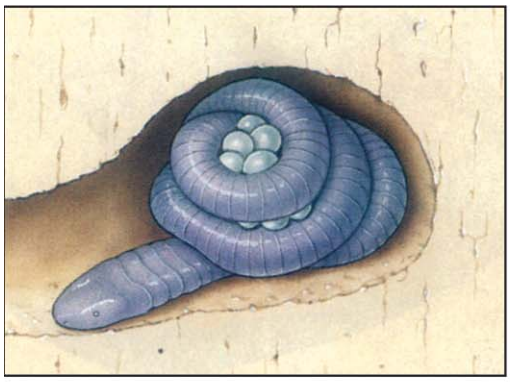
Fig: 9.32 Lobe-Finned Fish, The Coelacanth, *Latimeria*, is a living Fossil.

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

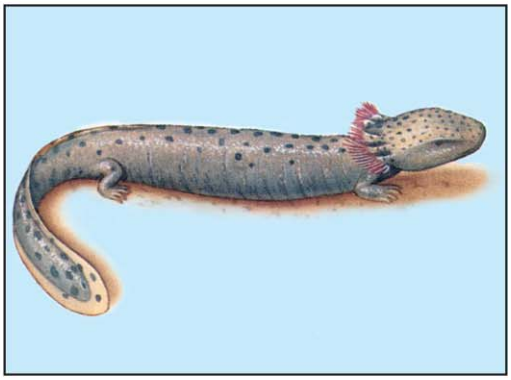
The general characteristics of class Amphibia are: Body varies considerably in forms. Body is divisible only into head and trunk. Most have



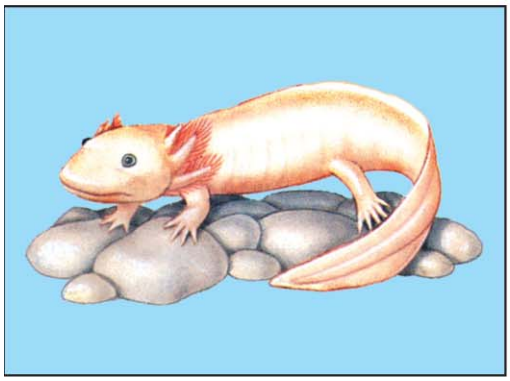
A Female Caecilian

Spotted Salamander

Longtail Salamander



Common Mud Puppy *(Necturus)*



Axolotl *(Ambystoma)*

Frog *(Rana)*

Fig: 9.33 Amphibians

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 and may be respiratory. Scales are generally absent. In some glands are poisonous, chromatophore pigment cells are present in the skin.

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**. Body temperature is variable i.e. poikilothermic (ectotherms) and most forms undergo hibernation in winter. The examples of amphibians are Frogs, Toads, Salamanders etc.

Evolutionary Adaptations in Class Amphibia

Amphibians mark the transition from aquatic to terrestrial life in vertebrates. Their notable adaptation on land are: 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.

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?

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

The general characteristics of class Reptilia are: Body form varies. 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.

Tortoise

Lizard

Corel Snake

Alligator

Fig: 9.34 Reptiles

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.

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) limbs better suited for rapid locomotion and raising the body off the ground (c) separation of oxygenated and deoxygenated blood in the heart (d) complete ossification of the skill (e) a neck movable independent of the body (f) better mechanism of breathing (g) fertilization is internal (h) egg with shell for protection on land (i) claws for defence.

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.

5. CLASS AVES

The general characteristics of class Aves are: 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. Lungs are compact, spongy. 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 ureter open into the cloaca and the urinary bladder is absent. The urine is semisolid and uric acid is main nitrogenous waste. Sexes are separate. Fertilization 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

Birds show the following evolutionary adaptations: An insulated covering over the body. Better aeration of blood in the lungs, taking place during both inspiration and expiration. Complete separation of venous and arterial blood in the heart. Birds have an active life and a high rate of metabolism. Very rapid locomotion is provided by the power of flight. A regulated body temperature that keeps them equally active all the year round. A highly developed power of producing sound. More efficient eyes with

Kiwi

Penguin

Duck

Parrot

Fig: 9.35 Birds

double means of accommodation. Better ears having cochlea with an **organ of Corti**. 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

The general characteristics of mammals are: 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**. Each half of the lower jaw consists of a single one, the dentry and articulates directly with skull. External ear or pinna is present. There is a chain of three bones in the ear incus, malleus and stapes (sta-pez).

Mammals have deciduous and permanent teeth. In some mammals for example in man there are two sets, one in early life the milk teeth and later the permanent teeth. Heart is four chambered. Only left aortic arch is present. RBC 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.

Classification of Mammals

Mammals are classified into three subclasses: (1) Prototheria-Egg laying mammals. (2) Metatheria-Pouched mammals. (3) Eutheria-Placental mammals.

SUB-CLASS PROTOTHERIA - The Monotremes

It 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 a webbed toes. The mammalian feature of the monotremes is that the female has mammary glands and they feed their youngs. The reptilian features includes 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 *(Ornithornhynchus)* **Spiny Ant Eater *(Trachyglossus)***

Fig: 9.36 The Monotremes

Science, Technology and Society Connections

Demonstrate an understanding of the connection of extinction of species with that of human activities.

SUB CLASS METATHERIA – The Marsupials

The females have an abdominal pouch the **marsupium**, where they rear their young. The young 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 Tasmanian wolf.

Kangaroo

Koala

Fig: 9.37 The Marsupials

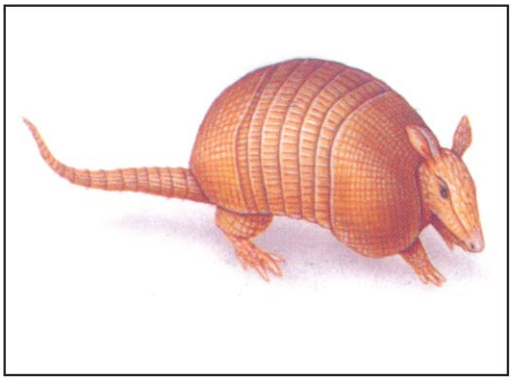
SUB-CLASS EUTHERIA – The Placentalis

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. 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. So these mammals are called placental mammals. 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

Mammals show the following evolutionary adaptations: A regulated body temperature. This makes them independent of environmental change, keeping active throughout the year, whereas reptiles must hibernate during much of the year. An insulating coat of hair that aids in regulating body

temperature. 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. A better developed larynx. 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, in most of these features the mammals resemble the birds.



Armadillo *(Dasypus)*

Panda

Tiger

Lion

Fig: 9.38 The Placentalis

Critical Thinking

How are the characteristics of the phyla of chordates related to their way of life?

Science, Technology and Society Connections

Trace the position in the phylogeny of major groups of animals.

Exercise

SECTION I : MULTIPLE CHOICE QUESTIONS

Select the correct answer

1. All animals are
   A) autotrophs B) heterotrophs
   C) unicellular D) motile
2. Which of the following is not included in grade bilateria
   A) cnidarians B) nematodes
   C) annelids D) molluscs
3. Which of the following classes 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) tunicata, the sea squirts
4. Which of these does not pertain to a protestome?
   A) spiral cleavage B) blasto pore—anus
   C) schizocoelom D) annelids
5. Sponges belong to the phylum.
   A) aschelminthes B) arthropoda
   C) porifera D) mollusca
6. Which of the following is not a parasite
   A) annelida B) nematoda
   C) platyhelminthes D) porifera
7. 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

8. 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
9. Amphibians arose from
   A) cartilaginous fish B) jawless fish
   C) ray finned D) bony fishes with lungs
10. 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
11. Which of the following has a gastrovescular cavity?
   A) sponges B) earthworms
   C) roundworms D) flatworms
12. Which of the following is not a subphylum of chordata
   A) hemichordata B) urochordata
   C) cephalochordata D) vertebrata

1. Write four distinct features of animals.

SECTION II : SHORT QUESTIONS

2. Name the criteria for animal classification.
3. To what life style is radial symmetry an adaptation? Bilateral symmetry?
4. How radial and intermediate cleavage occurs in eggs.
5. Give three features of platyhelminthes for parasitic mode of life.
6. Give three distinguishing features of Aschelminthes.
7. Write five salient features of phylum arthropoda.

8. List any six harmful roles of insects.
9. List the similarities between echinoderms and chordates.
10. Give three reasons why urochordates are classified as chordates.
11. Why amphibians are not considered a very successful group of vertebrates?
12. What does the term amphibian mean?
13. Distinguish between ectothermic and endothermic. Give an example of an ectothermic and an endothermic.
14. Name two phyla of animals that are radially symmetrical and two that are bilaterally, symmetrical.
15. 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) Placenta. (f) Lungs supplemented by air sacs.
16. Identify the phyla that have the following characteristics: (a) radial summetry (b) a coelomate (c) pseudocoelomate (d) alternation of sexual and axesual stages (e) cnidocytes.
17. Write three main differences between prototheria, metatheria and eutheria.

SECTION III : EXTENSIVE QUESTIONS

1. Write the characteristics of animals.
2. Describe in detail the criteria for animal classification.
3. Write the salient feature of phyla, Mollusca and Echinodermata.
4. Write the economic importance of the all the phyla, which includes the invertebrates.
5. Write the evolutionary adaptations of all the phyla, which include the invertebrates.
6. Write the general characteristics of annelids.
7. Arthropods and vertebrates are highly successful groups of animals on land. Explain with reference to adaptive features for existence on land.

8. Write notes on: (a) polymorphism, (b) alternation of generation (c) corals (d) invertebrates (e) fresh water annelids (f) metamorphosis (g) branchiostoma (h) classification

9. Write the characteristics of invertebrate chordates.

10. Write the evolutionary adaptation of all the classes of phylum chordata.

11. 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.

12. List the adaptations that distinguish reptiles from amphibians and help them adapt to life in dry terrestrial environment.

13. How do mammals differ form birds? And what adaptations do they share?

14. Artropods and verteberates are highly successful groups of animals on land. What characteristics shared by arthropods and vertebrates are adaptive to a land existence?

ANSWER MCQS

1. B 2. A 3. A 4. B 5. C 6. D 7. D 8. A 9. D 10. B

11. D 12. A

SUPPLEMENTARY READING MATERIAL

1. Ruppert, E.E. and R.D. Barnes. Invertebrate Zoology, 6th Ed. Saunders College Publishing, Philadelphia, 1994.

3. Hickman, C.P. Roberts, L.S. Larson M. Integrted Principles of Zoology. 9th Ed. Mosby. St. louis, Missouri. 1993.

USEFUL WEBSITES

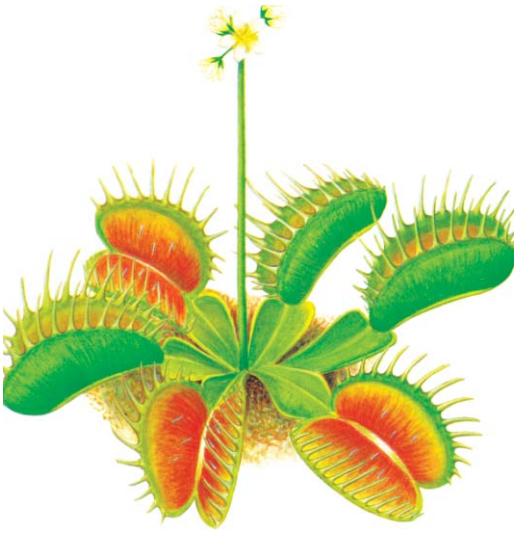
1. www.prenhall.com/~audesirk

2. www.mhhe.com/sciencemath/biology/mader/ (click on biology)

www.learningall.com

SECTION 3

Life Processes



Venus Flytrap

Pitcher Plant

Sundew

CHAPTER 10

FORM AND FUNCTIONS IN PLANTS

Number of allotted teaching periods: 27

Major Concepts:

Nutrition is one of the important life processes of an organism to obtain energy for various life activities. Plants and many microorganisms obtain raw materials from air and soil. All those raw materials that organisms need for various synthetic activities and for the production of energy are called **nutrients**. All the process of the uptake and utilization of raw materials by living organisms for various metabolic activities is called **nutrition**.

10.1 NUTRITION IN PLANTS

How do biologists determine whether an element is essential? It is impossible to conduct mineral nutrition experiments by growing plants in soil because soil is too complex and contains too many elements. Thus, one of the most useful methods to test whether or not an element is essential is **hydroponics**, which is the growing of plants in aerated water to which mineral salts have been added.

Sixteen elements have been found essential for plant growth. Nine of these are required in fairly large quantities (greater than 0.05% dry weights) and are therefore known as **macronutrients**. These include carbon, hydrogen, oxygen, nitrogen, phosphorus, potassium, sulphur, calcium and magnesium. The remaining seven **micronutrients** are needed in trace amounts (less then 0.05%dry weight) for normal plant growth and development. These include iron, boron, manganese, copper, molybdenum, chlorine and zinc.

Nutrition In Carnivorous Plants

Carnivorous or insectivorous plants have green leaves which serve for the photosynthesis and have roots which can absorb water and dissolved mineral salts from the soil. But in addition to these organs, insectivorous plants have special devices, such as modified leaves, bright in colours which are used for trapping, attracting and digesting insects and other small organisms.

These plants usually grow in places where nitrogenous salts are not readily available e.g., marshy areas and therefore they use insects and other small organisms as their source of nitrogen. The examples are Pitcher Plant, (*Nepenthes pupurea*), Venus Flytrap (*Dionaea muscipula*), Sundew (*Drosera intermedia*).

Science, Technology and Society Connections

Identify some major symptoms of mineral deficiencies in plants e.g. necrosis, chlorosis, stunted growth etc.

Table 10.1 Mineral Nutrition in Plants		
Macronutrients	**Major Functions**	**Deficiency Symptoms**
Carbon	Component of carbohydrates, lipids and nucleic acid molecules	Nil
Hydrogen	As above	Nil
Oxygen	As above	Nil
Nitrogen	Components of proteins, nucleic acids, chlorophyll, Coenzymes NAD, NADP, Cytochromes.	Chlorosis, development of purple colour due to formation of anthocyanins. Suppression growth with small leaves early defoliation. Flowering delayed
Phosphorus	In nucleic acids, phospholipids, ATP.	Stunted growth and premature leaf fall, development of anthocyanin pigment, brown necrotic areas appear on leaves, petioles and fruits. Restricted growth of root and shoot. Poor development of vascular tissue, delayed flowering.
Calcium	In cell wall, involved in membrane permeability, enzyme activator.	Meristematic regions badly effected. Chlorosis of margins of young leaves leading to necrosis. Flowering suppressed or premature fall of floweres.
Magnesium	In chlorophyll, enzyme activator in carbohydrate metabolism	Interveinal chlorosis. Formation of anthocyanin pigments. Necrosis in severe cases.
Sulphur	In certain amino acids and vitamins.	Stunted growth. Cholorosis first appearing in younger leaves. Formation of anthocynin.
Potassium	Osmosis and ionic balance, opening and closing of stomata, enzyme activator.	Stunted growth. Mottled chlorosis, necrotic shrivelling of leaves. Decrease in apical dominance. In cereals development of weak stem.
Micronutrients	**Major Functions**	**Deficiency Symptoms**
Chlorine	Ionic balance involved in photosynthesis.	Welting of leaf tips, following by chlorosis, bronzing and necrosis.
Iron	Part of enzymes involved in photosynthesis, respiration and nitrogen fixation	Interveinal chlorosis. Localised or generalized chlorosis.

Manganese	Part of enzymes involved in respiration and nitrogen metabolism, required for photosynthesis.	Chlorotic and necrotic spots in the interveinal regions of leaf. Leaves become mottled.
Copper	Part of enzymes involved in photosynthesis	Necrosis in the young leaves at the tip and along the margins. Exanthema in citrus tree and reclamation disease in cereals and legumes.
Zinc	Part of enzymes involved in respiration and nitrogen metabolism	Decreased growth. Reduction in size of internodes. Mottled leaf condition.
Molybdenum	Part of enzymes involved in nitrogen metabolism	Mottling and necrosis in older leaves. Deficiency causes whiptail disease in cauliflower
Boron	Involved in membrane transport and calcium utilization	Death of stem and root apices. Leaves become thick, curled and brittle. Flower production greatly reduced.

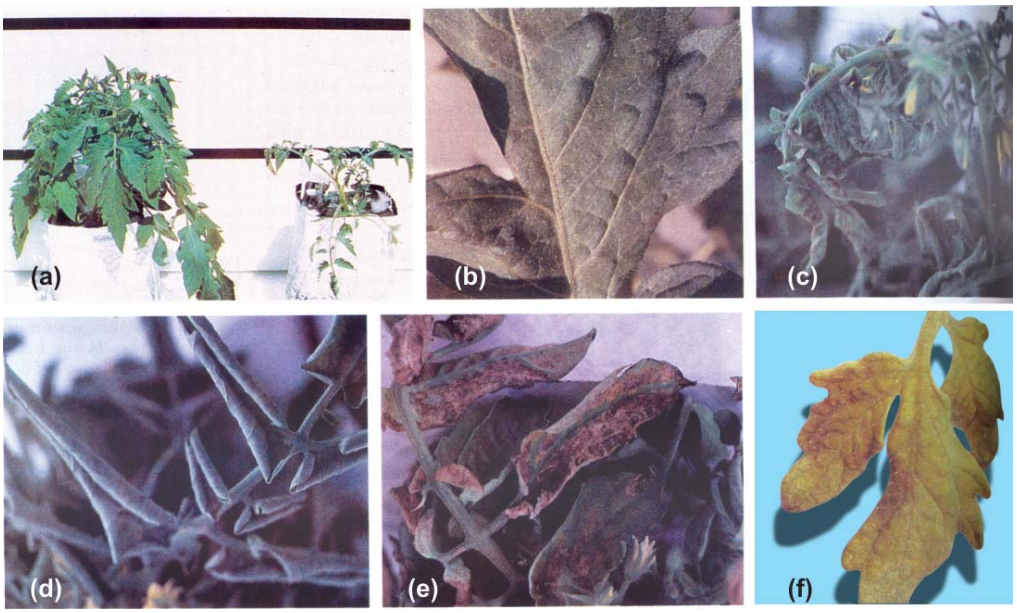


Fig 10.1: Mineral deficiencies in plants (a) Calcium deficiency (b) Leaf of a healthy plant (c) Chlorine-deficient plant leaves with patches of dead tissue (d) Copper- deficient plant with curled leaves (e) Zinc-deficient plant with small, necrotic leaves (f) Manganese-deficient plant, with yellowing between the veins.

10.2 GASEOUS EXCHANGE IN PLANTS

Respiration is one of the most important metabolic activities of all organisms. It occurs at two levels, i.e. organism and cellular level. The respiration occurring at organism level is called **breathing**, **ventilation** or simply the **exchange of gases**. The cellular respiration is directly involved in the production of energy. During this process cell utilizes oxygen and releases carbon dioxide. 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.

Role of Palisade Tissue

Mesophylls are special types of thin walled parenchymatous cells. This is the packing tissue found between the two epidermal layers of leaves. These are modified to carry out photosynthesis. In dicots there are two distinct layers of mesophyll, the palisade mesophyll and the spongy mesophyll. Palisade forms the upper layer of cells which are elongated and column shaped cells. The **spongy mesophyll** forms the lower layers. These cells are used for the exchange of gases. There are also a large number of **intercellular spaces**, which are filled with air and are used for efficient gaseous exchange.

Role of Stomata

The **stomatal transpiration** is the loss of water in the form of water vapors through stomatal openings. It is not only responsible for transportation of water and minerals but also plays a vital role in the exchange of gases. During daylight the stomata are widely open and provides a wide passage for the exchange of gases. In the presence of light the process of photosynthesis increases. It requires more and more carbon dioxide, which is provided by the widely opened stomata from the air. As the photosynthesis increases the evolution of oxygen also increases. The stomata provide a wide path for the release of oxygen in the air.

During day time in the presence of light, rate of photosynthesis is much greater which requires large amount of carbon dioxide, so the carbon dioxide released in respiration, is used within the tissues for photosynthesis and the oxygen needed for the process is made available in the tissues by photosynthesis. So there is a prominent intake of carbon dioxide and release of oxygen during daylights.

During nights as photosynthesis stops, and the stomata are closed, there is no evolution of oxygen so the carbon dioxide liberated in respiration is removed and oxygen is taken by the plant by simple diffusion through scars, gaps etc in the outer surfaces or through cuticle.

Relationship Between Transpiration and Gas Exchange in Plants

The mechanism of opening and closing of stomata enable the land plants to absorb carbon dioxide. The oxygen produced during photosynthesis is released through stomata. Stomata are primarily meant for absorption of carbon dioxide but these also help in exchange of gases. During exchange of gases water vapours also escape through stomata. The rate of transpiration in a plant is an indirect measure of the rate of photosynthesis as it indicates the degree of period of stomatal opening and exchange of gases.

Q. What gases would you expect a leaf to be (a) taking in, (b) giving out, in bright sunlight and in darkness?

10.3 TRANSPORT IN PLANTS

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 upto other parts of the plants. While phloem conducts organic food from the leaves both up and down the plant.

Xylem Tissues

Beside conduction these tissues are also used for support. It consists of four cell types; the tracheids, vessel elements, parenchyma and fibres. **Tracheids** are single cells, which are elongated, tapering and lignified. They have mechanical strength and give support. Tracheids function very efficiently, e.g. conifers rely exclusively on tracheids for the transportation of water. In angiosperms relatively there are fewer tracheids than vessels. **Vessels** are more effective structures for transportation, which are needed by angiosperms for high rates of transpiration in the group.

Xylem vessels are the conducting units of angiosperms. These are very long, tubular structures formed by the fusion of several vessel cells (vessel elements) end to end in a row. Vessels are shorter than tracheids and act as the pipeline. **Xylem parenchyma** occurs in both primary and secondary xylem. It is more extensive and important in secondary xylem. The functions of xylem parenchyma include food storage, deposition of crystals, radial transport of food and water and gaseous exchange through the intercellular spaces.

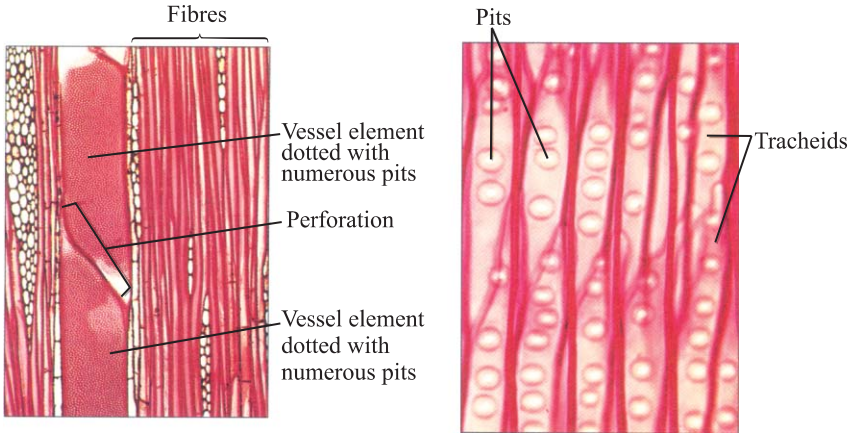


Fig: 10.2 Vessels and Tracheids

Xylem fibres are originated from tracheids. They are shorter and narrower than tracheids. They have much thicker walls. They are not involved in the conduct of water.

Phloem Tissues

These are composed of living cells and have no mechanical function. There are five types of cells, namely, sieve tube elements, companion cells, parenchyma fibres and sclereids. **Sieve tubes** are the long tube like structures, which translocate solutions of organic solutes (sucrose) throughout the plant. These are formed by the end-to-end fusion of cells called sieve tube elements or sieve elements. **Sieve tube elements** have walls made up of cellulose and pectic substances but the nuclei are lost as they mature. The cytoplasm confined to periphery of the cell. The sieve elements remain living but are dependent on the adjacent **companion cells**. The two, i.e. sieve elements and companion cells, together form a functional unit. **Plasmodesmata** run through the walls but the canals enlarge to form pores, making the walls look like a sieve and allows a flow of solution from one element to the next.

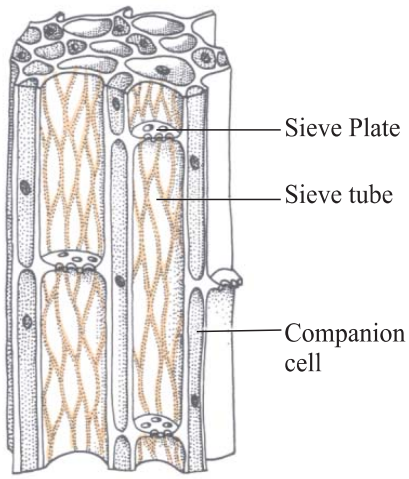


Fig: 10.3 Phloem

Movement of Water

Transport or movement of materials in between the organisms and their environment, as well as the transport of materials in various parts of a living organism is vital event, which determines the overall life activities of the organisms. In plants all their required substances (except light and carbon dioxide) are supplied through soils by the roots. The water, carbon dioxide and different mineral nutrients are used by the plants and are converted into energy rich organic food like carbohydrates, lipids and proteins by the universal phenomenon of photosynthesis. In this process the source of energy is sun.

Diffusion is the movement of substances in the form of molecules or ions from the regions of their higher concentrations to the regions of their low concentrations. It is the basis of transportations in all types of living organisms. This process is deadly slow so it may not be used alone as transporting means.

Osmosis is the diffusion of water through living membranes. The special nature and structure of cell membranes makes the process very efficient. **Osmosis** is the phenomenon of movement of water from its high potential (high conc.) to the region of low potential through a semipermeable membrane. The mineral nutrients are transported in dissolved form. In living organisms the transport of materials is in the form of solutions so the phenomenon may be defined as the movement of water from **hypotonic solutions** (dilute solutions) to the regions of hypertonic condition through a semipermeable membrane. The movement will continue until an equilibrium is maintained. At this level the two solutions across

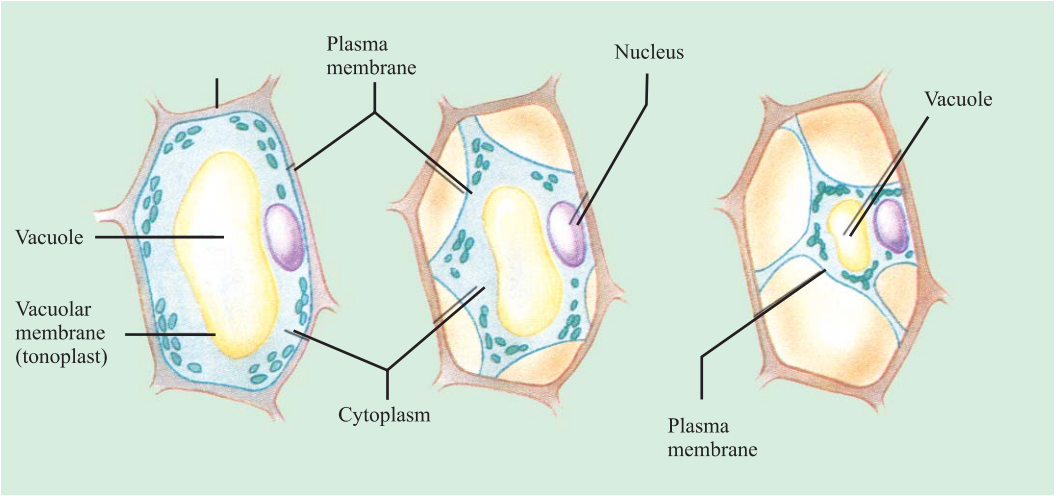


Fig: 10.4 Plasmolysis

the membrane are called **isotonic**. The plant as a whole and the individual cells get water and other substances by several other means besides diffusion and osmosis. Some of them are described below:

Plasmolysis can be defined as the shrinkage of the protoplasm of a cell due to exosmosis when it is placed in hypertonic solution. The cell in this condition is called **plasmolysed**. However if a plasmolysed cell is placed in a hypotonic solution the cell attains its normal state i.e. it becomes turgid again. The phenomenon is called **deplasmolysis** and occurs due to endosmosis.

10.3.1 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, 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.

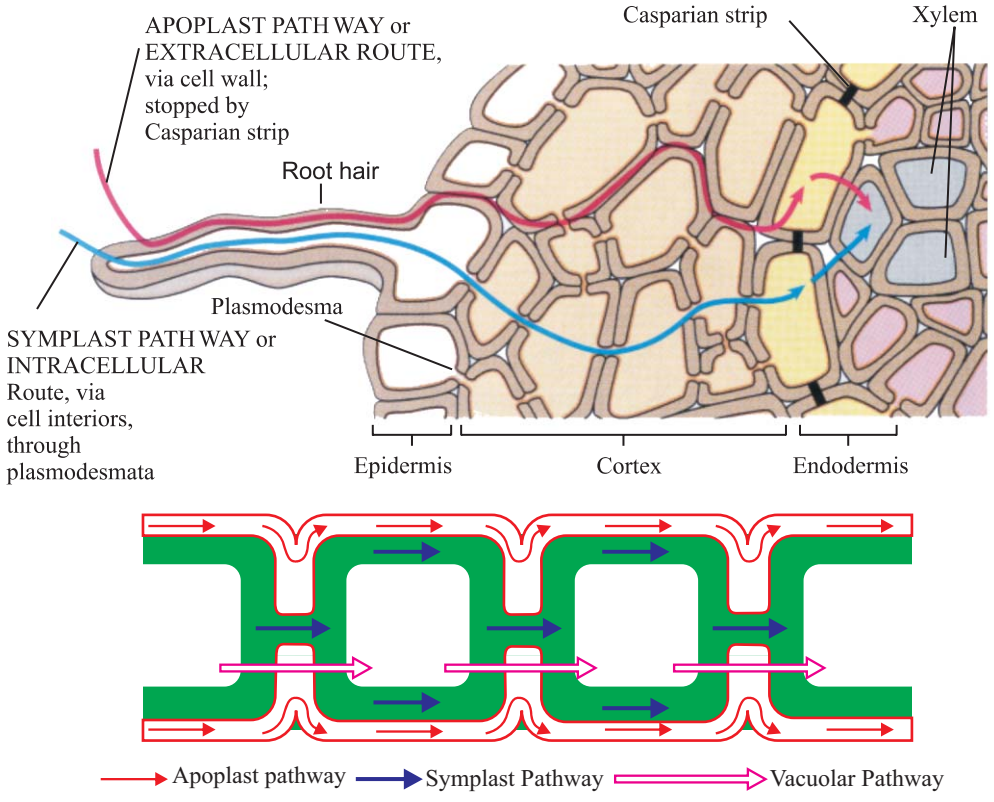


Fig. 10.5 Pathway of Water

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). Therefore water and solutes particularly salts in the form of ions must pass through the cell surface and into the cytoplasm of the cells of the endodermis. In this way the cells of the endodermis can control and regulate the movement of solutes through the xylem.

Symplast Pathway: Movement of cell sap that involves cytoplasmic connection of adjacent cells is termed as symplastic transport or pathway. The **symplast** is the system of interconnected protoplast in the plant. The **cytoplasm** of neighboring **protoplast** is linked by the **plasmodesmata**, the cytoplasmic strands which extend through pores in adjacent cell walls. 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 membranes and tonoplast by osmosis. It moves down a water potential gradient.

10.3.2 ASCENT OF SAP

Once water and mineral enter the root xylem, they still must be moved to the leaves of the plant. Four important forces combine to transport water solution from the roots through xylem elements and into the leaves. These **TACT forces** are: (1) Transpiration (2) Adhesion (3) Cohesion (4) Tension.

Transpiration

The loss of water vapours by evaporation from aerial parts of the plants is called **transpiration**. When stomata are open the water molecules move from high potential of water (inside the cells) to a region of low potential (in the air).

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, hold water in the xylem when transpiration is not occurring.

Cohesion

You may recall from chapter 2 section 2.2 that water is a polar molecule, with the oxygen carrying a slight negative charge while the hydrogen carry a slight positive charge. As a result, nearby water molecules attract one another, forming weak hydrogen bonds. The network of individually weak hydrogen bond within water collectively produces a very high **cohesion**.

The column of water molecule within the xylem is at least as strong and as unbreakable as a steal 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." Supplementing the cohesion between water molecules is adhesion between water molecules and the walls of xylem tubes help the water move upward, just as water is pulled up into a very narrow glass tube. This principle, called **capillary action**,

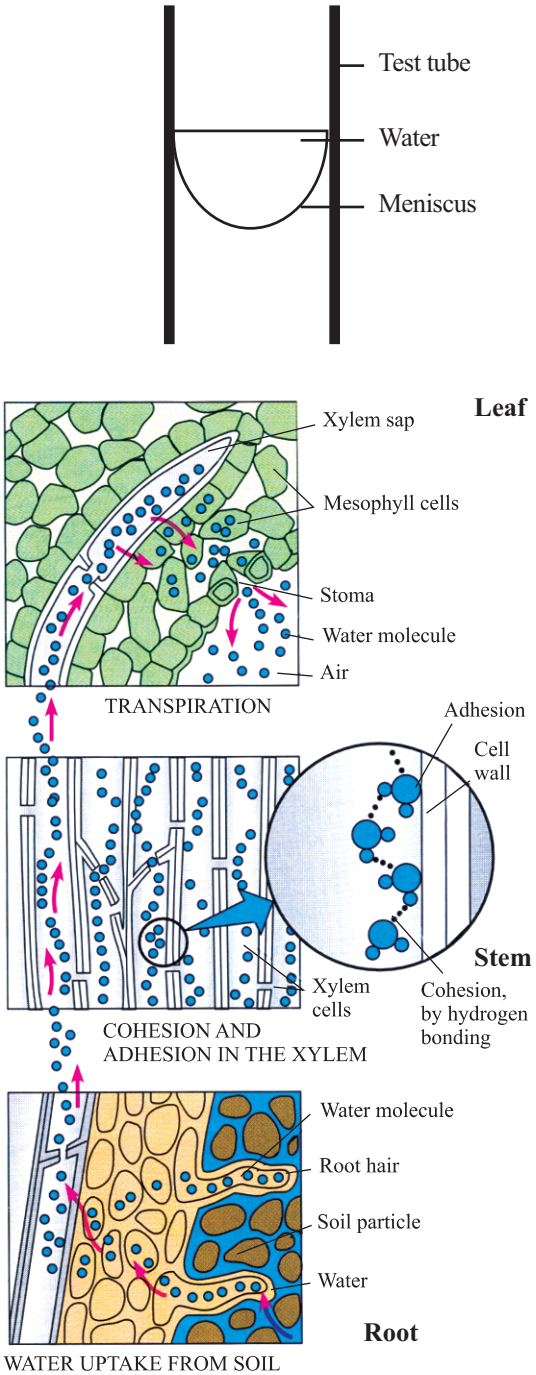


Fig. 10.6 Movement of Water in Xylem Through TACT Mechanism

helps water move upward within xylem. The U shaped surface formed by water as it climbs the walls of the tube is called **meniscus**.

Tension

What effect does transpiration have on a vertical string of water of xylem tubes? Before a water molecule can leave the leaf, it must break off from the top of the string. In effect, it is pulled off by a large diffusion gradient between the moist interior of the leaf and the surrounding air. Cohesion resists the pulling force of diffusion gradient, but it is not strong enough to overcome it. The molecules break off, and the opposing forces of cohesion and transpiration put tension on the rest of the molecular string.

As long as transpiration continues, the string is kept **tense** and is pulled upward as one molecule, exits the leaf and one right behind it is tugged up into its place. "Tension is a negative pressure – a force that pulls water from locations where the water potential is greater. 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.

10.3.3 OPENING AND CLOSING OF STOMATA

There are two hypothesis which may explain the opening and closing of stomata: (a) Starch sugar hypothesis, (b) Influx of K^+ ions hypothesis.

Starch Sugar Hypothesis

It was proposed by German botanist **H. Van Mohl**. The guard cell absorbs CO_2. Some CO_2 reacts with water in which it is dissolved to form carbonic acid. In the presence of light energy, carbonic acid in the guard cell is converted into CO_2 and water, which are rapidly used in the synthesis of carbohydrates. The contents of illuminated guard cell are: (i) The acid concentration is low i.e. pH is high. (ii) Sugar concentration is high. As sugar concentration increases in the guard cells, as a result water enters the guard cells. The guard cells become **turgid** (swollen with water). The thin outer walls bulge out and force the inner thick wall into a crescent shape. In this way a stoma or pore is formed between each pair of guard cell.

Closing of Stomata

In the dark, most of the sugar molecules are removed by respiration or are converted into insoluble starch. So there is an increase in the acidity of the cell contents. As sugar molecules are removed from the guard cell and the

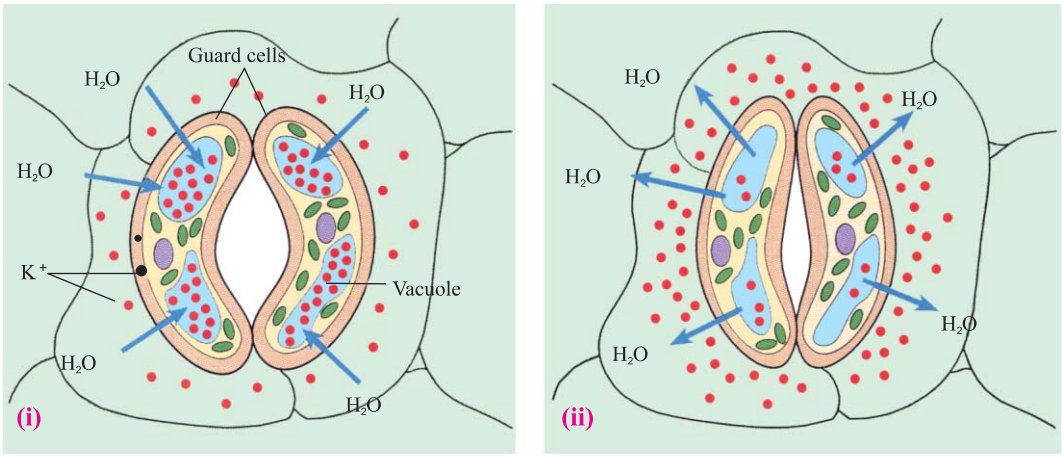


Fig: 10.7 (i) Stomata opening (ii) Stomata closing

relative concentration of H_2O in the guard cell increases, water molecules diffuse out to the epidermal cells. As the guard cell loses water, it becomes **flaccid**. In contrast to turgidity, the loss of water causes them to become weak limp and soft. This condition is known as **flaccidity** and the cells are said to be flaccid. The inner thick wall moves together until the pore between them is closed. Closing of stomata prevents (i) loss of water vapour (ii) the entry of CO_2 into the leaf. The CO_2 produced during respiration is used for photosynthesis even though the stomata are closed.

Influx of K^+ ions Hypothesis

The K^+ ion concentration in guard cells increase many times depending upon plant species. K^+ ions (shown in red dots in the fig. 10.7) enter guard cells from the surrounding epidermal cells by active transport. The accumulation of K^+ decreases the **osmotic potential** of guard cells. Water (shown in blue arrows) enters the guard cell by **osmosis**. The guard cells become turgid and are stretched and stomata are opened. The guard cells remain in this condition only so long as the pumping of K^+ ions into the cell is continued. So for keeping the stomata open a constant expenditure of energy is required. In darkness K^+ ions move out of the guard cells into surrounding epidermal cells. The **water potential** of the guard cells increase as a result water moves out of the cells. The loss of pressure makes the guard cells change their shape again and **stomata closes**. Level of CO_2 decreases in the spaces inside the leaf and light controls the movement of K^+ into and out of guard cells. A low level of CO_2 favours opening of the stomata and thus allow an increased CO_2 level and increased rate of photosynthesis.

10.3.4 TRANSLOCATION OF ORGANIC MATTER

Phloem tubes are delicate structures. These tubes are punctured by a small greenish insect, **aphid** during its feeding from the young shoots of a plant. Aphids are fluid (phloem) feeders. They suck sugary substance from phloem tissues. Biologists found that if the feeding aphid is removed by surgery and its style (pointed, tubular mouth part) is allowed to remain intended in the phloem tube. The phloem contents are continued to come out. On examining the contents it is found that it contains upto 30 percent sugars (sucrose), remaining 70 percent is water.

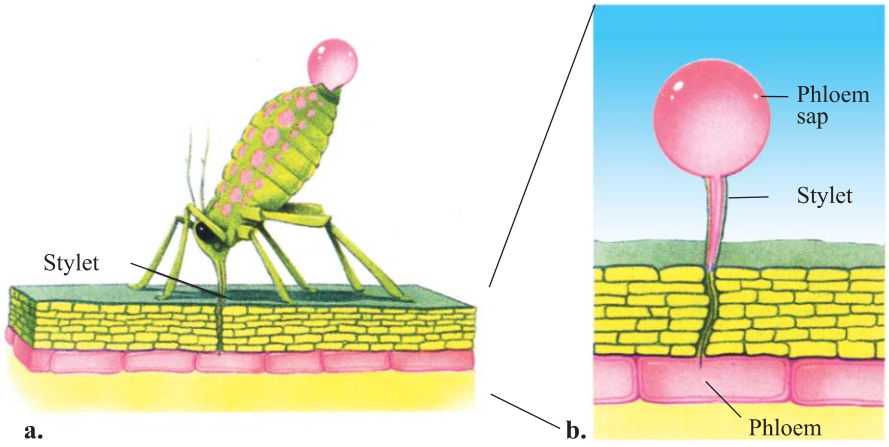


Fig 10.8 Aphid feeding on the branch of a tree. Excess sugar is released as a drop of honey-dew that serves as food for ants. The sap in the phloem enters the insect's mouth parts under pressure.

With the use of radioactive carbon dioxide during photosynthesis the path of the photosynthate may be traced. Biologists by conducting several of such experiments discovered that sugar flow involves a mass movement of phloem fluid based on bulk flow the movement of fluid from an area of high pressure (source) to an area of low pressure (**sink**). The plant physiologists suggest that 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. As a result water moves to phloem by osmosis from the nearby xylem cells and increases turgor pressure in the phloem cells, which pushes forcibly the sugary solution away from the leaf (**source**). Meanwhile the root cells absorb the organic solutes from the phloem, making the phloem solution hypotonic and so the water from the phloem flows back to the xylem tubes.

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.

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)

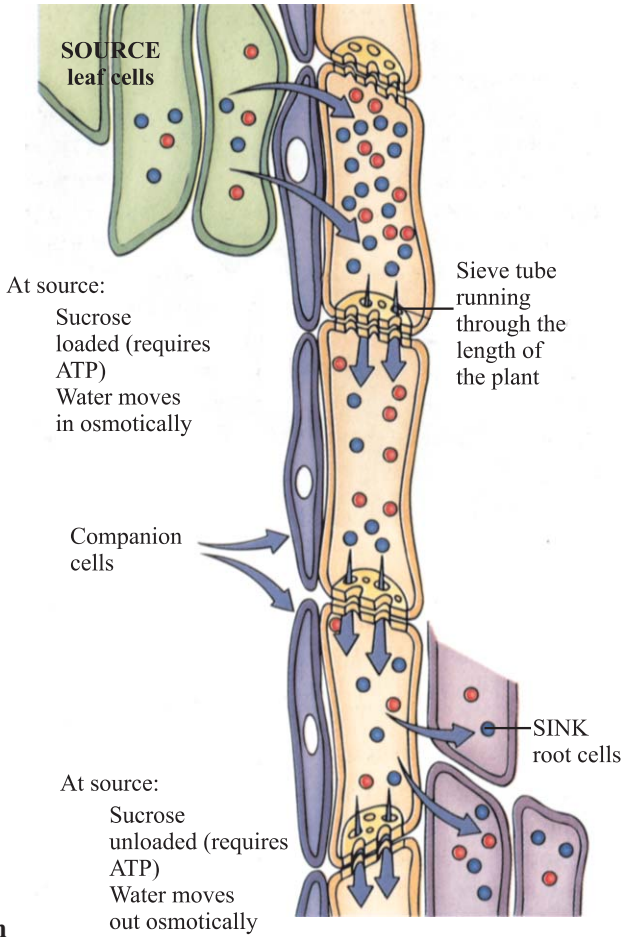


Fig: 10.9 Pressure flow Mechanism for Phloem Transport

By studying carefully the whole mechanism it may be concluded here that the water pressure and the loading activities of companion cells provide the base for the movement of sugars, amino acids and a few mineral ions from sources to sinks. In a plant the same organ may be a source at one time and at some other time it may act as a sink e.g. beetroot.

Skills: Performing and Recording

- Illustrate diagrammatically the pathway of water in root, stem and leaf.

10.4 HOMEOSTASIS IN PLANTS

Specialized structural and physiological adaptations allow different organisms to exploit their environment in different ways. The physiological systems continuously adjust to the aspects of surrounding environment outside the cells and making it suitable for efficient functionings of the body cells.

An organism may be defined as a physiochemical system existing in a steady state with its external environment. **Homeostasis** is the ability to maintain a steady state within a constantly changing environment that contributes towards the success of living systems.

Osmotic Adjustments

Plants differ in their ability to survive and grow under water stress. Plants that are exposed to severe drought use dehydration tolerance mechanism such as maintenance of high water potential either through stomatal regulation or extraction of water through an extensive root system. Generally growth of plants exposed to low water potential is reduced but dehydration tolerant plants are more productive compared to non-tolerant plants. Such plants can continue to grow at a reduced rate under low water potential because of low osmotic potential or **osmotic adjustment**, which maintain turgor. The lowering of osmotic potential by active solute accumulation is known as osmotic adjustment.

Isotonic, Hypertonic and Hypotonic Conditions

Dissolved in the fluid compartment of every living cell are salts, sugars and other substances that give that fluid a certain osmotic pressure. When a cell is placed in a fluid with exactly the same **osmotic pressure**, no net movement of water molecules occurs, either into or out of the cell, the cell neither swells not shrinks. Such a fluid is said to be **isotonic** (i.e. of equal osmotic pressure) to the fluid within the cell. If the surrounding has a concentration of dissolved substances greater than the concentration within the cell, it has a higher osmotic pressure than the cell is said to be **hypertonic** to the cell and cell would lose water. If the surrounding contains a lower concentration of dissolved materials than does the cell, it has a lower osmotic pressure and is said to be **hypotonic** to the cell water that enter the cell and causes it to swell (fig. 10.10).

Q. Why does over watering a plant often kill it?

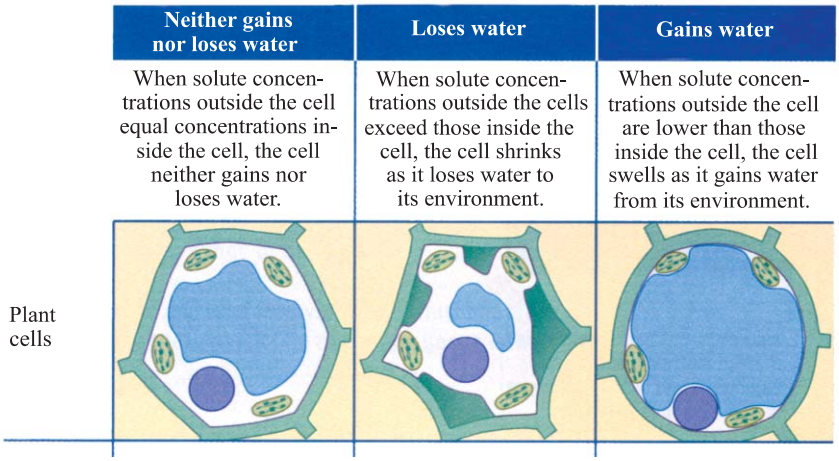


Fig: 10.10 Plant Cells Respond to Isotonic, Hypertonic and Hypotonic solution

Osmotic Adjustment in Hydrophytic, Xerophytic and Mesophytic Plants

Plants are considered simply in relation to their environment and are divided into the following categories.

Hydrophytes: Plant cells in fresh water are surrounded by a hypotonic environment. Hydrophytes have larger **surface area** of leaves, by which water is lost extensively. Moreover the presence of large number of **stomata** on upper surface of leaf promotes the loss of water at high rates. Osmotic adjustment in marine plants takes place through accumulation of solutes facilitates maintenance of cell turgor and water retention.

Mesophytes: They are moderate in water availability. The majority of flowering plants are mesophytes. The features which help to reduce water loss are both structural (xeromorphic) and physiological. The presence of waxy cuticle, protected stomata (at lower surfaces of leaves), the regulations of stomatal openings, variable leaf shape, abscission, their ecological distribution and many other adaptations enable these plants for their osmoregulation.

Xerophytes: The plants adapted to live in dry places and able to survive long period of drought are called xerophytes. These plants constitute the typical flora of deserts and semi-desert regions. Xerophytes show many structural (xeromorphic) and physiological adaptations to survive in extremely dry conditions. e.g. waxy cuticle, few and sunken stomata in leaves, reduced or fleshy succulent leaves and stems, an extensive and deep root system etc.

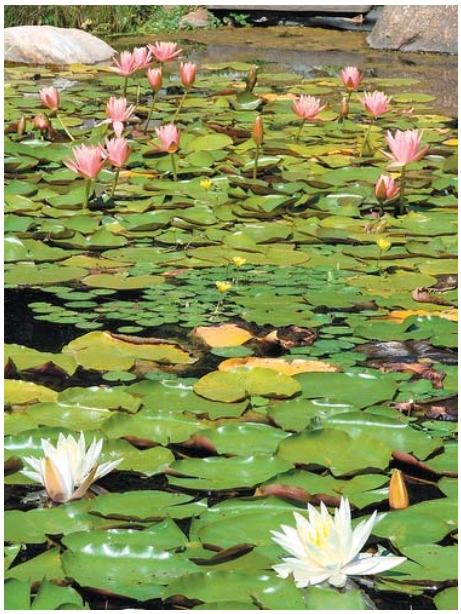


Fig: 10.11 Hydrophytic Plants

Fig: 10.12 Xerophytic Plants

Osmotic Adjustment of Plants in Saline Soils

High salinity soils are characteristics of salt marshes. As salt water from the ocean inundates and recedes from the system in a daily cycle, sodium chloride is deposited into marsh soils where evapotraspirtion amplifies soils concentrations. Saline soils can be detrimental to plants in a variety of ways; therefore, plants living in saline environments have adapted mechanisms to deal with these problems. These are:

Salt Exclusion: Salt can be excluded from entering the plant through its root system by exchanging K^+ ions for N^+ ions as they passed through the xylem.

Salt Excretion: Some plants simply get rid their systems of salt by excreting it back into the environment.

Succulence: One defence against salt in plant tissues is simply to dilute the concentration of ions. Plant achieve this by increasing their storage volume by developing thick, fleshy, succulent structure.

Osmotic Adjustment: Some salt tolerant plants control the accumulation of salt ions to counterbalance low water potential created by saline soils. Salt ions are compartmentalized in vacuoles to protect proteins and membranes from ion toxicity by active transport. Plants also produce

osmotically active organic solutes called **compatible solutes**, such as amino acids and amides e.g. proline and soluble carbohydrates etc.

Osmoregualtion: Water uptake and flow through a plant is driven by a water potential gradient where water flows from least to most negative water potentials. Some plants living in saline soils adjust their water potentials through the accumulation of solutes in plant tissues.

Thermoregulation in Plants

Heat is a form of energy. It is important to maintain a living system because all living systems require a continuous supply of heat. The major source of heat for all living systems is the sun. Solar radiations are converted into an exogenous source of heat. The extent and effect of the radiations depend upon geographical location. The organisms may be found living in a vast range of temperature 4°C (arctic region) to 50°C (desert region) temperatures. Majority of living organisms are found in confined temperatures between 10-35°C. Various organisms show a number of adaptations, enabling them to live in both extremes of temperatures.

Temperature indicates the amount of heat energy in a system. Temperature can act as a limiting factor in the growth and development of plants by influencing the rates of cell division, cell metabolism and photosynthesis. The dark reactions of photosynthesis is a temperature dependent phase. The rate of photosynthesis, enables the plant to complete its life cycle.

Adaptations to Low Temperatures in Plants

The vegetation of the northern temperate areas and the tundra shows several adaptations. Most of the temperate woody perennials are deciduous, to prevent water loss by transpiration. Wind and snow damages are also avoided by the shedding of leaves of the plants. The buds are protected by scale leaves and their activities are made slow by a regulator substance, called ‘dormin’. Many conifers dominate the vegetation of these areas and have needle like leaves with a thick cuticle. Many species of annual plants have a brief growing period and survive the winter by producing resistant seeds or other structures.

Adaptations to High Temperatures in Plants

The leaves are thin and with a large surface area to facilitate gaseous exchange and light absorption. A thin leaf has relatively low heat capacity. 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 also remove the heat from the plant. **Wilting** is a common response to high temperatures.In some plants, growing in hot regions, special types of proteins called **heat shock proteins** are, produced. They protect enzymes from denaturing.

Skills: Interpreting and Analyzing

- Interpret the adaptive differences through survey of xerophytic, mesophytic and hydrophytic plants.
- Illustrate the structure and position of stoma in xerophytic, mesophytic and hydrophytic plants.

Science, Technology and Society Connections

Correlate climatic record with tree growth.

Q. 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?

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. In plants the 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 keep 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. In these cases the plant may wilt or collapse due to a decrease in turgidity (decrease in the internal hydrostatic pressure). Besides the hydrostatic pressure the plants specially shrubs and trees have some supporting tissues, like collenchyma, sclerenchyma, and conducting tissues.

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

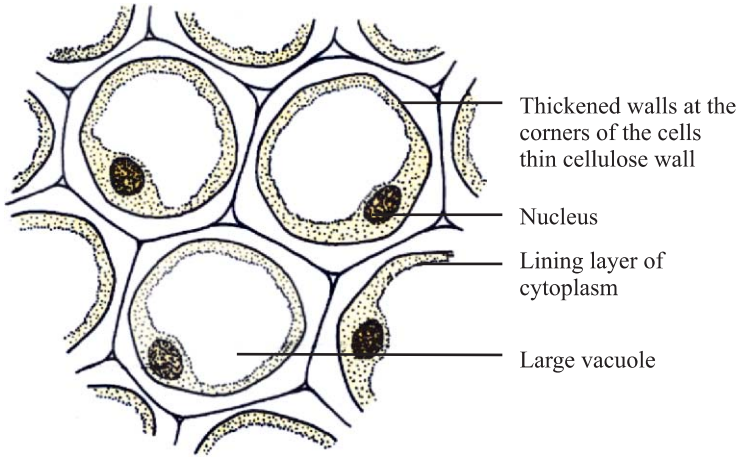
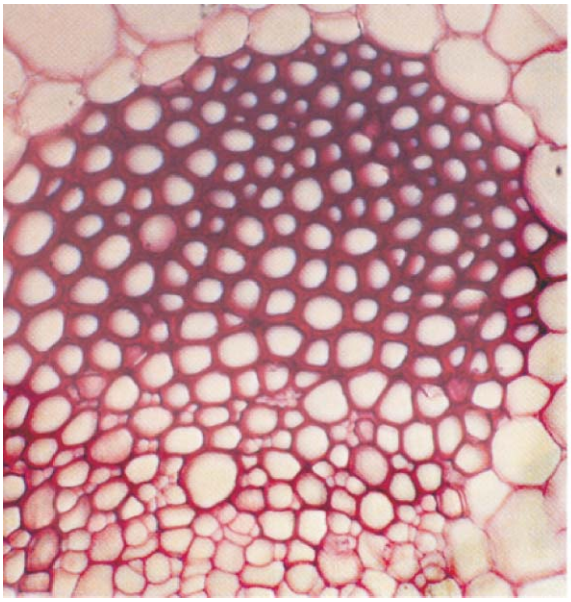


Fig: 10.13 Collenchyma

stems and petioles it plays more important role in support because of its location in peripheral regions near epidermis.

Sclerenchyma

These tissues are solely means for giving support and mechanical strength for the plants. The mature cells are dead and their entire walls are lignified (deposition throughout the walls). The sclerenchyma is of two types



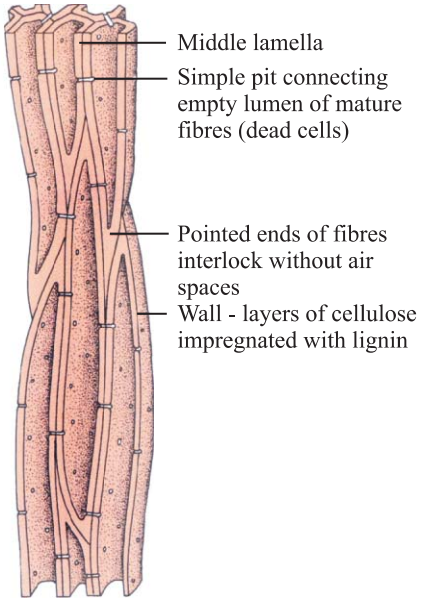


Fig: 10.14 (a) T.S. of Sclerenchyma Cells **(b) L.S. of Sclerenchyma Cells**

i.e. fibres and sclereids. Fibres are elongated cells and sclereids are roughly spherical otherwise both have heavily thickened walls with lignin and with great tensile strength.

Fibres are arranged in strands or sheets and provide collectively a greater strength to the plant. Moreover their ends interlock with one another to give more 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 generally scattered singly or in groups anywhere in the plant body, but common in the cortex, pith, phloem, fruits and seeds. In seeds they toughen the seed coat.

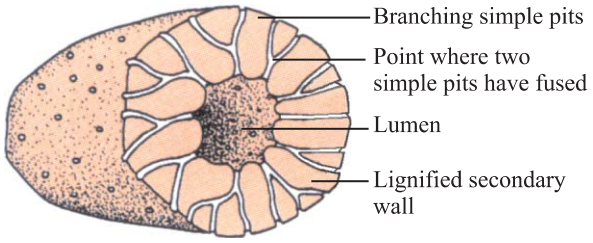


Fig: 10.15 T.S. of Sclereids

Xylem Tissues

These also provide support and strength beside conduction of water and salts. Their role is already discussed in 'Transport in Plants' (section 10.3).

10.6 GROWTH AND DEVELOPMENT IN PLANTS

Growth is the phenomenon of life. Like animals plants also show growth. The growth in plants differs from growth in animals. In plants the growth is of 'open growth' i.e. plants add new organs like, branches, leaves, roots etc throughout life. The growth may be defined as an increase in the size and volume. It is achieved by the mitotic cell division and the enlargement of the dividing cells.

10.6.1 TISSUES FOR GROWTH- Apical and Lateral Meristems

The continual growth is based on 'meristems' the tissues which retain their dividing ability and gives rise to new cells. Meristems allow adult plants to produce eggs and sperms as well as new tissues and organs. Plants have two types of meristems: (a) Apical meristems (b) Lateral meristems

Apical Meristems

These are the growth zones at the tips of roots and stems. It allows shoots to grow upward towards the light and allows roots to grow into the soil to a water source. The growth by apical meristems is called primary growth.

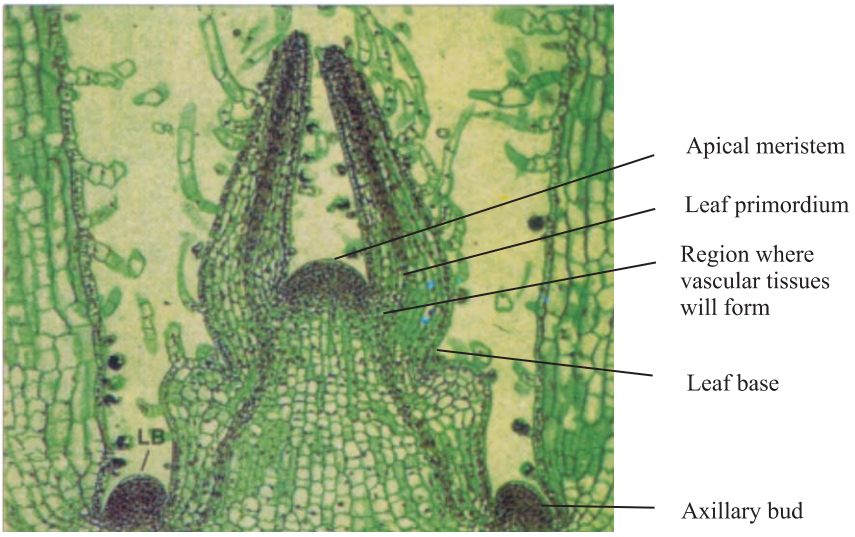


Fig: 10.16 Photomicrograph of Shoot, Apical Meristem

Primary growth occurs by the meristems of two apices (i.e. root apex and shoot apex) so it results in an increase in the size of plants.

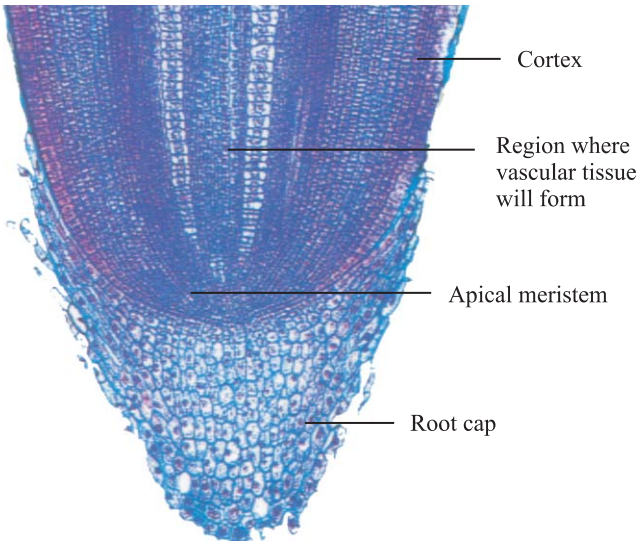


Fig: 10.17 Photomicrograph of Root Apical Meristem

Lateral meristems

These meristems are cylinders of dividing cells in stems and roots of dicots and gymnosperms and increase their thickness and diameter. This increase in diameter of plants by lateral meristems is called 'secondary growth'. During **secondary growth** the bulk of tissues added laterally is mainly secondary xylem and is called **wood**.

The lateral meristem is generally called **'cambium'**. It may be located between primary xylem and phloem and is called **vascular cambium** whereas the **cambium** present on the surface (outside cortex) is called **cork cambium** and adds cork cells.

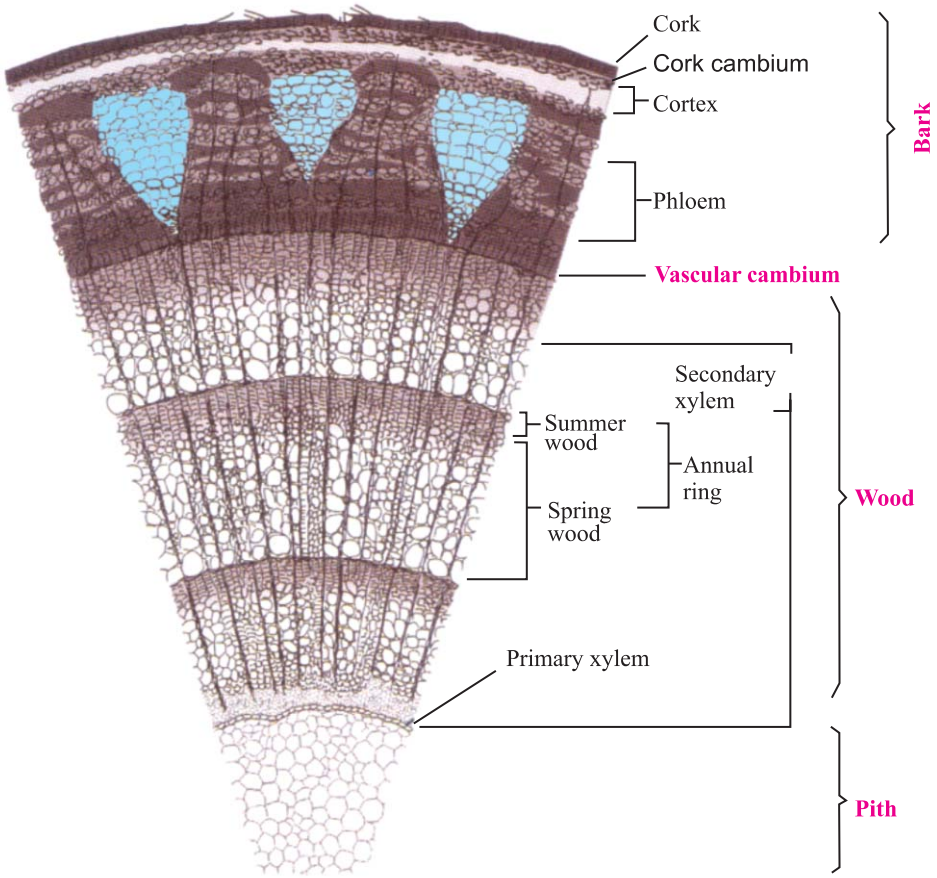


Fig: 10.18 Secondary Growth in Dicot Woody Stem

The production of secondary xylem in growing plants increases the efficiency of conduction of water and salts. The size of xylem tissues depend on the needs and availability of water. During spring and summer water is plentiful and also the light conditions are better whereas during winter and autumn the water available and light conditions are not suitable. The xylem tissues are formed accordingly and the two xylem tissues (spring and autumn) are differentiated on the basis of their large sizes in spring and small sizes

Skills: Performing and Recording

- Locate annual rings in the log of a tree
- Calculate the age of a plant by counting number of annual rings.

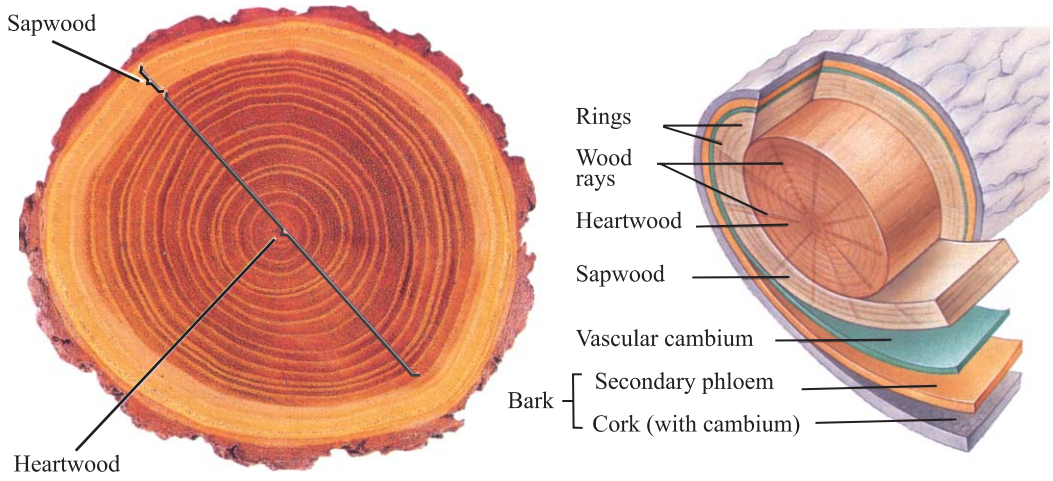


Fig: 10.19 Secondary Growth

during autumn. It makes ring structures. These are called **'annual rings'** and are used to determine the age of the plant.

Apical Dominance

It is a phenomenon in which the presence of a growing apical bud inhibits growth of lateral buds. It also includes the suppression of lateral root growth by growth of the main root. The removal of the shoot apex results in the growth of lateral branches. It is known that **auxins** promotes growth in the stem but inhibits growth of lateral buds. Auxins continuously break down as it moves down the stem, its concentration drops off. Apical dominance is a classical example of one part of a plant controlling another via the influence of a growth substance. This is called **growth correlation**.

Apical Meristem and the Growth of Lateral Shoots

Development of shoot is carried out by apical shoot meristem. The same meristem is also responsible for the growth of leaves and lateral branches of the plants. Leaves arise as small outgrowths, called **leaf primordia**. They contain groups of meristematic cells.

The primordial elongate rapidly and soon enclose and protect the apical meristem, both physically and by the heat they generate in respiration. Then they grow and increase in area to form the leaf blade. Soon after the leaves start to grow, **buds** develop in the axils. These are small groups of meristematic cells, which had retained the capacity to divide and grow.

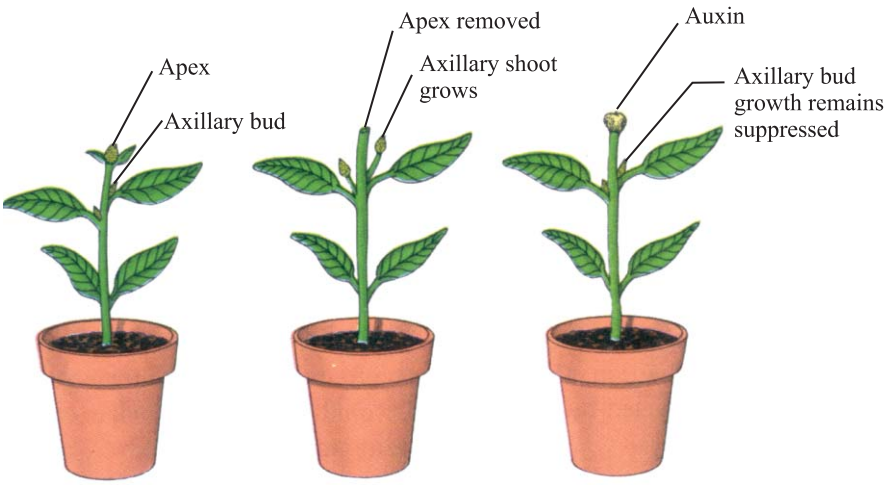


Fig: 10.20 Experiment to show influence of Auxin on Apical Dominance

They become active at this stage and start the formation of lateral branches or specialized structures such as flowers, rhizomes or tubers. It is known that growths are under the control of apical meristem.

10.7 GROWTH RESPONSES IN PLANTS

Plants unlike animals cannot move from one place to the other as a whole. They show response against various factors, which may be beneficial or harmful. These responses are shown by their parts like shoots, roots, etc. 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 (PRGs)

Plants are co-ordinated by chemicals which necessarily move from their sites of synthesis and because their effects are usually on some aspect of growth, they are called **growth substances**. Five major types of growth substances are recognised (a) auxins (b) gibberellins (c) cytokinins (d) abscisic acid (e) ethene.

Auxins

These are **indole acetic acid** (IAA) or their varieties. The discovery of auxins was the result of investigations into phototropism that began with the experiment of **Charles Darwin** and his son **Francis**(1880).

The **effects of auxins** are (a) In stem, promote cell enlargement in region behind apex. Promote cell division in cambium. (b) In root promote growth at very low concentrations. Inhibit growth at higher concentrations. e.g. geotropism. Promote growth of roots from cutting and callus. (c) Promote bud initiation in shoots but sometimes antagonistic to cytokinins and is inhibitory. (d) Promote apical dominance and fruit growth. (e) Sometimes can induce parthenocarpy. Cause delay in leaf aging in a few species. (f) Inhibit abscission.

Discovery of IAA lead to the synthesis of a wide range of active compounds with similar structure. Synthetic auxins have proved commercially useful in a variety of ways. They are cheaper than IAA to produce and often more physiologically active because plants generally do not have necessary enzymes to break them down.

Gibberellins

The compound extracted from fungus Gibberella (now called Fusarium) is called gibberellins. The third and most active gibberellin isolated is called gibberellic acid (GA3). Now more than 50 naturally occurring gibberellins are known.

Fig 10.21 The biennial plant called honesty will "bolt" when it is treated with gibberellins.

The **effects of Gibberellins** are: (a) The main effect of gibberellins is on stem elongation, mainly by affecting cell elongation. Cause cell division in apical meristem and cambium (b) Promote bolting in some rosette stage of plants e.g, a lettuce plant, typically formed into a compact head can be made to "bolt" that is to stretch its stem upward and separate the leaves. (c) Promote bud (shoot) initiation in Chrysanthemum callus. Sometimes promote in intact plant if apical dominance is broken. (d) Promote leaf growth and fruit growth can sometimes induce parthenocarpy. (e) In apical dominance, enhance action of auxins. Break bud dormancy (f) Break seed dormancy e.g. cereals. (g) Sometimes substitute for red light. Therefore promote flowering in long day plants, inhibit in short day plants (h) Delay leaf senescence (aging) in a few species.

The **commercial applications** of the of gibberellins are: (1) They promote fruit setting e.g. in tangerines and pears and are used for growing

seedless grapes, (parthenocarpy) and also increase the berry size. (2) GA3 is used in brewing industry to stimulate a amylase production in barley and this promotes "malting". (3) To delay ripening and improve storage life of bananas and grape fruits.

Cytokinins

Cytokinins are most abundant where rapid cell division is occuring, particularly in fruits and seeds where they are associated with embryo growth.

The **effects of cytokinins** are: (1) Cytokinins promote cell division in the apical meristem, only in the presence of auxins. Gibberellins may also play a role, as in the cambium. (2) Inhibit primary root growth. (3) Promote lateral root growth. (4) Promote bud initiation and leaf growth. (5) Promote fruit growth but can rarely induce parthenocarpy. (6) Promote lateral bud growth, also break bud dormancy. (7) Cause delay in leaf senescence. (8) Promote stomatal opening.

The **commercial applications** of cytokinins are that they delay aging of fresh crops, such as cabbage and lettuce, as well as keeping flowers fresh. They can also be used to break dormancy of some seeds.

Abscisic acid

The substances which accelerated abscission (an act of cutting off) was called abscisic acid (ABA) in 1967.

The **effect of ABA** are: (1) Inhibits stem and root growth notably during physiological stress e.g. drought, waterlogging. (2) Promotes bud and seed dormancy. (3) Promotes flowering in short day plants and inhibits in long day plants (antagonistic to gibberellins). (4) Sometimes promotes leaf senescence. (5) Promotes abscission. (6) Promotes closing of stomata under conditions of water stress (wilting)

The **commercial applications** of **ABA** are that they can be sprayed on tree crops to regulate fruit drop at the end of the season. This removes the need for picking over a long time-span.

Ethene

Ethene is made by most or all plant organs and tends to escape more easily from the plant surface.

The **effects of ethene** are: (1) Inhibits stem growth, notably during physiological stress. (2) Inhibits root growth. (3) Break dormancy of bud.

(4) Promotes flowering in pine apple. (5) Promotes fruit ripening. (6) Like ABA it acts as a growth inhibitor in some circumstances and can promote abscission of fruits and leaves.

The **commercial applications** of ethene are that they induces flowering in pineapple. Stimulates ripening of tomatoes and citrus fruit. The commercial compound ethephon breaks down to release ethene in plants and is applied to rubber plant to stimulate the flow of latex.

Science, Technology and Society Connections

Describe the reasons for bushy and cylindrical growth.

10.7.2 GEOTROPISM AND PHOTOTROPISM

Unlike animals, the plants have no nervous system and for their coordination they completely depend on hormonal coordination. It is very slow and generally shown in the form of **growth**. This growth results in some sort of movements of some organs of the plant. The plants as their characteristics do not show locomotion, but the individual plant organs may show movements in response of some stimulus (internal or external).

Phototropism: It is the response of a shoot or a root towards the source of light (positive in shoots) or away from light (negative in roots).

Thigmotropism: These movements are due to the touch stimulus.

Geotropism: Movement of shoots and roots against and towards force of gravity.

Chemotropism: The stimulus is a chemical e.g. movement of hyphae is chemotropic.

10.7.3 PHOTOPERIODISM

Photoperiodism may be defined as the effect of the length of light period on the formation of flowers in plants.

Light exerts its influence on living organisms through variation in day length called photoperiod. In plants, photoperiod and temperature affects flowering, fruit and seed production, bud and seed dormancy, leaf fall and germination. **Photoperiod** affect flowering, when shoot meristem, starts producing floral buds instead of leaves and lateral buds.

In 1920 **W.W. Garner** and **H.A Allard** (agronomist in USA) were working with various varieties of tobacco plants. Tobacco plants (*Nicotiana tobacum*) are self pollinated and gave flowers in summer. One day it was noticed that a single plant was quite different from other varieties. It had broad leaves, was 3 metres tall and did not flower. It was named **Maryland mammoth tobacco plant**.

Under field condition during summer when the days were warm and long, all other tobacco plants flowered profusely, but Maryland mammoth showed no sign of flowering. At the end of the growing season, they transferred the plant to green house to protect it from frost. In the middle of December the plant flowered. It was then allowed to self pollinate and seeds were obtained. These seeds produced new Maryland mammoth plants. The plants flowered in winter.

Garner and Allard put seedlings of the mutant i.e. Maryland mammoth plant in special chamber, where day lengths could be regulated. When day lengths were shortened artificially to about 9 hours, the plant flowered.

Experiment on Soyabean: Garner and Allard made a series of soyabean (soybean) planting over a period of several weeks. In the late summer, they observed the flowering time of the plants in the various groups. Despite age difference due to different planting time, all the soyabean flowered surprisingly close to the same time, in late summer as the day shortened.

The critical factor in both tobacco and soyabean was the length of the day. Flowering occurred when the day shortened below a critical length. This phenomenon is called **photoperiodism**. Photoperiodism is any response by a plant to a relative lengths of daylight and darkness.

Plants are classified into three main groups on the basis of how photoperiodism affects their flowering.

Short-day plants: These plants flower when the day length is less than a certain critical length e.g. Maryland mammoth, cocklebur, chrysanthemum.

Long-day plants: They flower, only when the day length exceeds from the critical length period e.g. spinach, sugar beet, clove, lettuce, Henbane (*Hyoscyamus niger*), snapdragon, cabbage, spring wheat, spring barley etc.

The critical lengths for both long day and short day plants tend to fall in the 12-14 hours range.

Day-neutral plants: In these plants the flowering is not affected by day length or darkness. Thus the plants flower in response to some other type of stimulus, either external or internal e.g. tomato, pansy, bean, sweet, pea, rose, etc.

Now it has been discovered that the actual stimulus for flowering is the uninterrupted dark period rather than the light period. So the short day plants are actually **long night plants** and long-day plants are **short-night plants**.

Mechanism of Photoperiodism

For more than one hundred years, biologists have searched for a flowering hormone, a substance that causes the growth changes leading to a flower development. What evidence is there for a flowering hormone? Evidence has been accumulated since 1936 when **M.H. Chaila-khyan** and his colleagues in Russia experimented with photoperiodic induction of flowering and found that a flowering stimulus appeared to be transmitted from leaves to other parts of the plants. He proposed that leaves produce a chemical, flowering substance that is transported through the plant. He suggested that the substance be called **'florigen'** (meaning flower maker), but the flowering hormone has not, yet, been isolated.

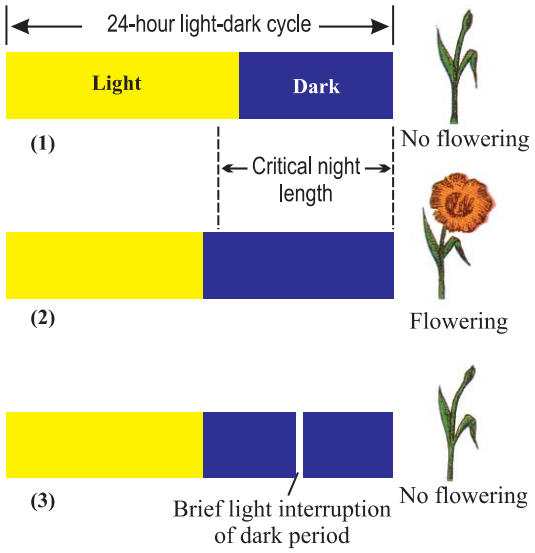


Fig: 10.22 Phytochrome detects varying periods of day length and darkness.

For biological response to light, there must be a photoreceptor (light sensitive pigment) in the organisms to absorb light. The **photoreceptor** involved in photoperiodism is called **phytochrome**. Although present in exceedingly small amounts, Phytochrome has been isolated from plant tissues. It is a protein to which is attached a non-protein part. Phytochrome is a blue-green pigment.

One form of phyto-chrome, designated as P_R, strongly absorbs red light (at 660 nm). In the process the shape of the phytochrome molecule changes to

the second form of phytochrome P_{FR}. Red light of longer wavelengths than P_R, described as far-red light (at 730 nm). When P_{FR} (P730) absorbs far-red light, it reverts back to the original form, P_R (P660). The P_{FR} (P730) form is less stable than the P_R (P660) form and so it reverts to P_R in the dark. The form of phytochrome that triggers physiological responses such as flowering is P_{FR}, (P730)

The sunlight has more red light (P660) than far-red light (P730). Therefore, the phytochrome in a plant exposed to the sunlight is a mixture of both P_R (P660) and P_{FR} (P730), with P_{FR} (P730) predominating. During day P_R (P660) is converted to P_{FR}, (P730) and during the night, the P_{FR} (P730) slowly reverts back to P_R (P660).

Phytochrome Affects Flowering

In **short-day plants** the active form of phytochrome P_{FR}, inhibits flowering in short-day plant. In order to flower, these plants need long night. The long period of darkness allows the P_{FR} to completely revert back to P_R so the plant has some minimum time during the 24-hour period with no P_{FR} present. This initiates flowering.

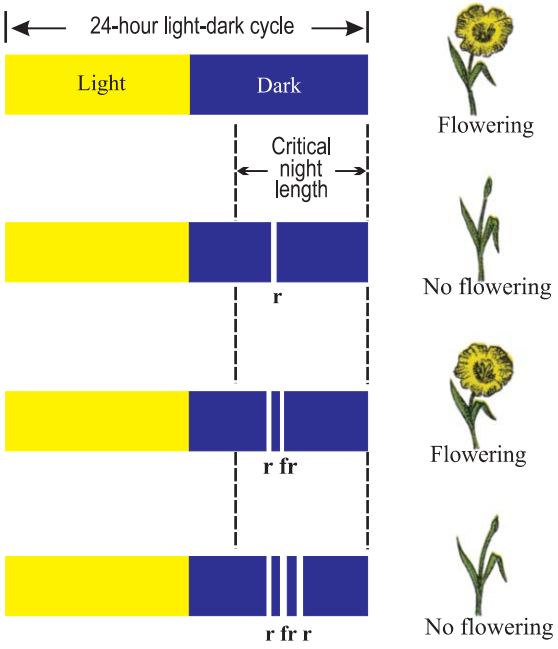


Fig: 10.23 Night interruption experiments on short-day plants using a red light interruption and combinations of red and far-red (fr) light interruptions

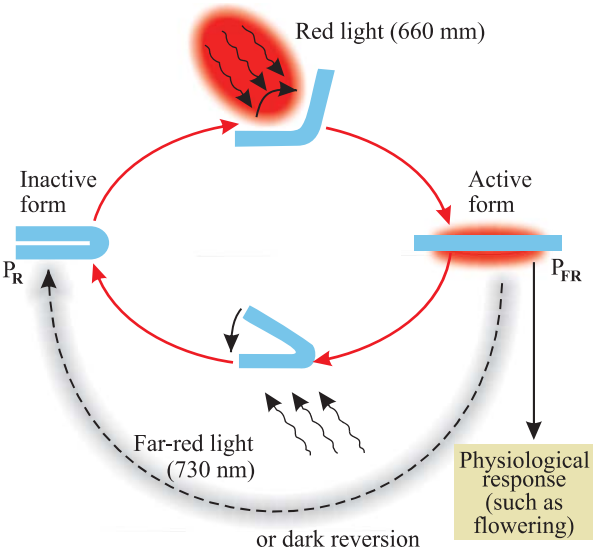


Fig: 10.24 Interconversion of two forms of phytochromes

Short-day plants were grown under a short day/long-night condition. The night was interrupted with a short burst of red light. Exposure to red light for a brief period as 10 minutes in the middle of the night prevents flowering in short day plants. This effect occurs because the brief exposure to red light converts some of the phytochrome from the P_R (P660) form to the P_{FR} (P730)form.

Therefore the plant does not have a sufficient period of time at night for the conversion of P_{FR} (P730). Short day plants need long nights to allow complete dark for reversion of P_{FR}(P730) to P_R (P660) to initiate flowering. A brief flash of **red light** in the middle of the night converts P_R (P660) to P_{FR} (P730). However, if this is followed by a brief period of **far red light**, the P_{FR} (P730) is converted back to P_R (P660). Therefore, flowering occurs.

In **Long-day Plants** the active form of Phytochrome P_{FR} (P730) induces flowering in long-day plants. Long-day plants exposed to a long-day/short-night condition flower. The long days cause these plants to produce predominantly P_{FR} (P730). During the short night some P_{FR} (P730) is slowly changed to P_R but sufficient P_{FR} (P730) remains to induce flowering. Plant biologists are puzzled by the observation that P_{FR} (P730), the active form of **phytochrome**, inhibits flowering in short-day plants and induces flowering in long-day plants. Why different plants respond to opposite way to P_{FR} (P730) is not known at this time.

10.7.4 VERNALIZATION

In certain plants, temperature has an affect on flowering. The promotion of flowering by exposure to low temperature is known as **vernalization** (after a Latin term meaning "to make spring like"). The low temperature stimulus is received by the shoot apex of a mature or plant embryo (not by the leaves as in **photoperiodism**). Although the exact **temperature** and amount of time required varies among species, most vernalization temperature occur between 0^0C to 10^0C, but temperature around 4^0C is found to be most effective. The part of the plant that must be exposed to low temperature varies. For some plants, the moist seeds must be exposed to several weeks of low temperature in order for flowering to be induced. For other plants, recently germinated seedlings have a cold requirement.

In some plants, the requirement of **low temperature** period is absolute, meaning that they will not flower without vernalization. Other plants will flower sooner if exposed to low temperature but still flower at a late date if not exposed to low temperature.

Examples of plants with a low temperature requirement include biennials (plants lasting for two years) like carrots and annuals like winter wheat. Carrot left in a warm environment and not exposed to low temperature continue vegetative growth indefinitely and do not initiate sexual reproduction. Low temperature stimulates production of **vernalin** hormone which induces vernalization. It is actually **gibberellin**.

Photoperiodism and vernalization serve to synchronize the reproductive behaviour of plants with their environment, ensuring reproduction of the same species flower at the same time for cross pollination and genetic variability.

Exercise

SECTION I : MULTIPLE CHOICE QUESTIONS

Select the correct answer

1. It is found essentically in organic compounds
   A) calcium B) nitrogen
   C) carbon D) phosphorus
2) Chlorosis occurs due to the deficiency of
   A) sulphur B) magnesium
   C) phosphorus D) calcium
3) Carnivorous plants use insects as a source of
   A) water B) glucose
   C) oxygen D) nitrogen
4) Most of the uptake of water and minerals from soil takes place through
   A) epidermal cells B) root cap
   C) root D) root hair
5) Which of the following is closest to the centre of a woody stem?
   A) vasular cambium B) young xylem
   C) old phloem D) old xylem
6) Symplast is the movement of water through
   A) vacuoles B) cell walls
   C) cytoplasm of cells D) inter spaces

7) Guard cells are the only cells of epidermis, which have

A) vacuole B) chloroplasts

C) cytoplasm D) leucoplasts

8) The sugar moves through phloem is mostly in the form of

A) glucose B) sucrose C) maltose D) lactose

9) Succulent tissues are formed in

A) hydrophytes B) thallophytes

C) mesophyll D) xerophytes

10) Why does a plant auxin produce different effects on the growth of a root and of a shoot?

A) gravity affects the action of the auxin

B) the growth rates of shoot and roots differ

C) the shoot and root respond differently to similar auxin concentrations

D) light effects the action of the auxin

11) Collenchyma is a supporting tissue in

A) seeds B) seedlings C) shrubs D) trees

12) The phenomenon of growth includes

A) cell differentiation B) cell elongation

C) cell maturation D) cell decomposition

13) 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

SECTION II : SHORT QUESTIONS

1. Define osmosis in terms of diffusion.
2. What is water potential?
3. Why exchange of gases occurs more effeciently in air than water?
4. Give adaptive characters in hydrophytes

5. Name the hormones involved in each of the following physiological processes: (a) germination of seeds: (b) stem elongation: (c) ripening of fruits: (d) abscission of leaves; (c) dormancy of seeds.
6. Differentiate between: collenchyma and sclerenchyma, photoperiodism and phototropism, transpiration and evaporation.
7. What do you understand by open growth?
8. Define: nutrition, nutrients, osmotic adjustment, primary growth, secondary growth, homeostasis, cohesion and adhesion
9. Why support is needed in terrestrial life?
10. What is the path of salts and water in vascular plants?
11. How does symplast differ from apoplast?
12. Why support is needed? Enlist the names of supporting tissues in plants.
13. What are annual rings? Define primary and secondary growth in plants.
14. Physiological processes are coordinated in organisms. Give an example to show that plant hormones are involved in coordinating physiological processes.
15. What happens to the primary tissue of a stem when secondary growth occurs?
16. Why does the wood of many tropical trees lack annual rings?
17. Why is hardwood more desirable than softwood for making furniture?

SECTION III : EXTENSIVE QUESTIONS

1. What are nutrients? Describe the role or mineral in plants.
2. Describe the role of stomata in the exchange of gases in plants.
3. Explain water movement between plant cells.
4. Discuss the movement of water in xylem through TACT mechanism.
5. How sugars move in plants? Why it is called translocation?
6. How guard cells control the rate of water loss from a plant on a hot dry day. Why is this both helpful and harmful to the plant?

7. What are the adaptations in plants to cope with low and high temperature.
8. Explain the types and role of meristems.
9. Discuss the role of important growth regulators.
10. What is photoperiodism? What is the role of phytochromes in the mechanism of photoperiodism?
11. Describe the pressure flow theory.
12. Name the elements that make up most of plant's body. What are essential minerals nutrients and beneficial mineral nutrients?

ANSWER MCQS

1. C 2. C 3. D 4. D 5. D. 6. C 7. B 8. B 9. D 10. C 11. B

12. B 13. B

SUPPLEMENTARY READING MATERIAL

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USEFUL WEBSITES

1. www.scipub.net/botany/root-hairs.html
2. www.sirinet/~jgjohnso/plants.html
3. hcs.osu.edu/mg/manual/botany.html
4. plantphys.info/Plant_Biology/lecppt/root.ppt
5. en.wikipedia.org/wiki/Vascular_tissue

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CHAPTER 11

DIGESTION

Major Concepts:

Number of allotted teaching periods: 13

11.1 Digestive System of Man (9 Periods)

11.1.1 Alimentary Canal: Structure and Functional Details

11.1.2 Role of Accessory Glands

11.2 Disorders: Digestive System and Food Habits (4 Periods)

Every cell of the body needs nourishment, but most cells cannot travel to a food source, so the food must be delivered. 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. Ingested food is not technically inside the body until it is absorbed, in fact a large portion of this food remains undigested and passes through the body as waste material. This chapter presents a general view of the digestive system describes its anatomy and 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) or **digestive tract** or alimentary canal and **accessory digestive organs**. **Viscera** are frequently used to refer the abdominal organs of digestion but actually **viscera** can be any organ such as spleen, stomach, lungs etc. **Gut** is an anatomical term that generally refers to the developing stomach and intestine. The first section of the digestive tract is the mouth, or oral cavity. The oral cavity opens posteriorly into the **pharynx**, which in turn, continues inferiorly into the **oesophagus** (meaning: passageway) (American spelling: esophagus). Oesophagus opens into the stomach.

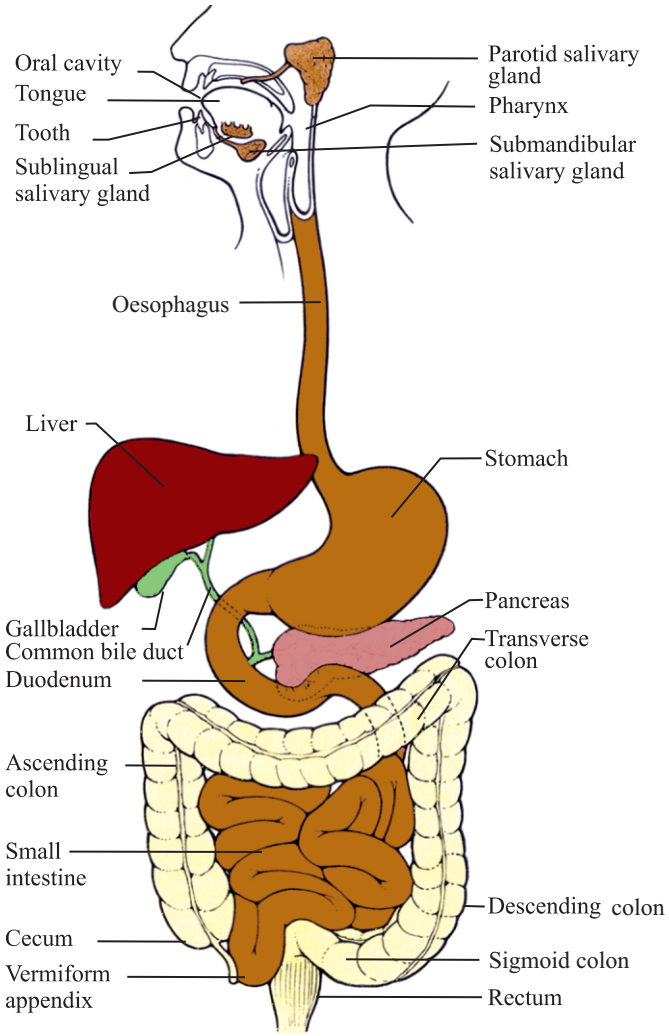


Fig: 11.1 Digestive System of Man

The stomach opens inferiorly into the **small intestine**. The first segment of the small intestine is the **duodenum** (meaning: twelve fingers breadth in length). The next segment of small intestine is the **jejunum** (meaning, empty). The last segment of the small intestine is the **ileum** (meaning, twisted). The last section of the digestive tract is the **large intestine**. The first segment is the **cecum** (meaning, blind), with the attached **vermiform** (meaning, wormlike) **appendix**. The cecum is followed by the **ascending**, **transverse**, **descending** and **sigmoid colon** and the **rectum** (meaning, straight). The rectum joins the **anal canal**, which ends at the **anus**, the inferior termination of the digestive tract.

11.1.1 ALIMENTARY CANAL - Structure and Functional Details

The organs of **GI tract** include oral cavity, pharynx, oesophagus, stomach, small intestine and large intestine. The accessory organs include the teeth, tongue, salivary glands, liver, gallbladder and pancreas. The GI tract, 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 in the overall process of digestion and absorption. GI is approximately 9m (30 ft) long. It traverses the thoracic cavity and enters the abdominal cavity at the level of diaphragm.

The digestive tube consists of four major layers, or **tunics**: an internal mucosa and an external serosa with a submucosa and muscularis in between. These four tunics are present in all areas of the digestive tract from the oesophagus to the anus.

Oral Cavity

The oral cavity, or mouth, is that part of the digestive tract bounded by the lips anteriorly, the fauces (meaning, throat, opening into the pharynx) posteriorly, the cheeks laterally, the palate superiorly and a muscular floor inferiorly. The oral cavity is lined with moist stratified squamous epithelium, which provides protection against abrasion.

Palate and Palatine Tonsils

The **palate** (fig. 11.2) consists of a two parts, an anterior bony part, the **hard palate** and a posterior, non-bony part, the **soft palate**, which consists of skeletal muscle and connective tissue. The **uvula** (meaning, a grape) is the projection from the posterior edge of the soft palate. The palate is important in the swallowing process, preventing food from passing into the nasal cavity. **Palatine tonsils** are located in the lateral wall of the fauces.

Salivary Glands

A considerable number of salivary glands are scattered throughout the oral cavity. There are three pairs of the large multicellular glands: the **parotid**, the **submandibular** and the **sublingual glands** (fig. 11.1).

Science Titbits

Inflammation of the parotid is called parotiditis. The most common type of parotidits, caused by a viral infection, is mumps.

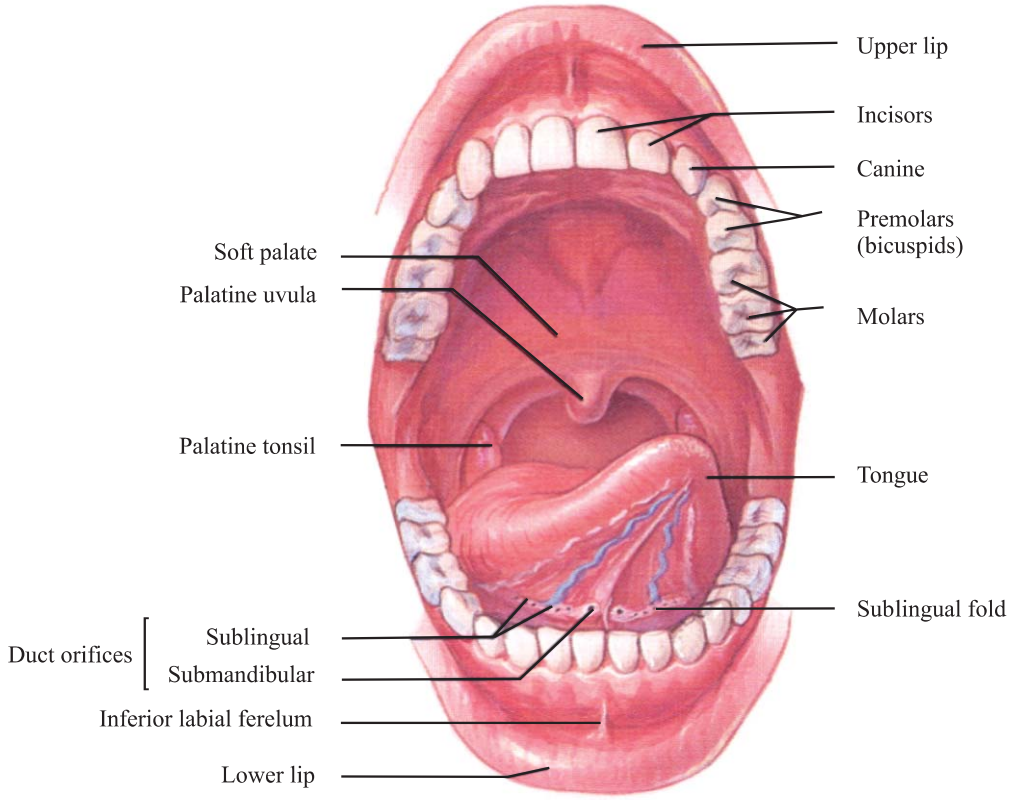


Fig 11.2 Superficial Structures of the Oral Cavity

Pharynx

The pharynx consists of three parts: the nasopharynx, the oropharynx and the laryngopharynx. Normally only the **oropharynx** and **laryngopharynx** transmit food. The oropharynx communicates with the nasopharynx superiorly, the larynx and laryngopharynx inferiorly, and the mouth anteriorly.

Oesophagus

The oesophagus is that part of the digestive tube that extends between the pharynx and the stomach. It is about 25 cm long and lies in anterior to the vertebrae and posterior to the trachea. It passes through the oesophageal hiatus (opening) of the diaphragm and ends at the stomach. An **upper oesophageal sphincter** and a **lower oesophageal sphincter** are present at the upper and lower ends of the oesophagus respectively, regulate the movement of materials into and out of the oesophagus.

Science Titbits

A hiatal hernia is a widening of the oesophageal hiatus, occurring most commonly in adults, which allows part of the stomach to extend through the opening into the thorax.

Stomach

The stomach is an enlarged segment of the digestive tract in the left superior part of the abdomen immediately below the diaphragm. Typically J-shaped when empty, the stomach is continuous with the oesophagus superiorly and empties into the small intestine inferiorly. The opening from the oesophagus into the stomach is the gastro-oesophageal, or **cardiac opening** (located near the heart), and the region of the stomach around the cardiac opening is the **cardiac region** (fig. 11.3). The lower oesophageal sphincter, also called the **cardiac sphincter**, surrounds the cardiac opening. Although this is an important structure in the normal function of the stomach, it is a physiologic constrictor only and cannot be seen anatomically. The largest part of the stomach is the **body** which narrows to form the **pyloric** (meaning, gatekeeper) region, that joins the small intestine. The opening between the stomach and the small intestine is the **pyloric opening**, which is surrounded by a relatively thick ring of smooth muscle called the **pyloric sphincter**. The stomach is lined with simple columnar epithelium. The mucosal surface forms

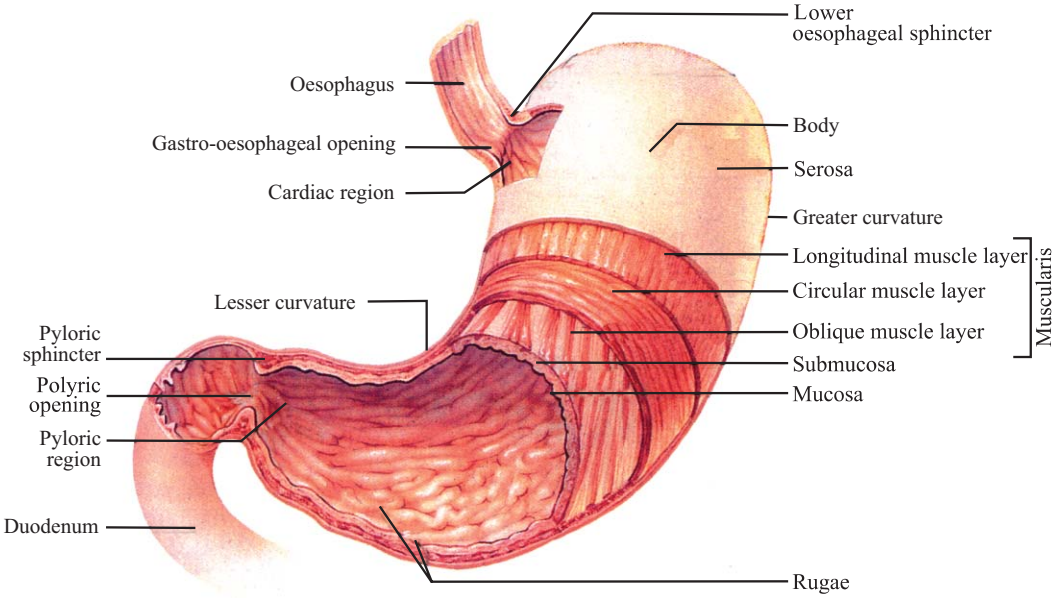


Fig: 11.3 Cutaway section of the Stomach reveals Muscular layers and internal Anatomy

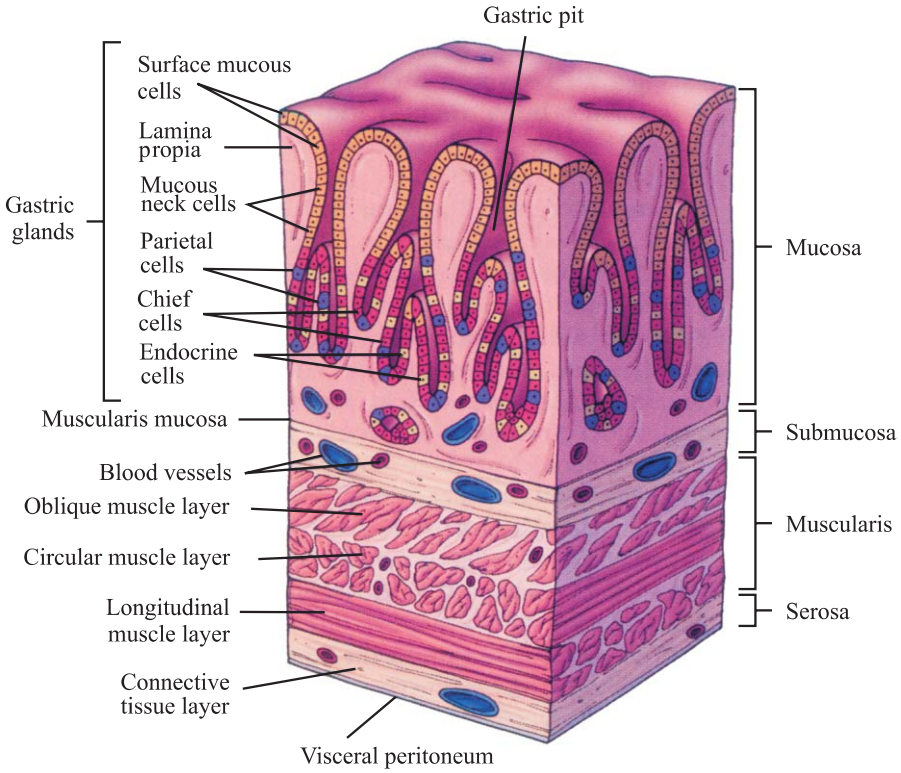


Fig. 11.4 A Section of the Stomach wall that Illustrates its Histology, Including Several Gastric Pits and Glands

numerous tubelike **gastric pits**, which are the openings for the gastric glands. There are five types of epithelial cells in the stomach:

(1) **Goblet cells** secrete protective mucus (2) **Parietal (oxyntic) cells** produce hydrochloric acid (3) **Principal cells** or **chief (zymogenic) cells** secrete pepsinogen (4) Endocrine cells secrete the hormone gastrin into the blood. In addition to these products, the gastrin mucosa (the parietal cells) secretes intrinsic factors.

Small Intestine

The small intestine consists of three parts: the duodenum, the jejunum, and the ileum (fig. 11.5). The entire small intestine is about 6m long (range: 4.6-9 m). The duodenum is about 25 cm long. The jejunum, constituting about two-fifths of the total length of the small intestine, is about 2.5 m long; and the ileum, constituting three-fifths of the small intestine, is about 3.5 m long. Two major accessory glands, the liver and the pancreas, are associated with the duodenum.

Duodenum

The duodenum begins with a short superior part, which is where it exits the pylorus of the stomach and ends in a sharp bend, which is where it joins the jejunum. Tiny fingerlike projections of the mucosa form numerous **villi** (meaning, shaggy hair, fig. 11.6), which are 0.5-1.5 mm in length. Each villus is covered by simple columnar epithelium and contains a blood capillary network and a lymph capillary called a **lacteal**.

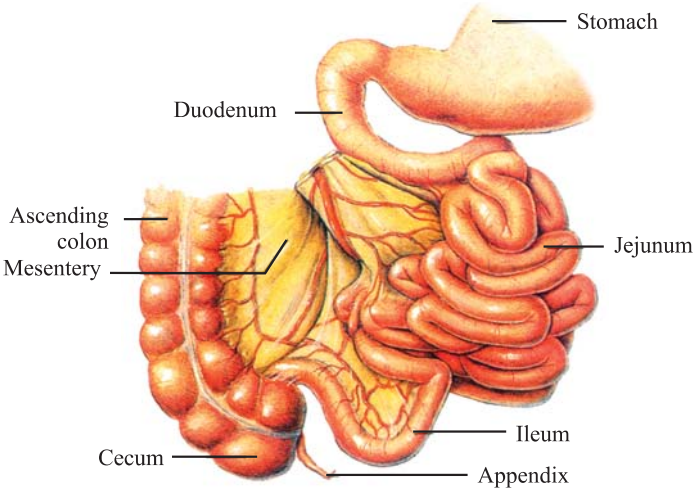


Fig 11.5 The Small Intestine

Jejunum and Ileum

The jejunum and ileum are similar in structure to the duodenum, except that there is a gradual decrease in the diameter of the small intestine, the thickness of the intestinal wall, the number of circular folds and the number of villi as one progresses through the small intestine. The duodenum and jejunum are the major sites of nutrient absorption, The junction between the ileum and the large intestine is the **ileocecal junction**. It has a ring of smooth muscle the **ileocecal sphincter**, and a one-way **ileocecal valve**.

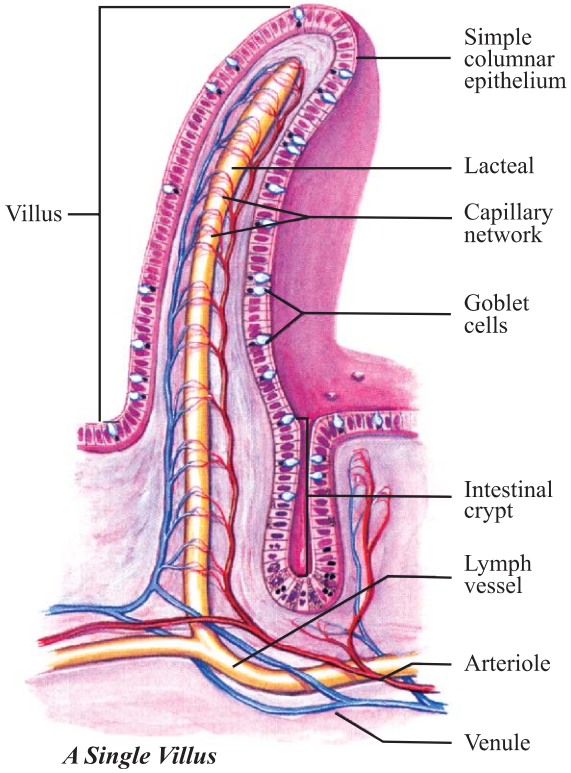
The structural features increase the surface area of small intestine and make it the largest part of the alimentary canal. The internal walls are folded to increase surface area for absorption. Villi and microvilli further increase surface area for absorption.

Large Intestine

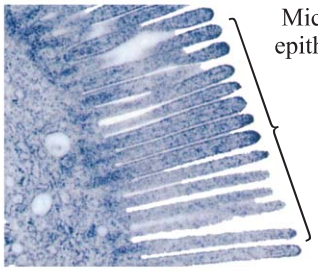
The **cecum**, which is the proximal end of the large intestine, is where the large and small intestines meet. The cecum extends inferiorly about 6 cm behind the ileocecal junction in the form of a blind sac. Attached to the cecum

Skills: Analyzing, Interpreting and Communication

- List structural features that increase surface area of small intestine



A Single Villus



Transmission electron micrograph of microvilli on the surface a villus.

Fig: 11.6 Histology of the Duodenum

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 to 1.8 m long and consists of four parts: the **ascending colon**, **transverse colon**, **descending colon**, and **sigmoid colon**. The **rectum** (means: straight) is a straight, muscular tube that begins at the termination of the sigmoid colon and ends at the anal canal. The last 2-3 cm of the digestive tract is the **anal canal**. It begins at the inferior end of the **rectum** and ends at the **anus** (external GI tract opening). The smooth muscle layer and skeletal muscle form **sphincter** of the anal canal.

Appendicitis

Appendicitis is an inflammation of the vermiform appendix and usually occurs because of obstruction of the appendix. Secretions from the appendix cannot pass the obstruction and accumulate, causing enlargement and pain. Symptoms include sudden abdominal pain. If the appendix bursts, the infection can spread throughout the peritoneal cavity, causing peritonitis, with life-threatening results. An appendectomy is removal of the appendix.

Functions of the Digestive System

As food moves through the digestive tract, secretions are added to liquify and digest it and to provide lubrication. Each segment of the digestive tract is specialized to assist in moving its contents from the oral end to the anal end. Parts of the digestive system are also specialized to transport molecules from lumen of the digestive tract into the extracellular spaces. The processes of secretion, movement, and absorption are regulated by elaborate nervous and hormonal mechanisms.

Functions of the Oral Cavity

Saliva is secreted at the rate of about 1-1.5 liter per day. The serous (watery) part of saliva contains a digestive enzyme called **salivary amylase** (meaning, starch-splitting enzyme), 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. 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.

Composition of Saliva

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 ND 7.0, a favourable range for the digestive action of amylase.

Q. How is chewing important to human digestion?

Deglutition or 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 begins the swallowing reflex, an involuntary

action. As part of this reflex action the voice box or **larynx** raises up to meet the **epiglottis** (meaning upon the glottis), 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 (Adam's apple), you can feel it moves up when you swallow. After food enters the oesophagus, the soft palate lowers and the epiglottis is raised.

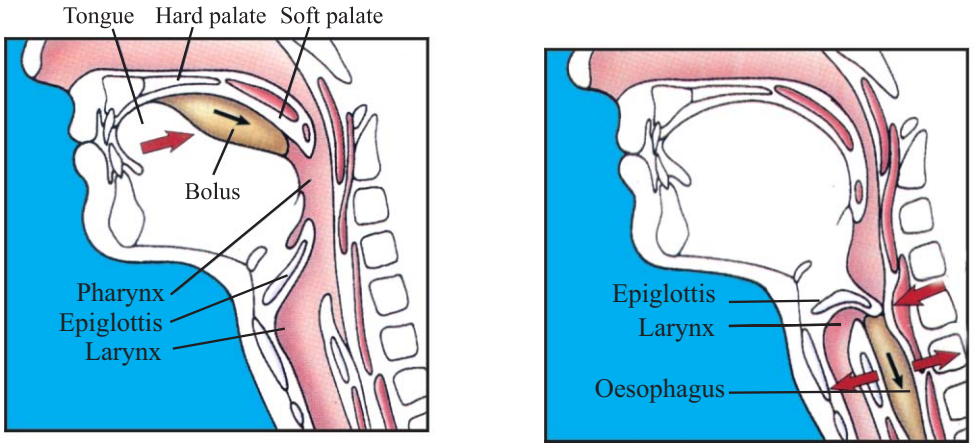


Fig: 11.7 Process of Swallowing

Peristalsis

In peristalsis a wave of relaxation of circular muscles infront 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. If there is any irritation of the oesophagus or stomach the process of peristalsis may be reversed and vomiting occurs. This reversal of peristalsis is called **antiperistalsis**.

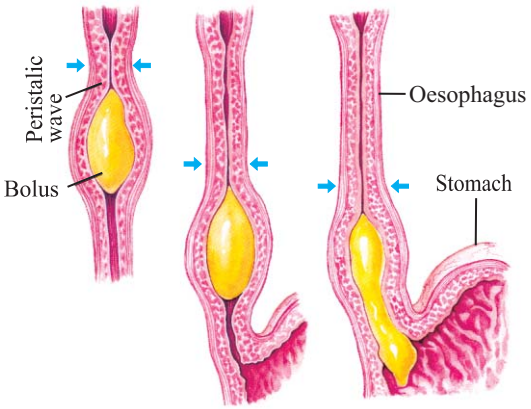


Fig. 11.8 Peristalsis

Stomach Function

Ingested food and stomach secretions, mixed together, form a semi fluid material called **chyme** (meaning, juice). The stomach functions primarily as storage and mixing chamber for the chyme. 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 B_{12} 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. 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** (meaning, related to enzymes) 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.

Q. Why is it necessary for pepsin to be secreted in an inactive state?

Regulation of Stomach Secretion

Approximately 2-3 litres of gastric secretions (gastric juice) is produced each day. Both nervous and hormonal mechanisms regulate gastric secretions. The neural mechanisms involve reflexes integrated within the medulla oblongata and local reflexes integrated within the GI tract. 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 hydrochloric acid and pepsinogen 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. Distention of the stomach wall, especially in the body or fundus, results in the stimulation of mechanoreceptors. As food enters the stomach, its volume increases. Ingested food is thoroughly mixed with the secretions of the stomach glands to form **chyme**. This mixing is accomplished by gentle mixing waves, which are peristaltic-like contractions that occur about every 20 seconds and proceed from the body toward the pyloric sphincter to mix the ingested material with the secretions of 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.

Q. Is human digestive system intracellular or extracellular?

Functions of the Small Intestine

The small intestine is the site at which the greatest amount of digestion and absorption occurs. The intestinal phase of gastric regulation is controlled by the entrance of acidic stomach contents into the duodenum. Acidic solutions in the duodenum cause the release of the hormone **secretin** into the circulatory system. Secretin inhibits gastric secretion by inhibiting both parietal and chief cells. Fatty acids and certain other lipids in the duodenum and the proximal jejunum initiate the release of two hormones: **gastric inhibitory peptide** and **cholecystokinin**. Gastric inhibitory peptide strongly inhibits gastric secretion, and cholecystokinin inhibits gastric secretions to a lesser degree. Hypertonic solutions in the duodenum and jejunum also inhibit gastric secretions.

The mucosa of the intestine produces secretions that primarily contain mucus, electrolytes, and water. Intestinal secretions lubricate and protect the intestinal wall from the acidic chyme and the action of digestive enzymes. They also keep the chyme in the small intestine in a liquid form to facilitate the digestive process. Most of the digestive enzymes that enter the small intestine come from the pancreas. The intestinal mucosa also produces enzymes that remain associated with the intestinal epithelial surface.

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. Secretin and cholecystokinin are released from the intestinal mucosa and stimulate hepatic and pancreatic secretions. Secretion by duodenal glands is stimulated by the vagus nerve, secretion, and chemical or tactile irritation of the duodenal mucosa.

Movement in the Small Intestine

Mixing and propulsion of chyme are the primary mechanical events that occur in the small intestine. Segmental contractions mix the intestinal contents, and peristaltic contractions propel the intestinal contents along the digestive tract. The ileocecal sphincter at the junction between the ileum and the large intestine remains mildly contracted most of the time, but peristaltic contractions reaching it from the small intestine cause it to relax and allow movement of chyme from the small intestine into the cecum.

Absorption and Transport

Absorption of certain molecules can occur all along the digestive tract, a few chemicals, can be absorbed through the thin mucosa of the oral cavity below the tongue. Some small molecules (e.g. alcohol and aspirin) can pass through the stomach epithelium into the circulation. Most absorption, however, occurs in the duodenum and jejunum, although some absorption occurs in the ileum.

Science Titbits

Certain drugs, which are lipid-soluble and can, diffuse through the cell membranes of the oral cavity, can be quickly absorbed into the circulation. An example is nitroglycerin, which is a vasodilator used to treat cases of angina pectoris. The drug is placed under the tongue, where, in less than 1 minute, it dissolves and passes through the very thin oral mucosa into the lingual vein.

Carbohydrates: Ingested carbohydrates consist primarily of polysaccharides, and monosaccharides such as glucose and fructose. During the digestion process polysaccharides are broken down into monosaccharides. Carbohydrate digestion begins in the oral cavity with the partial digestion of starches by salivary amylase and is completed in the intestine by **pancreatic**

amylase. The monosaccharides are transferred by facilitated diffusion to the capillaries of the intestinal villi and are carried by the hepatic portal system to the liver, where the nonglucose sugars are converted to glucose. Glucose enters the cells through facilitated diffusion.

Lipids: The first step in lipid digestion is **emulsification**. Emulsification is accomplished by bile salts secreted by the liver. **Lipase** secreted by the pancreas digests lipid molecules. The primary products of this digestive process are free fatty acids and glycerol. Cholesterol and phospholipids also constitute part of the lipid digestion products. Once lipids are digested in the intestine, bile salts aggregate around the small droplets to form **micelles** (meaning a small morsel). When a micelle comes into contact with the epithelial cell of the small intestine, the contents of the micelle pass by means of simple diffusion through the lipid cell membrane of the epithelial cells.

Lipid Transport: In the intestinal epithelial cell, **triacylglycerol** is formed. Proteins combine with triacylglycerold to form **chylomicrons**. The chylomicrons leave the epithelial cell and enter the lacteals of the lymphatic system within the villi. They are carried through the lymphatic system to the blood stream. Before entering the adipose cells, **triacylglycerol** is broken back down into fatty acids and glycerol, which enter the fat cells and are once more converted back to triacylglycerol. Triacylglycerol is stored in **adipose tissue**. In the liver the chylomicron lipids are stored, converted into other molecules, or used as energy. Because lipids are either insoluble or only slightly soluble in water, they are transported through the blood in combination with proteins, which are water-soluble. Chylomicrons are one type of lipoproteins.

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.

Proteins: Pepsin secreted by the stomach catalyzes the cleavage of covalent bonds in proteins, producing smaller **polypeptide chains**. Once the proteins and polypeptide chains leave the stomach, proteolytic enzymes produced in the pancreas continue the digestive process, producing small peptide chains. These are broken down into dipepetide, tripeptides and amino acids by **peptidases** bound to the **microvilli** of the small intestine. Dipeptides and tripeptides enter intestinal epithelial cells.

Once inside the cells, dipeptidase and tripeptidase split the dipeptides and tripeptides into their component **amino acids**. Individual amino acids then leave the epithelial cells and enter 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.

Water: About 9 litres of water enters the digestive tract each day, of which about 92% is absorbed in the small intestine, and another 6%-7% is absorbed in the large intestine. Water can move in either direction across the wall of the small intestine by osmosis.

Ions: Sodium, potassium, calcium, magnesium, and phosphate ions are also actively transported.

Function of the Large Intestine

In the colon, chyme is converted to faeces. Absorption of water and salts, the secretion of mucus, and extensive action of microorganisms are involved in the formation of faeces, which the colon stores until the faeces are eliminated by the process of **defaecation**.

Movement in the Large Intestine

Peristaltic waves are largely responsible for moving chyme along the ascending colon. Distention of the rectal wall by faeces acts as a stimulus that initiates the **defaecation reflex**. Local reflex action causes weak contractions of the rectum and relaxation of the internal anal sphincter.

The external anal sphincter, which is composed of skeletal muscle and is under conscious cerebral control, prevents the movement of faeces out of the rectum and through the anal opening. If this sphincter is relaxed voluntarily, faeces are expelled. The defaecation reflex persists only for a few minutes and quickly dies. In **infants**, the **defaecation reflexes** cause automatic 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.

Science Titbits

Some bacteria in the intestine 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.

11.1.2 ROLE OF ACCESSORY GLANDS

The Accessory glands of the digestive sysem 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. A **porta** (gate) is on the inferior surface of the liver where the various vessels, ducts, and nerves enter and exit the liver. The **hepatic ducts** transport **bile** out of the liver. The right and left hepatic ducts unite to form a single **common hepatic duct**. The common hepatic duct is joined by the **cystic duct** from the gallbladder to form the **common bile duct**, which empties into the duodenum at the major duodenal papilla in union with the pancreatic duct.

Functions of Liver

The liver performs important digestive and excretory functions, stores and processes nutrients, synthesizes new molecules and detoxifies harmful chemicals.

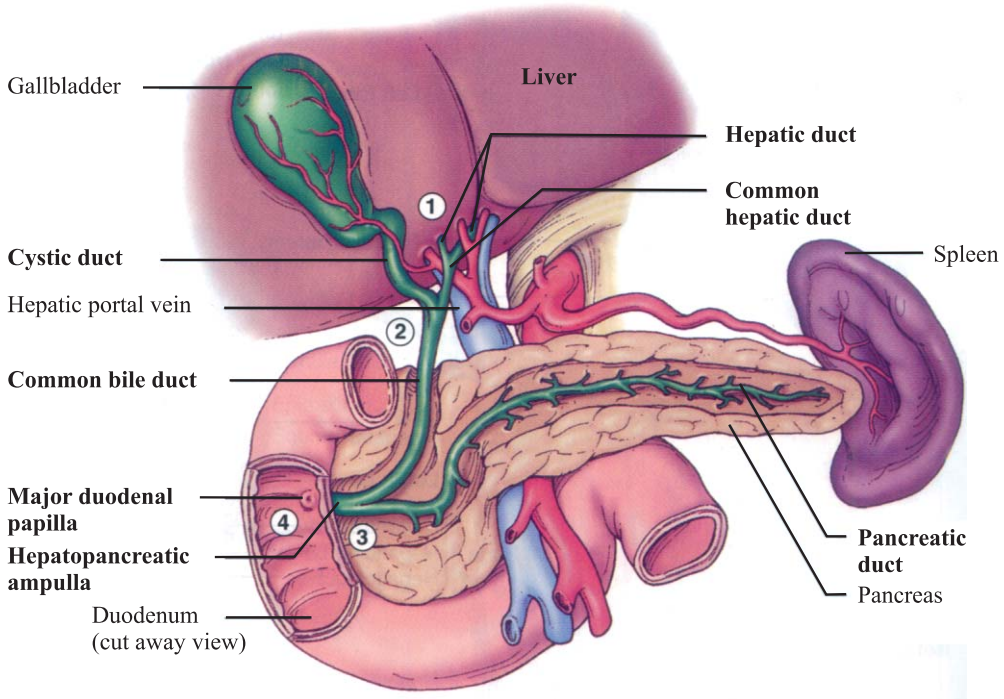


Fig: 11.9 Duct System of the Major Abdominal Digestive Glands

Bile Production

The liver produces and secretes **bile**, which contains no digestive enzymes. Bile helps to neutralize the acidic chymes and to bring the pH up to a level at which pancreatic enzymes can function. Bile salts emulsify fats. Bile also contains excretory products such as bile pigments. Bilirubin is a bile pigment that results from the breakdown of **hemoglobin**. Most bile salts are reabsorbed in the ileum and carried in the blood back to the liver, where they stimulate further bile secretion.

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, B_{12}, 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. Excess of glucose from blood is converted into glycogen (glycogenesis) and stored in the liver cells. 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 carotin 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. Kupffer cells destroy dead RBCs. The bile pigments **bilirubin** and **biliverdin** 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 (fetal) life. **Detoxification** occurs in liver. Liver cells detoxify or inactive the toxic substances like cresol, carbolic acid, etc. (produce by intestinal bacteria) or convert them to non-toxic substances. Similarly prussic acid produced during metabolism is converted into non-toxic substance. Liver is centre of heat production.

Science, Technology and Society Connections

Relate hepatitis and Jaundice with the function of liver.

Gallbladder

The gallbladder is a saclike structure on the inferior surface of the liver that is about 8 cm long and 4 cm wide. The gallbladder is connected to the common bile duct by the cystic duct.

Functions of the Gallbladder

Bile is continually secreted by the liver and stored in the gallbladder. While the bile is in the gallbladder, water and electrolytes are absorbed, and bile salts and pigments become as much as 5 to 10 times more concentrated than they were when secreted by the liver.

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).

Functions of the Pancreas

The exocrine secretion of the pancreas is called **pancreatic juice** and has two major components: an aqueous component and an enzymatic component. The aqueous component is produced principally by columnar epithelial cells that line the smaller ducts of the pancreas. It contains sodium and potassium ions in about the same concentration found in exracellular fluid. Bicarbonate neutralize the acidic chyme that enters the small intestine from the stomach.

Pancreatic Enzymes

The enzymatic component of the pancreatic juice is produced by the acini cells of the pancreas and is important for the digestion of all major classes of food. Without the enzymes produced by the pancreas, lipids, proteins, and carbohydrates are not adequately digested. The **proteolytic pancreatic enzymes**, which digest proteins, are secreted in inactive forms, whereas many of the other enzymes are secreted in active form. 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 (meaning, intestinal enzyme), which is an enzyme attached to the brush border (microvilli) of the small intestine.

Trypsin then activates more trypsinogen, as well as **chymotrypsinogen** and **procarboxypeptidase**. Pancreatic juice also contains pancreatic **amylase**, which continues the polysaccharide digestion that was initiated in the oral cavity. In addition, pancreatic juice contains a group of lipid digesting enzymes called **pancreatic lipases**, which break down lipids into free fatty acids, glycerides, cholesterol, and other components. Enzymes that reduce DNA and ribonucleic acid to their component nucleotides, **deoxyribonucleases** and **ribonucleases**, respectively are also present in pancreatic juice.

Control of Pancreatic Secretion

The exocrine secretions of the pancreas are controlled by both hormonal and neural mechanisms. **Secretin** stimulates the secretion of a watery solution that contains a large amount of bicarbonates ions from the pancreas. The primary stimulus for secretin release is the presence of acidic chyme in duodenum.

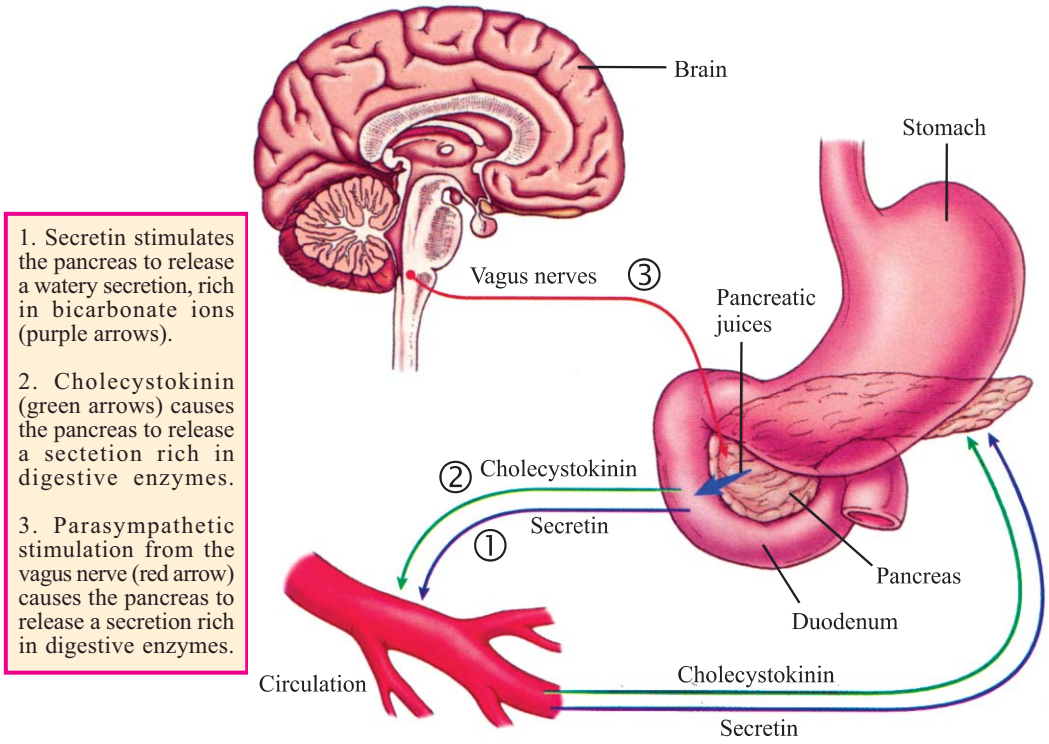


Fig: 11.10 Control of Pancreatic Secetion

Q. What would happen if sodium bicarbonate from the pancreas do not reach the small intestine?

11.2 DISORDERS: Digestive System and Food Habits

Ulcer

Etiology: Peptic ulcer is classically viewed as a condition in which the stomach acids digest the mucosal lining of the GI tract itself. The sites of peptic ulcer are: oesophagus, stomach, duodenum and jejunum. 90-95% of duodenal ulcer occurs in the first part of duodenum, 50% are on the anterior wall. It is common four times than gastric ulcer. More than 90% of gastric ulcer occurs in the lesser curvature. *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 etiologic factor. Peptic ulcer tends to run in families i.e. it is a hereditary disease. Those with blood group O and those unable to secrete their blood group antigen into the saliva and gastric juice are more predisposed to peptic ulceration. Smoking is an important risk factor.

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.

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 co-workder Robin Varan

Food Poisoning

It includes diarrhoea (American spelling: diarrhea), vomitting and abdominal pain. They occur within 12-24 hours after eating contaminated food. It is an illness from indigestion of food containing toxic substances.

Etiology: Due to the **toxins** produced by bacteria, *Salmonella* and *Campylobacter*. These bacteria live in the intestines of cattle, chicken and duck without causing disease symptoms. Human, however, may develop food poisoning by taking the liquid that escapes during defrosting as frozen meat contains *Salmonela* bacteria. The dishes and utensils while the meat is defrosting must not be allowed to come in contact with any other food.

Symptoms: These include fatigue, dizziness, double vision, headache, nausea, vomitting, diarrhoea and abdominal pain.

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.

S.T.S Connections

Relate Ulcer, food poisoning and dyspepsia with eating habits of the society.

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 Lepromide, antibiotics are prescribed.

Dyspepsia

Incomplete or imperfect digestion is called dyspepsia. It is not a disease in itself but symptomatic of other diseases. This is characterized by abdominal discomfort, flatulence, heartburn, nausea, vomiting.

Etiology: 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. It can be classified according to the number and size of the cells. In hyperplastic obesity a greater than normal number of fat cells occur that are also larger than the normal. Hypertrophic obesity results from a normal number of fat cells that have increased in size. The distribution of fat in obese individual can vary.

Etiology: Obesity can occur for many reasons and obesity in an individual can have more than one cause. 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.

Q. Write the adverse affects of obesity on health.

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 followed immediately by self-induced vomitting, fasting or purging 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 age 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 over weight, 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 child like 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.

Exercise

SECTION I : MULTIPLE CHOICE QUESTIONS

Select the correct answer

1. Pepsinogen is activated to pepsin by
   A) active secretin B) hydrochloric acid
   C) active pepsin and HCl D) gastrin
2. Liver secretes bile into the
   A) duodenum B) ileum
   C) jejunum D) peritoneum
3. Emulsification of fat will not occur in the absence of
   A) lipase B) bile pigment
   C) bile sat D) pancreatic juice
4. pH of stomach is 7, which component of food will be digested?
   A) sucrose B) protein
   C) fat D) glucose
5. Fatty acids and glycerol are first absorbed by
   A) lymph vessel B) villi
   C) blood capillaries D) hepatic portal vein

6. The hormone responsible for stimulating secretion of hydrochloroic acid by stomach cells is

A) pepsin B) secretin
C) gastrin D) insulin

7. On removal of pancreas the compound, which remains undigested, is

A) protein B) fat
C) glucose D) lactose

8. Excess intake of the following causes obesity

A) vitamin B) proteins
C) carbohydrates D) mineral

9. Enzyme trypsinogen is changed to trypsin by

A) gastrin B) enterokinase
C) secretin D) hydrochloric acid

10. Cholesterol is synthesized in

A) liver B) pancreas
C) spleen D) gallbladder

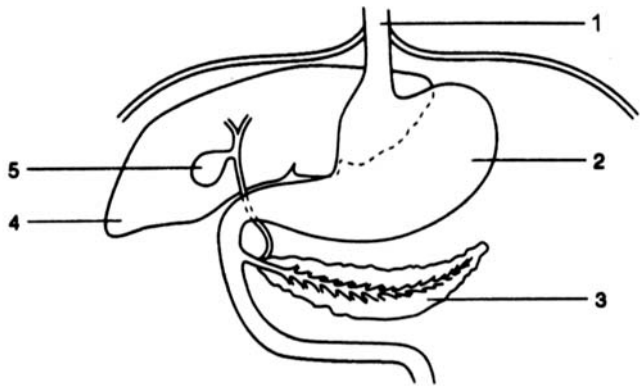
11. Largest gland in human body is

A) pituitary B) thyroid
C) pancreas D) liver

12. Narrow distal part of stomach is

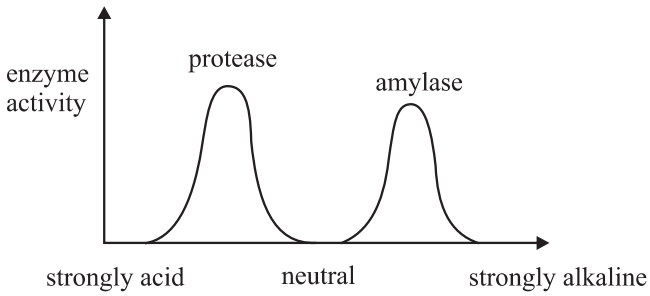
A) cardiac B) pharynx
C) duodenum D) pylorus

13. The diagram shows part of the human alimentary canal. Which two structures produce substances involved in the digestion of fat?



A) 1 and 5 B) 3 and 4 C) 2 and 3 D) 4 and 5

14. The diagram shows the effect of pH on the activity of two enzymes, a protease and an amylase, in the alimentary canal.



In which regions of the alimentary canal would these enzymes be most active?

A	duodenum	colon
B	duodenum	stomach
C	stomach	colon
D	stomach	duodenum

15. If the mucus lining covering the stomach breaks down and stomach tissue is damaged.

A) a peptic ulcer will form

B) appendicitis will result

C) microvilli will invade the stomach

D) absorption of food molecules cananot take place.

SECTION II : SHORT QUESTIONS

1. Why there are villi in the intestine and not in stomach?
2. Bile juice contains no digestive enzymes, yet it is important for digestion. Why?
3. Give one reason as to why some enzymes in stomach and intestine are secreted in inactive form?
4. Name the three intestinal enzymes involved in protein digestion.
5. How could no secretion of HCl in our stomach affect food digestion?
6. Trypsin acts at alkaline pH. What provides the alkalinity?
7. Distinguish between gastrointestinal tract, viscera, accessory digestive organs and gut.
8. Name three eating disorders.
9. How does the stomach protects itself from the damaging effect of HCl?
10. List the functions of large intestine.
11. Name and state the functions of hormones that assist the nervous system in regulating digestive secretions.
12. Is the muscle activity of peristalsis under voluntary control or is it an involuntary process? Does digestion occur in the oesophagus as paristalsis is occurring?
13. How does the absorption of fat differ from absorption of glucose?
14. What happens to ingested cellulose in humans?
15. What would happen to the activity of the intestinal enzymes if the pH in the small intestine remained at 2?

SECTION III : EXTENSIVE QUESTIONS

1. List the organs of the digestive tract and state the contribution of each to the digestive process.
2. Describe the process of chemical digestion in man.
3. Describe the structure, storage and metabolic role of liver of man.
4. Describe with diagram the process of deglutition in man.
5. Outline the structure of pancreas and explain its functions as an exocrine gland.

ANSWER MCQS

1. C 2. A 3. C 4. B 5. A 6. C 7. A 8. C 9. B 10. A
11. D 12. D 13. B 14. C 15. A

SUPPLEMENTARY READING MATERIAL

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3. Taylor, D.J., Green, N.P.O. and Stout, G.W. Biological science 3rd Ed. Cambridge university press, reprint, 2004.
4. Campbell N.A. Mhchell, L.G. & Reece J.B., *Biology Concepts and connections*, 2nd edition Benjamin/Cummings Company California, 2003

USEFUL WEBSITES

1) avalon.unomaha.edu/lichens/Bio%201450%20PDF/MINERAL%20NUTRITION%20IN%20PLANTS.pdf –
2) www.esf.edu/efb/course/efb530/lectures/nutritio.html
3) www.hbci.com/~wenonah/min-def/index.html
4) www.biology-online.org/biology-forum/about628.html
5) www.sinauer.com/detail.php?id=1724
6) en.wikipedia.org/wiki/Carbohydrate
7) www.hsph.harvard.edu/nutritionsource/carbohydrates.html

www.learningall.com

CHAPTER 12

CIRCULATION

Number of allotted teaching periods: 14

Major Concepts:

INTRODUCTION

All organisms must exchange materials with their environment and distribute materials within their bodies. Most animals 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.

12.1 BLOOD CIRCULATORY SYSTEM OF MAN

The 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.

12.1.1 HEART

The heart functions as a pump and is responsible for the circulation of the blood through the blood vessels. The heart `produces the pressure responsible for making blood flow through the blood vessels by contracting forcefully. 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 heart, trachea, oesophagus and associated structures form a middle portion called **mediastinum**. The heart lies deep and obliquely in the mediastinum and slightly to the left of the sternum. The base of heart deep to the sternum, extends to the second intercostals space and the apex of the heart is in the fifth intercostals space, approximately 9 cm to the left of the midline.

Pericardium

The **pericardium** is a closed sac that surrounds heart. It consists of two parts; the out 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 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.

Science Titbits

Pericarditis is an inflammation of the serous pericardium. It can be extremely painful, with sensations of pain referred to the back and the chest which can be confused with the pain of myocardial infarction (heart attack).

Q. What are the functions of pericardium?

Anatomy of the Heart

The heart consists of four chambers: two atria (meaning, entrance chamber) and two ventricles (meaning, belly)

External Features

The atria lie above and behind the ventricles. On the surface of the heart they are separated from each other by an **atrioventricular groove** or **sulcus** (meaning ditch). The atria are separated from each other by an **interatrial groove**. The ventricles are separated from each other by an **interventricular groove**. In normal intact heart the **sulci** are covered by fat and only after this fat is removed the actual sulci can be seen.

Structure of the Walls of the Heart

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 and is responsible for the ability of the heart to contract. The smooth inner surface of the heart chambers is the **endocardium**, which consists of simple squamous epithelium over a layer of connective tissue. The smooth inner surface allows blood to move easily through the heart. The **heart valves** are formed by a fold of the endocardium, making a double layer of endocardium with connective tissue in between.

Thickness of the Walls of each Chamber

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 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 round the whole body.

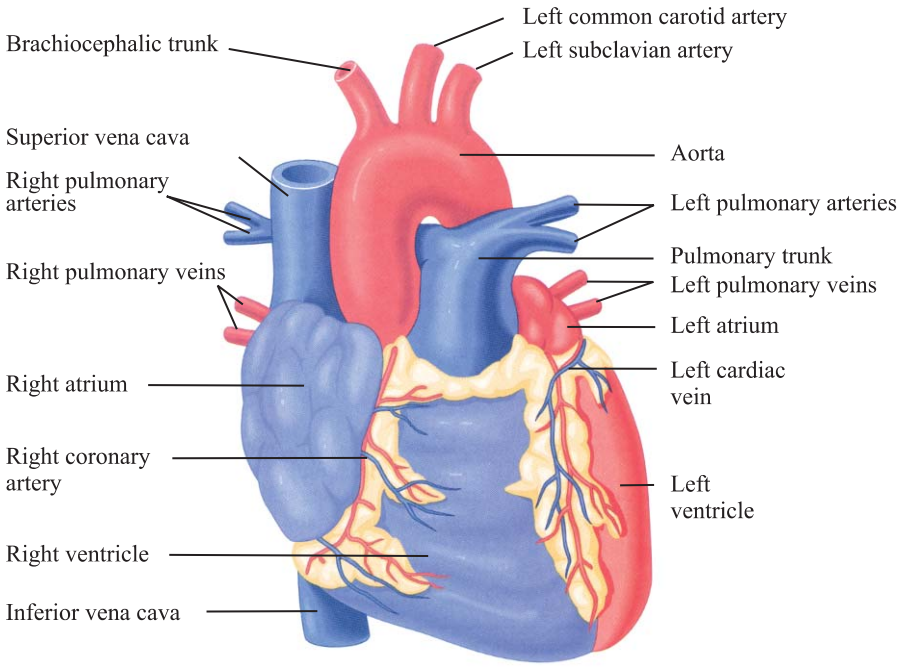


Fig: 12.1 Human Heart, External view

Heart Chambers and Valves

The **right atrium** receives three veins: the superior vena cava, the inferior vena cava, and the coronary sinus. 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.**

Atrioventricular Valves

An **atrioventricular valve** is on each atrioventricular canal and is composed of **cusps**, or flaps. These valves allow blood to flow from the atria into the ventricles, but prevent blood from flowing back into the atria. 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** (meaning, resembling a bishop's miter, a two-pointed hat), **valve**. Each ventricle contains cone-shaped muscular pillars called **papillary** (meaning, pimple-shaped) **muscles**. These muscles are attached by thin, strong connective tissue strings called **chordae tendineae** (meaning, heart strings) to the cusps of the atrioventricular valves. The papillary muscles

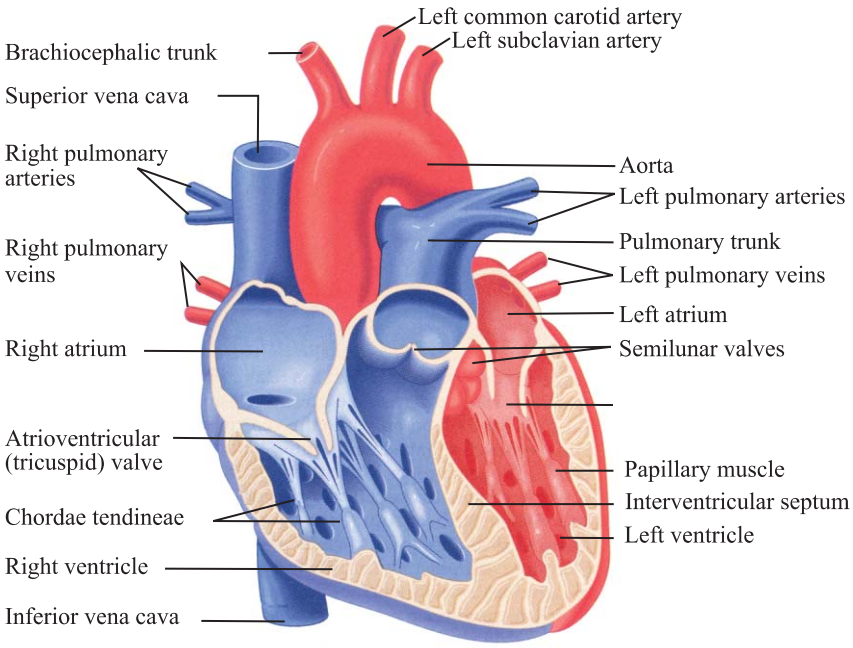


Fig: 12.2 Dissection of a human heart, as seen from the front, with the ventral part of both atria and both ventricles removed

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. Blood flowing from the atrium into the ventricle pushes the valve open into the ventricle, but, when the ventricle contract, blood pushes the valve back towards the atrium. The atrioventricular canal is closed as the valve cusps meet.

Q. What is the function of chordae tendineae?

Semilunar Valves

The aorta and pulmonary trunk possess **aortic** and **pulmonary semilunar** (meaning halfmoon-shaped) **valves**. Each valve consists of three pocketlike semilunar cusps, the free inner borders of which meet in the centre of the artery to block blood flow.

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 an atrioventricular valve (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 an atrioventricular valve (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 through the lungs, and the left ventricle sends blood throughout the body.

12.1.4 HEARTBEAT AND ITS CONTROL

The heart is the hub of the circulatory system. In a continuous, rhythmic cycle it passively fills with blood from the large veins and then 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

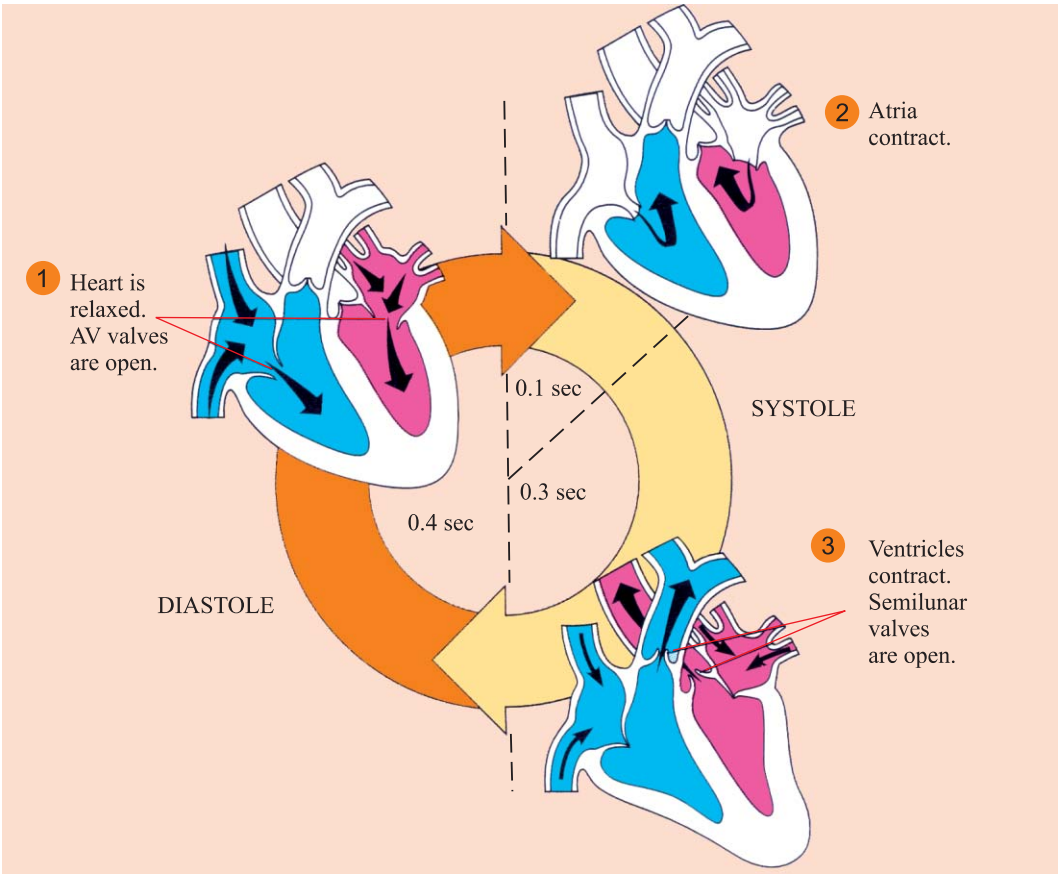


Fig 12.3 Cardiac Cycle

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.

Atrial Diastole : Blood enter 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 open.

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.

Ventricular Systole: Almost immediately the **ventricle** 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.

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** are closed. The normal cardiac cycle of 0.7 to 08 second depending on the capability of cardiac muscle to contract. The heart muscle rests 0.1 to 0.3 second between the beats.

Heart Sounds

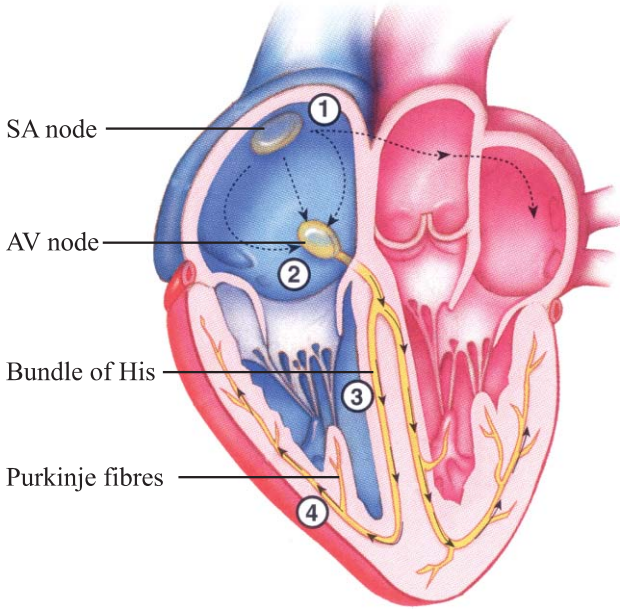
When a stethoscope is used to listen to the heart sounds, distinct sounds normally are heard. The **first heart sound** is a low-pitched sound, often described as a **"lubb"** (lub) sound. It is caused by vibration of the atrioventricular valves which close near the beginning of ventricular systole. The **second heart sound** is a higher pitched sound often described as a **"dupp"** (dub) sound. It results from closure of the aortic and pulmonary valves, near the end of systole.

Critical Thinking

Where are the sounds lub and dub produced in heart during cardiac cycle?

Conducting System of the Heart

Most muscles contract as a result of impulses reaching them from nerves. This is not, however true of the heart, which will continue beating



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.

Figure 12.4 Conducting System of the Heart

rhythmically even after its nerve supply has been severed. The heart will go on beating after it has been cut right out of the body. Cardiac muscles are therefore **myogenic** (*myo*: muscle, *genic*, giving rise to) 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 it 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.

Atrioventricular 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.

Atrioventricular Bundle: AV node is connected to a strand of specialized muscles (in the ventricular septum) known as **AV bundle** or

bundle of His (pronounced as "hiss"). 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.

Q. Why action potentials travel along the Purkinje fibres more rapidly than through other muscle fibres?

Reason for the slight delay between the atrial and ventricular contraction

The wave does not immediately spread to the ventricles from SA node. Almost 0.1 second passes before the ventricles start to contract. The reason for the delay is that the atria of the heart are separated from the ventricles by connective tissues, which cannot propagate a wave of electrical excitation. Secondly the cells that carry wave of impulse from the atria to the ventricle have smaller diameter. Thus they propagate the depolarization slowly, causing the delay of contraction of ventricles. This delay permits the atria to finish the emptying the contents into the corresponding ventricles before the ventricles start to contract.

Pacemaker

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.

Science, Technology and Society Connections

Rationalize the use of artificial pacemaker in patients of cardiac arrhythmias.

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. 12.5. The wave deflections, designated P, QRS, and T, are produced as specific events of the cardiac cycle occur. Any heart disease that disturbs the electrical activity will produce characteristic changes in one or more of these waves, so understanding the normal wave-deflection patterns is clinically important. 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.

Q. How is an ECG related to cardiac cycle?

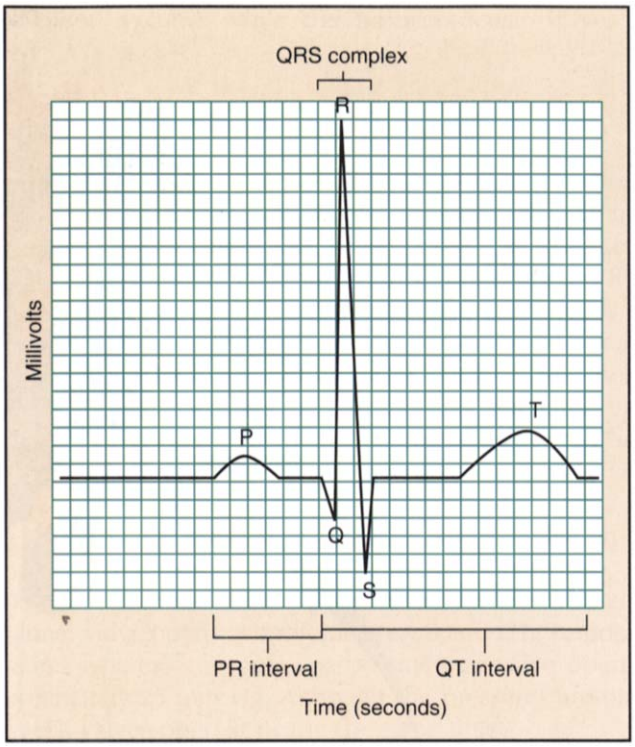


Figure 12.5 Electrocardiogram (ECG)

Uses of Electrocardiogram

ECG is used to detect cardiac arrythmias and conduction defects. It is used to diagnose and localize myocardial hypertrophy (increase in size of heart), ischemia or infarction (decrease in oxygen content) . It may also give information about electrolyte imbalance and toxicity of certain drugs.

12.2 BLOOD VESSELS

The heart provides the major force that causes blood to circulate, but the blood vessels carry blood to all tissues of the body and back to the heart. In addition, the blood vessels take part in the regulation of blood pressure and help to direct blood flow to tissues that are most active. The circulatory system has 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. Now we will discuss a detailed structure of blood vessels i.e. arteries, veins and capillaries.

Arteries

Arteries carry blood away from the heart. All arteries carry oxygenated blood except the pulmonary arteries, which carry deoxygenated blood. Arteries are pink in colour and are situated within the muscles. Arteries vary in size. Aorta is approximately 23 mm and arterioles are about 0.2 mm in diameter. Arteries have thick muscular walls.

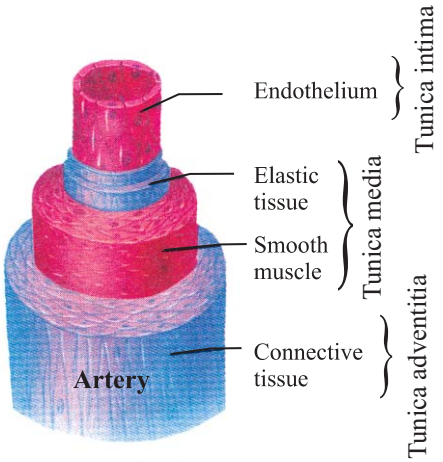


Fig: 12.6 Artery

These branch into **arterioles** and **capillaries**. Arteries are distributing vessel and carry blood under pressure. The lumens of arteries have no valves. The wall of an artery consists of three coats or tunics: tunica adventitia or tunica externa, tunica media, tunica intima.

The outermost layer is called **tunica adventitia** or tunica externa. 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. 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 and are the smallest arteries in which the three tunics can be identified. The tunica intima has no internal elastic membrane and the tunica media consists of one or two layers of circular smooth muscle cells.

Capillaries

All blood vessels have an internal lining of simple squamous epithelial cells called the **endothelium**, which is continuous with the endocardium of the heart. The capillary wall consists primarily of endothelial cells, which rest on a basement membrane. Outside the basement membrane a delicate layer of loose connective tissue called the **adventitia** that merge with the connective tissue surrounding the capillary. Most capillaries range from 7 to 9 µm in diameter, and thus branch without a change in their diameter.

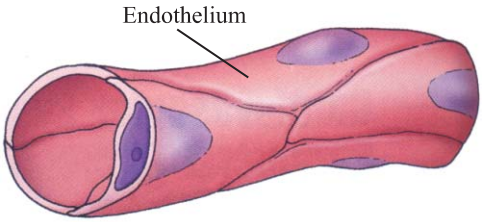


Fig: 12.7 Blood Capillary

Capillaries are approximately 1 mm long. Red blood cells flow through most of capillaries in a single file.

Capillary Network

Arterioles supply blood to each capillary network, (fig. 12.8) 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. (see fig. 12.8). This sphincter can open and close the entrance to the capillary.

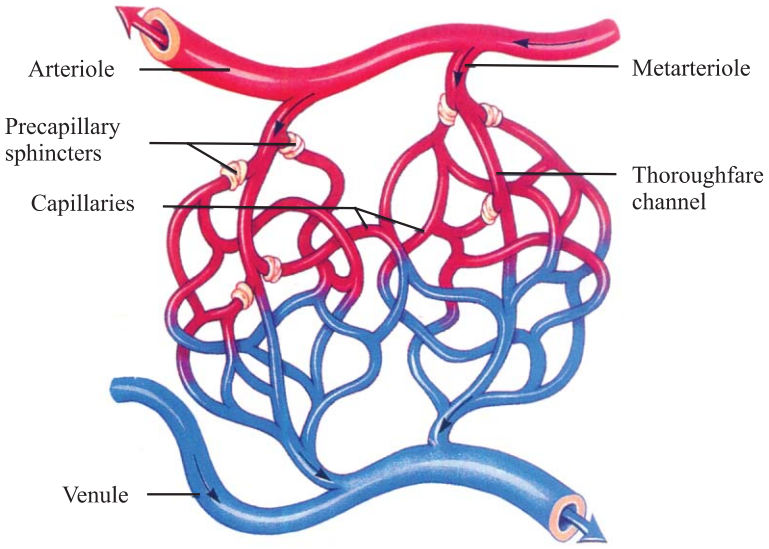


Fig. 12.8 Capillary Network

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 a composed of a thin layer of circularly arranged smooth muscle cells, collagen fibres and a few sparsely distributed elastic fibres. **Tunica intima** is a thin layer and consists of endothelial cells, a relatively thin layer of collagenous connective tissue and a few scattered elastic fibres. Venules with a diameter of 40 to50 μm are tubes composed of endothelium resting on a delicate basement membrane.

Their structure, except for their diameter is very similar to that of capillaries. As the vessels increase to 0.2 to 03 mm in diameter, the smooth muscle cells form a continuous layer; the vessels then are called small veins. The **venules** collect blood from the capillaries and transport it to the small veins, which in turn transport it to the medium sized vein. Medium and large veins collect blood from small veins and deliver it to large veins. The large veins transport blood from medium veins to the heart.

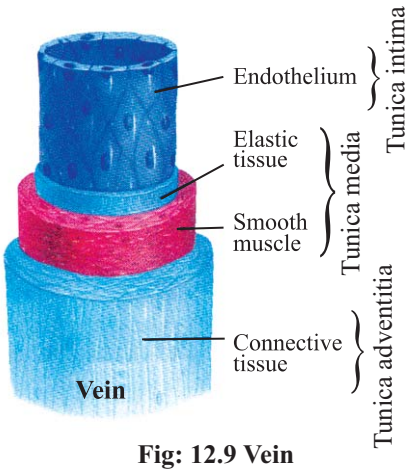


Fig: 12.9 Vein

Valves in Veins

Veins having diameters greater then 2mm contain valves that allow blood flow toward the heart but not in the opposite direction (fig. 12.10). The valves consists of fold in the tunica intima that form two flaps that are shaped and function like the semilunar valves of the heart. The two fold overlap in the middle of the vein, when blood attempts to flow in a reverse 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.

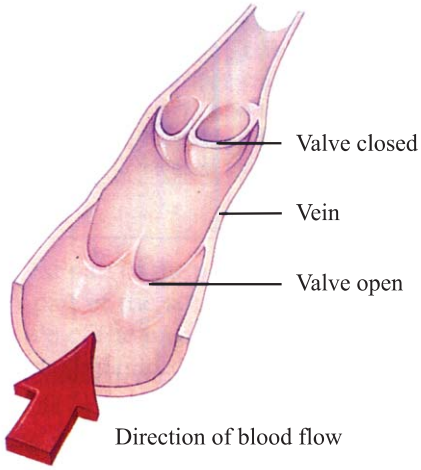


Fig: 12.10 Valves in veins

Critical Thinking

Blood in arteries flows with jerks, while that in veins flows continuously. Why?

Q. What factors assist venous return of the blood?

Role of Arterioles in Vasoconstriction and Vasodilation

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.

Vasoconstriction Agents

Blood circulation is also controlled by hormones (vasoconstriction agents) acting on arterioles. Norepinephrine is an especially powerful vasoconstriction hormone, and epinephrine is less.

Vasodilator Agents

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.

Skills: Analyzing and Interpreting

- **Justify how Vasoconstriction and Vasodilation 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 preserve and the skin becomes cold. Situations such as shock, hypotention and tachycardia occur by stimulation of arterial stretch receptors and production of hypertension and bradycardia occur by increased intracranial pressure.

Role of Precapillary Sphincter in Regulating the Flow of Blood Through Capillaries

At the point where true capillaries originate from the metarterioles a smooth muscle fibre usually encircles the capillary. This is called **precapillary sphincter** (fig. 12.8). 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 number of precapillary sphincters that are open at any given time is about proportional to the requirements of the tissue for nutrition. In addition 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**.

12.2.1 VASCULAR PATHWAY

Cardiovascular system (fig 12.11) includes two circuits, the **pulmonary circuit** which circulates blood through lungs and **systemic circuit** which circulates blood to all other parts of the body.

Pulmonary Circulation

The path of blood through the lungs can be traced as follows: The left atrium receives oxygenates 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 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.

Q. What are the advantages of supplying blood to the pulmonary circulation at a low pressure than that of the systemic circulation?

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** and 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.

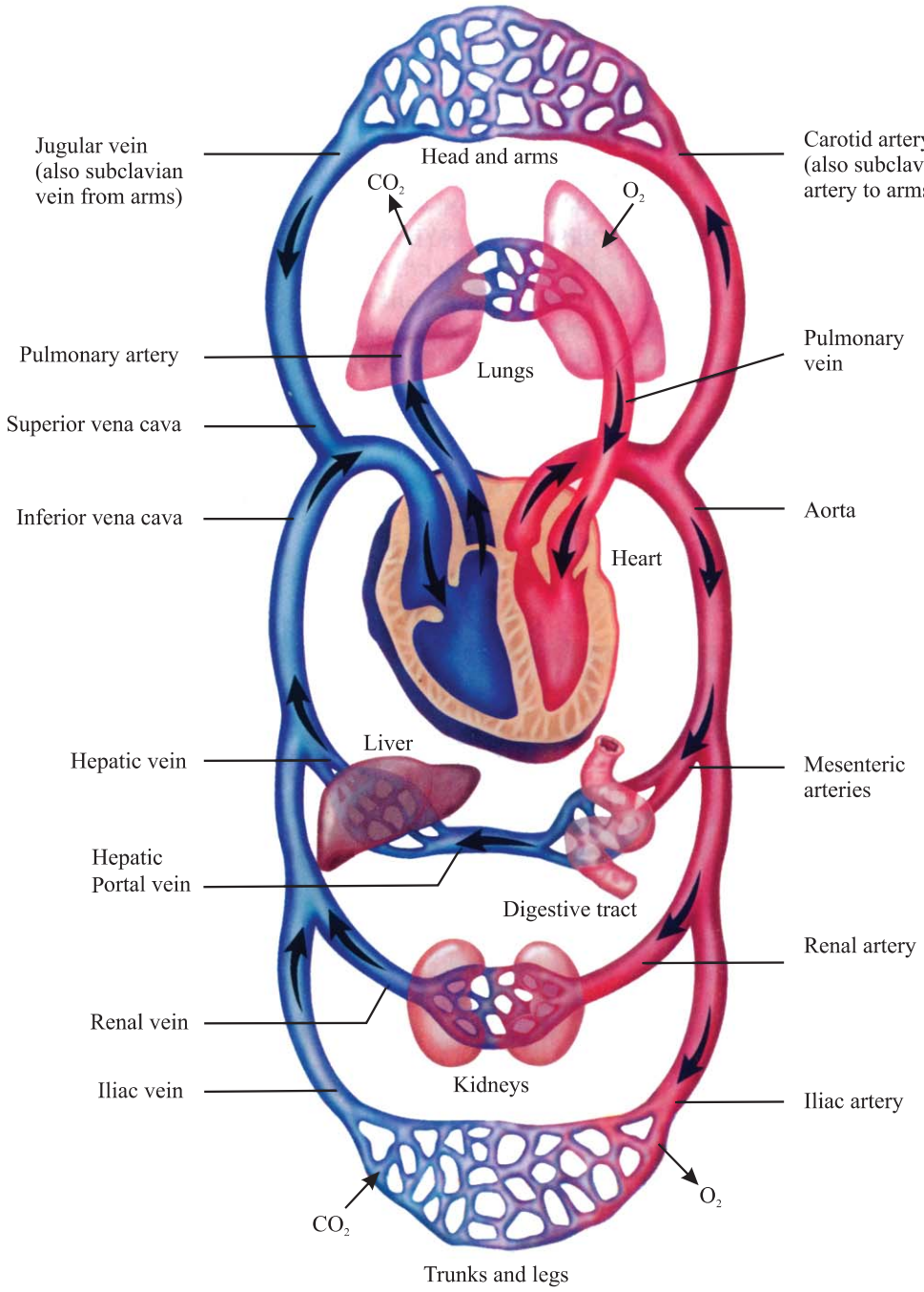


Fig: 12.11 Cardiovascular System

Branches from **aorta** go to the organs and major body regions. The **superior vena cava** collects blood from the head and the chest and the arms and the **inferior vena cava** collects blood from the lower body regions. Both enter the right atrium. The aorta and the vanae 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** (fig. 12.1).

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

Blood from the capillaries within most of the abdominal viscera such as the stomach, intestines, and spleen drains through a specialized system of blood vessels to the liver. Within the liver the blood flows through a series of dilated capillaries called **sinusoids**. A **portal** (meaning door) 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 sinusoidal capillaries in the liver is the hepatic (meaning, relating to the liver) portal system. The **hepatic portal vein**, the largest vein of the system, is formed by the union of the **superior mesenteric vein**, which drains the small intestine and the **splenic vein**, which drains the spleen. The splenic vein receives the **inferior mesenteric** and **pancreatic veins**, which drain the large intestine and pancreas, respectively. The hepatic portal vein also receives gastric veins before entering the liver. Blood from the liver sinusoids is collected into **central veins**, which empty into **hepatic veins**. Blood from the cystic veins also enters the hepatic veins. The hepatic veins join the inferior vena cava.

Critical Thinking

How does the sequence of blood vessels of the hepatic portal system differ form that in most other circulatory roots?

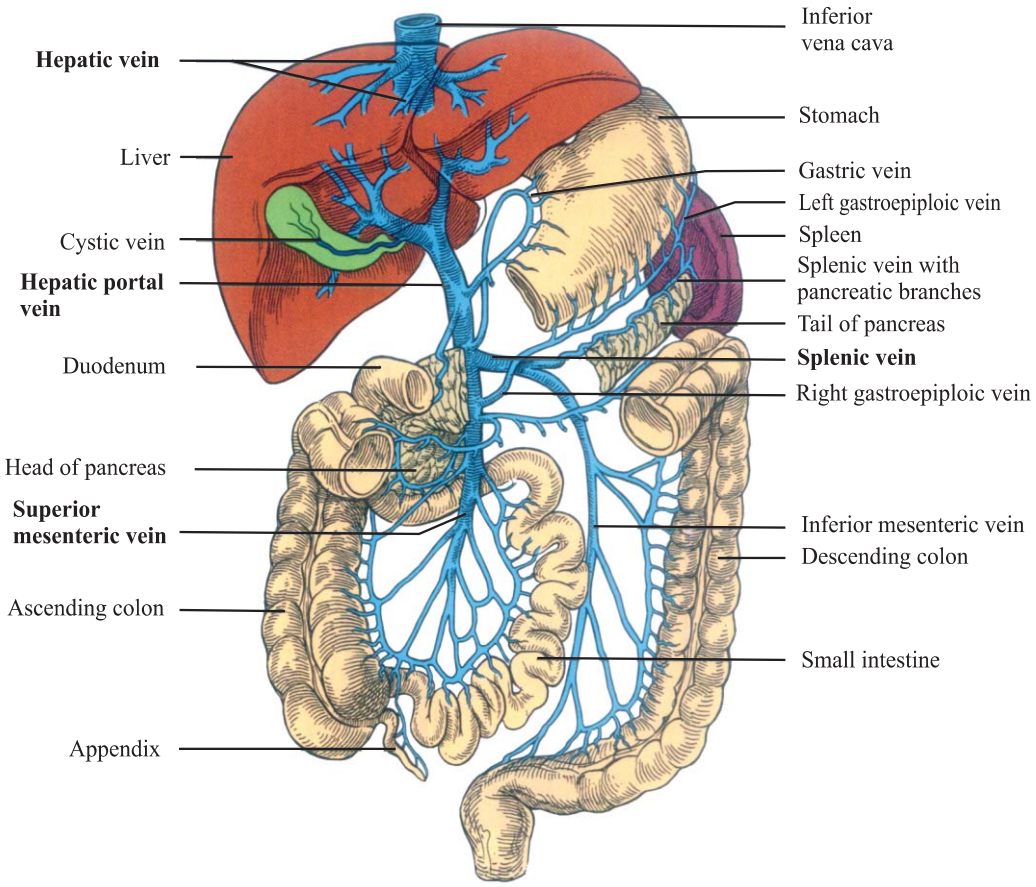


Fig: 12.12 Hepatic Portal System

Renal Circulation

Arterial blood enters the kidney at the hilum through **renal artery**, which divides, into **interlobar arteries**, **arcuate arteries** branch from the interlobular arteries at the boundary of renal cortex and **renal medulla**. Small interlobular arteries radiate from the arcuate arteries and project into the renal cortex. Microscopic **afferent glomerular arterioles** arise from the branches of the interlobular arteries. From

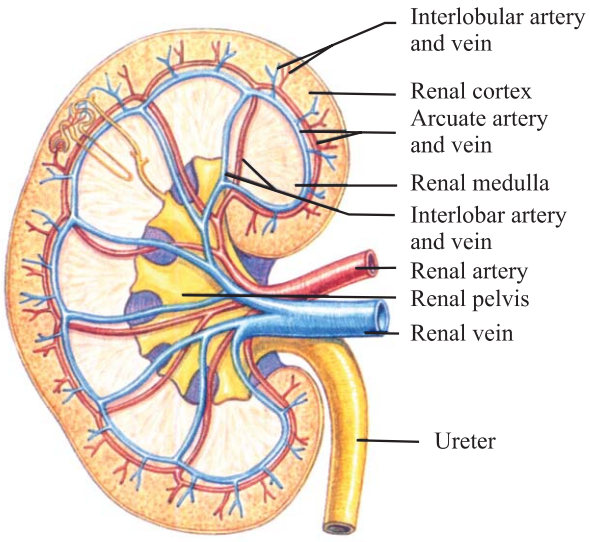


Fig. 12.13 Principal Arteries and Veins of Kidney

here blood enters either the **peritubular capillaries** or **vasa recta**. From these capillary networks the blood is drained into interlobular veins and arcuate veins which leave the kidney as a single **renal vein**.

Q. What is the function of hepatic portal system?

12.2.2 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. Ordinarily, blood flow is expressed in milliliter or liter per minute, but can be expressed in milliliter, per second or any other unit of flow. The over all 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.

The velocity of blood flow is greatest in the aorta, but the total cross-sectional area for the capillaries is large, but the velocity of blood flow is low. As the veins become larger in diameter, their total cross-sectional area decreases, and the velocity of blood flow increases. The relationship between blood vessel diameter and velocity of blood flow is much like a stream that flows rapidly through a narrow gorge, but flows slowly through a broad plane.

12.3 BLOOD PRESSURE AND ITS MEASUREMENT

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**.

Baroreceptor Reflexes

Baroreceptors, or pressoreceptors, are sensory receptors sensitive to stretch. They are scattered along the walls of most of the large arteries of the neck and the thorax and are most numerous in the area of the carotid sinus at the base of the internal carotid artery and in the walls of the aortic arch (fig: 12.15). Stimulation of baroreceptors produces reflexes which control blood within a narrow range of values.

Table: 12.1 Velocities of Blood Flow			
Vessels	**Approximate Cross Sectional Area**	**Volume/Ccm^2**	**Velocity/cm s^{-1}**
Aorta	2.5 cm^2	100	40 cm / second
Arteries	20 cm^2	300	40-10 cm / second
Arterioles	40 cm^2	50	10-0.1cm / second
Capillaries	2.500 cm^2	250	0.1 cm / second
Venules	250 cm^2	300	0.3 cm / second
Veins	80 cm^2	2200	0.3-5 cm/ second
Venae Cavae	8 cm^2	300	5-20 cm / second
Velocity values with two numbers represent changes in velocity as blood passes through that part of the circulatory system. For example, 40-10 indicates a decrease in velocity from 40cm /second to 10cm/second.			

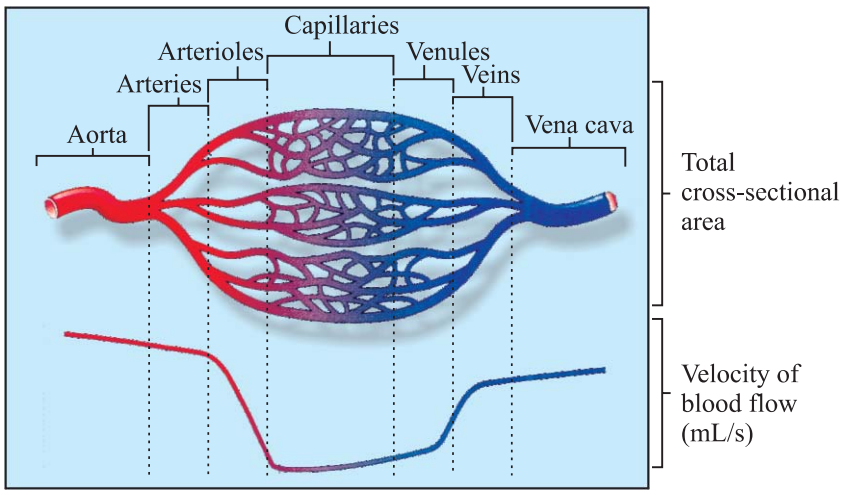


Fig: 12.14 Blood Vessel Types and Velocity of Blood Flow: Total cross-sectional area for each of the major blood vessel types is the space through which blood flows, measured in square centimeters. The cross-sectional area of the aorta is about 5 cm^2. The cross-sectional area of each capillary is much 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.

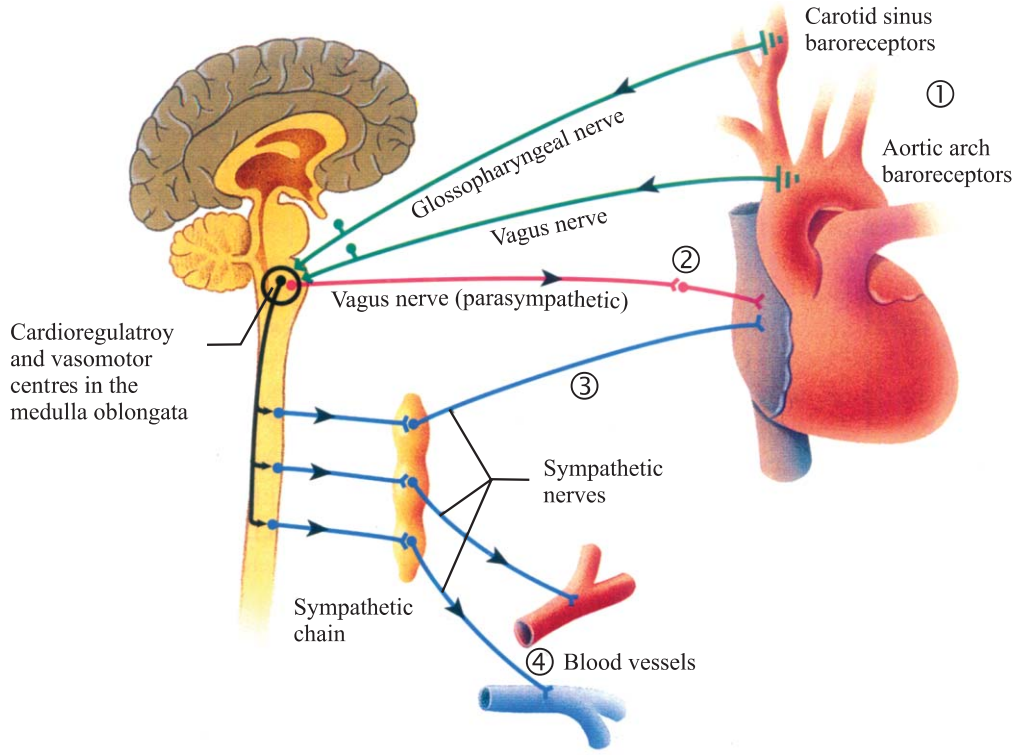


Figure 12.15 Baroreceptor Reflex Control of Blood Pressure (1) Baroreceptors in the carotid sinus and aortic arch monitor blood pressure. (2) Increased parasympathetic stimulation of the heart decreases the heart rate. (3) Increased sympathetic stimulation of the heart increases the heart rate and stroke volume. (4) Increased sympathetic stimulation of blood vessels increase vasoconstriction.

In the carotid sinus and the aortic arch, normal blood pressure partially stretches the arterial wall so that a constant, but low, frequency of action potentials are produced by the baroreceptors. Increased pressure in the blood vessels stretches the vessel walls and results in an increased frequency of action potentials generated by the baroreceptors. Conversely, a decrease in blood pressure reduces the stretch of the arterial wall and results in a decreased frequency of action potentials. The carotid sinus and aortic arch baroreceptor reflexes are important in regulating blood pressure moment to moment.

Volume Receptors

Stretch of the atria also causes **reflex dilation** of the afferent arterioles in the kidneys. Also, signals are transmitted simultaneously to the **hypothalamus** to decrease the secretion of antidiuretic hormone, thereby

indirectly effecting kidney function. The decreased afferent arteriolar resistance causes the **glomerular capillary pressure** to rise, with resultant increase in filtration of fluid into the kidney tubules. The diminution of **antidiuretic hormone** diminishes the re-absorption of water from tubules. The combination of these two effects causes rapid loss of fluid into the urine, which serves as a powerful mean to return the blood volume back to normal.

All these mechanisms that tend to return the blood volume back towards normal after a volume overload act indirectly as pressure controller as well as volume controller, because axcess volume drives the heart to greater cardiac output and lead, therefore to greater arterial pressure.

Science, Technology and Society Connections

Hypothesize the role and effects of diuretic drugs in regulating blood pressure.

12.4 CARDIOVASCULAR DISORDERS

Cardiovascular disorders or disease (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 in called **thrombosis**. The clotted mass of blood within a vessel or the heart during life is called **thrombus**. Morphologically there are two types of thrombi: Pale or white thrombi and red thrombi. **Pale thrombi** are composed of platelets and fibrin and few R.B.C.

They are dry easily breakable, develop in arterial circulation and are attached to vessel wall. **Red thrombi** are composed of platelets fibrin and large number of R.B.C, develop in venous circulation. There are three types of clinical thrombi, arterial thrombi, cardiac thrombi, and venous thrombi.

The occlusion 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**. The emboli may be solid, gas and liquid. Thrombus and embolus cause death.

12.4.2 HEART PROBLEMS

In this section we will discuss diseases related to heart, such as: Atherosclerosis, angina pectoris, heart attack, heart failure.

Atherosclerosis

Atherosclerosis is characterized by formation of yellow fatty streaks containing high proportion of cholesterol in the intima of large and medium sized arteries resulting in the narrowing of the vascular lumen. Later, fibres are deposited in the cholesterol and these often start to calcify and become hard, a process known as **arteriosclerosis**. The deposits are called **athromatous plaques**. As a **plaque** increases in size it protrudes into the lumen of the artery and begins to block it. The plaque first forms thrombus and may form embolus.

Factors Causing Atherosclerosis and Arteriosclerosis

The major risk factors are: (a) Hypercholesterolemia (hyperlipidemia) (b) Hypertension (c) Cigarette smoking (d) Diabetes mellitus (e) Male sex (f) Familial predisposition (occurring in or affecting more members of a family than would be exposed by chance). The other minor risk factors are:(a) Increasing age (b) Lack of exercise, (c) Stressful competitive life (d) Obesity (e) High carbohydrate diet, (f) Hyperuricemia (g) Oral contraceptives.

Angina Pectoris

Due to atherosclerosis a person may feel occasional pain, a condition known as **angina pectoris** (Latin *angere* to choke and *pecto* breast). **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. There are three types of angina pectoris: Typical angina pectoris, variant angina pectoris, unstable angina pectoris.

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 muscle die, they are not replaced because cardiac muscle 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 has

died. The scar tissue cannot contract as cardiac muscle. As a result the damaged heart is permanently weakened.

Heart Failure

Congestive heart failure is a clinical syndrome resulting from deficient cardiac stroke volume, relative to body need, with inability of the cardiac output to keep pace with the venous return i.e. heart is unable to pump all the blood coming to it.

Congenital heart problem: it is related to the malfunctioning of cardiac valves includes: Valvular Stenosis, Regurgitation, Patent Ductus Arteriosus (PDA), Fallot's Tetralogy.

Valvular Stenosis: Scaring of the valve leaflets may cause reduction in diameter of the valve orifice.

Regurgitation: Severe destruction of valve apparatus may cause valve ring dilation, with thickening and shortening of chordae tendinae resulting in regurgitation of blood through the valve when it is closed i.e. valve closed is incomplete.

Patent Ductus Arteriosus (PDA)

PDA is most often diagnosed in childhood. During fetal life, before the lungs begin to function most of the blood from pulmonary artery passes through the **ductus arteriosus** into the aorta. Normally the ductus closes soon after birth but sometimes it fails to do so. This causes blue babies due to mixing of oxygenated and deoxygenated blood.

Fallot's Tetralogy

It is the most common cause of congenital cyanotic heart disease. e.g. Ventricular hypertrophy (increase in the size of ventricle).

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

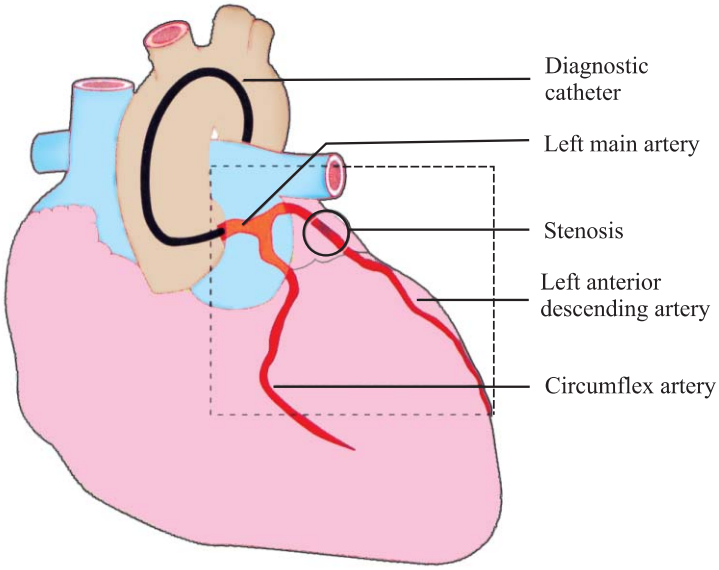


Figure.12.16 Coronary Angiogram-Schematic of the Vessels and Branches

size and function of the left ventricle. Coronary angiography is used to detect stenosis (constriction, narrowing of a tube or passage) and guide revascularisation procedures such as balloon angiography and stenting (fig. 12.18).

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 segments of blood vessel from other parts of the patient's body usually a vein from the leg called **great saphenous vein** and an artery of thorax called **internal thoracic artery** and using them to bypass obstructions in the coronary arteries. The technique is common for those who suffer from severe occlusion of parts of the coronary arteries.

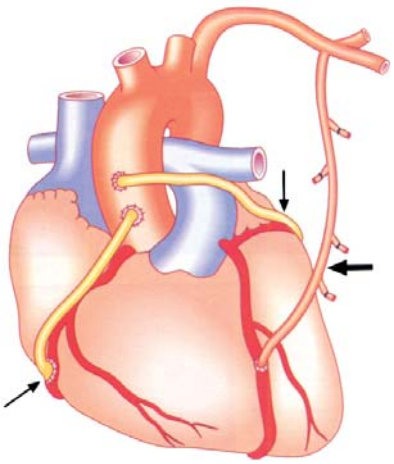


Fig: 12.17 A triple Coronary Artery Bypass Graft Operation

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.

Science, Technology and Society Connections

List the advantages and disadvantages of coronary by pass.

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. Stent are coated with heparin to prevent blood clotting and chemicals to prevent arterial closing.

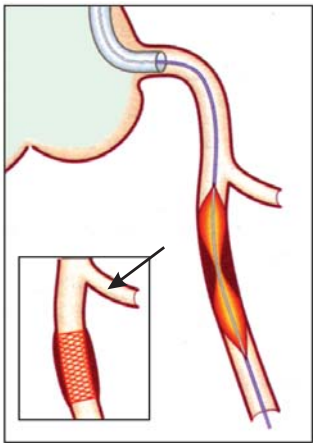


Fig: 12.18 Coronary Angioplasty and Stenting

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 open heart bsurgery is performed under , which requires that the patient be on a ventilator during surgery. The chest is opened by making an incision along the sternum, or breastbone. The surgeon then cuts the sternum, allowing the chest cavity to be opened, giving the surgeon access to the heart. At this time the heart-lung machine does the work of the heart and the lungs, and the ventilator is not used. Once the surgery is complete, the heart beat is started and provides blood and oxygen to the body. The sternum is returned to its original position and closed using surgical wire, to provide strength the bone needs to heal, and the incision is closed.

12.4.5 HYPERTENSION AND HYPOTENSION

Hypertension

Sustained high blood pressure is known as hypertension. Blood pressure 140/90, at least two different readings six hours apart is considered hypertension.

Factors Regulating Blood Pressure

Pressure difference between the two ends of the vessels (also frequently called pressure gradient) which is the force that pushes the blood through the vessels. Blood flows directly proportional to the pressure difference but indirectly to proportional resistance. The circulatory system is provided with an extensive system for controlling the arterial pressure. For instance if at any time the pressure falls significantly below its normal level of about 100mmHg a barrage of nervous reflexes within seconds elicits a series of circulatory changes to raise the pressure back to normal. Nervous control of the circulation provides additional specific attributes to tissue blood flow control.

Postural Hypotension

In some individuals, sudden standing causes a fall in blood pressure, dizziness, dimness of vision, and even fainting. The causes of this **orthostatic (postural) hypotension** are multiple. It is common in patients receiving sympatholytic drugs. It also occurs in diseases such as diabetes, syphilis, and Parkinson's disease, in which there is damage to the sympathetic nervous

Table: 12.2 Classification and Follow up of Blood Pressure Measurements

Category	Systolic Blood Pressure (mm Hg)	Diastolic Blood Pressure (mm Hg)	Follow up recommended
Normal	< 130	< 85	Recheck in 2 years
High Normal	130-139	85-89	Recheck in 1 year
Hypertension Stage 1 *(Mild)*	140-159	90-99	Confirm within 2 months
Stage 2 (moderate)	160-179	100-109	Evaluate or refer within 2 months
Stage 3 (severe)	180-209	110-119	Evaluate refer within 1 week
Stage 4 (very severe)	> 210	>120	Evaluate refer immediately

system. This underscores the importance of the sympathetic vasoconstrictor fibres in compensating for the effects of gravity on the circulation. Mineralocorticoids are used to treat patients with postural hypotension.

Prevention of Cardio Vascular Diseases

All of us can take steps to prevent the occurrence of CVD. One should pay particular attention to these guidelines for a heart-healthy-life-style. 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. Hypertension occurs more often in persons who are **obese**. So one should try to maintain normal body weight. It is recommended and one should take **diet** having low cholesterol and low in saturated fats, and take low salt diet. The LDL-cholesterol level together with other risk factors such as age, family history general health and whether the patient smokes will determine who need dietary therapy to lower their LDL.

12.5 LYMPHATIC SYSTEM OF MAN

The lymphatic system includes lymph, lymphocytes, lymphatic vessels, lymph nodes, tonsils, spleen and thymus gland.

Interstitial Fluid

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: It 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. The interstitial fluid is mainly entrapped in the minute space among the proteoglycan filaments. This combination of proteoglycan filaments and the fluid entrapped within them has the characteristics of gel and therefore is called **tissue gel**.

Function: Instead of flowing, fluid mainly **diffuse** through the gel. Diffusion through the gel occurs about 95 to 99 percent as rapidly as it does through free fluid. For the short distances between the capillaries and the tissue cells, this diffusion allows rapid transport through the interstitium not only of water molecules but also of electrolytes, nutrients, cellular excreta, oxygen, carbon dioxide etc. Materials are exchanged between the blood and interstitial fluid and between the interstitial 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.

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Comparison: Composition of Interstitial Fluid and Lypmph

Approximately 30 litres of fluid pass from the blood capillaries into the interstitial space each day, whereas only 27 litres pass from the interstitial

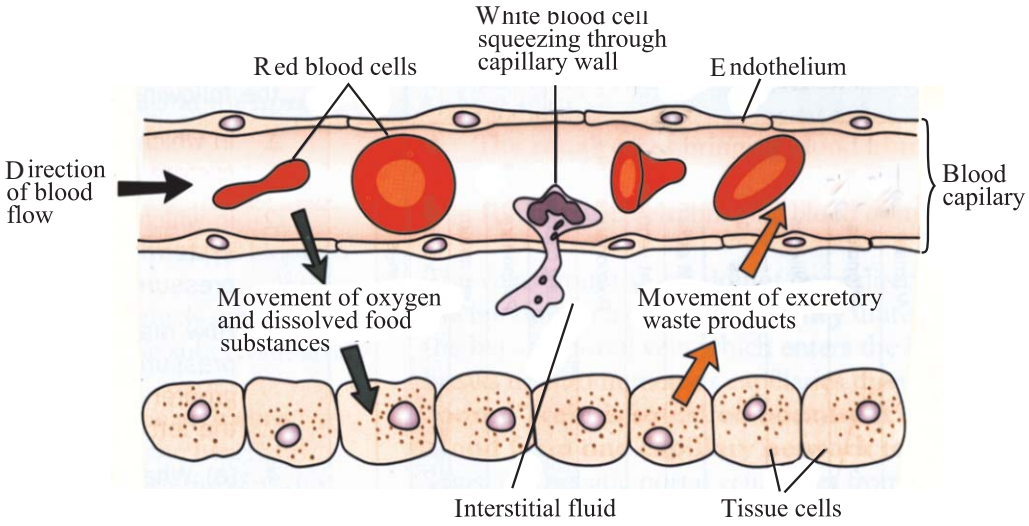

Fig: 12.19 Relationship between a Blood Capillary, Interstitial Fluid and Tissue Cells

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 lymphatie vessels back to the blood.

In addition to water lymph contains solutes derived from two sources: (a) substances in plasma such as ions, nutrients, gases and some proteins, pass from blood capillaries into the interstitial space and become part of the lymph and (b) substances derived from cells, such as hormones, enzymes and waste products are also found in the lymph.

12.5.1 LYMPHATIC VESSELS

The lymphatic system (figure 12.20) unlike the circulatory system only carries fluid away from tissue. The lymphatic system begins in the tissues as **lymph capillaries**, which differ from 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, Second, 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.

Critical Thinking

What causes lymph to move through the lymph vessels?

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.

Thoracic Duct

The thoracic duct drains the lower limbs, abdomen, the left thorax, the left upper extremity, and the left side of the head and neck (fig.12.21). The duct ends by entering the left subclavian vein.

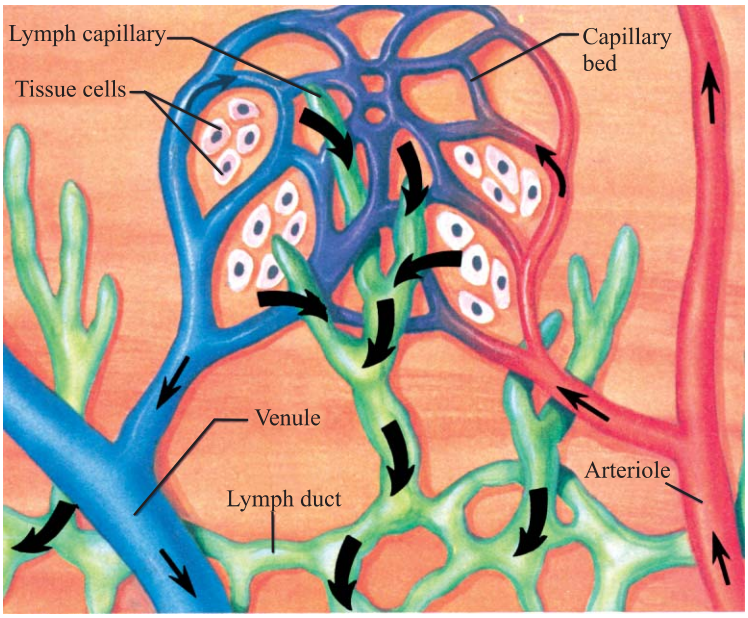

Fig: 12.20 Lymphatic Vessels

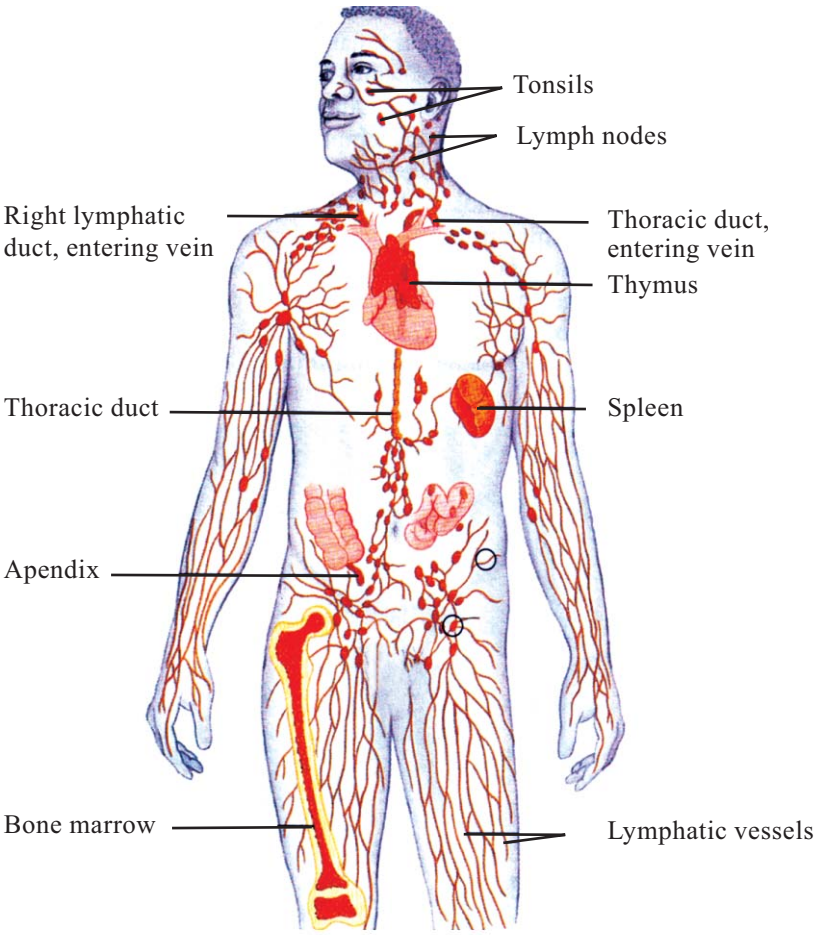

Fig: 12.21 Human Lymphatic System

Right Lymphatic Duct

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 Villi

Each villus contains a **lymph capillary** called **lacteal**. The lymphatic system absorbs fats and other substances from the digestive tract. Fat enters the lacteals and pass through these lymphatic vessels to venous circulation. The lymph passing through these lacteals has a milky appearance because of its fat contents. **Chylomicrons** (these are proteins, triglycerol 90% phospholipids 4% and cholesterol 5%) enter the lacteal. Chylomicrons enter the lymph capillaries because lymph capillaries lack basement membrane and are more permeable to large particles.

Lymph Nodes

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 congregate (assemble), function and proliferate within lymph nodes. Lymph nodes are found throughout the body.

Skills: Analysing and Interpreting

- Trace the path of lymph from lymph capillary until it is returned to the blood.

12.5.2 SPLEEN

The spleen, which is roughly the size of a clenched fist, is located on the left side in the extreme superior, posterior part of the abdominal cavity. The spleen detects and responds to foreign substances in the blood, destroys worn-out erythrocytes, and acts as a blood reservoir. Foreigen substances in the blood passing through the white pulp can stimulate lymphocytes in the periarterial sheath or the lymph nodules in the same manner as in lymph nodes. Before blood leaves the spleen through veins, it passes into the red pulp. Macrophages in the red pulp remove foreign substances and worn-out erythrocytes through phagocytosis. In emergency situations such as haemorrhage, smooth muscle in splenic blood vessels and in the splenic capsule contract in response to sympathetic stimulation. The result is the movement of a small amount of blood from the spleen into the general circulation.

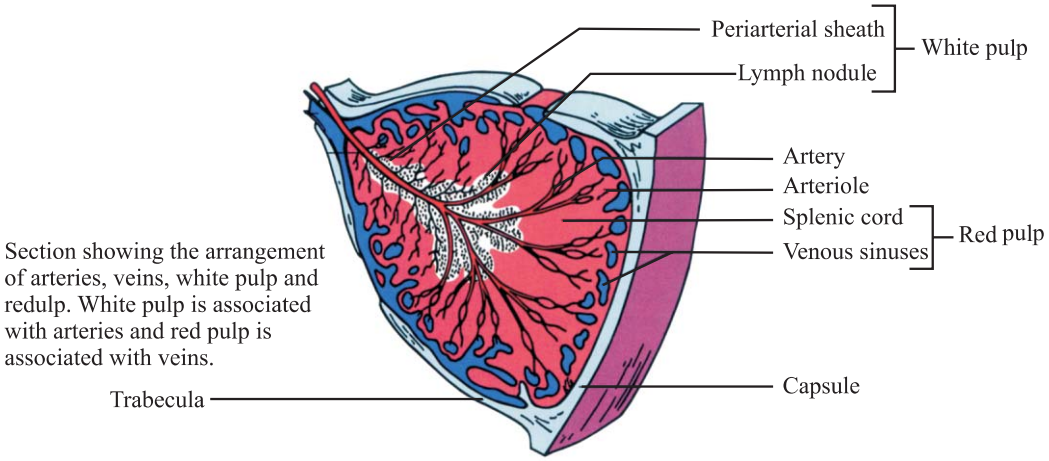

Fig: 12.22 Spleen

Table: 12.4 Differences Between Blood Capillaries and Lymphatic Capillaries

	Blood Capillaries		Lymph Capillaries
1	These are reddish and easy to locate.	1	These are colourless, thus difficult to locate.
2	These are joined to arterioles at one end and to venules at the other end.	2	These are joined to arterioles at one end and to venules at the other end.
3	These have no free end.	3	Their free ends are blind and expanded into a knob.
4	These are narrower than lymphatic capillaries.	4	These are wider than blood capillaries.
5	These have a uniform diameter.	5	These are not of uniform thickness.
6	These carry blood received from arterioles to the venules.	6	These carry colourless lymph received from tissue spaces by lymphatic vessels.
7	Blood flows through them under high pressure.	7	Lymph flows through them under low pressure.
8	Provide tissue fluid to intercellular spaces.	8	These absorb tissue fluid from intercellular spaces.

Table: 12.5 Differences Between Blood and Lymph

	Blood		Lymph
1	It is a red fluid tissue.	1	It is a colourless fluid tissue.
2	It circulates and flows through the arteries, capillaries and veins.	2	It flows in the tissue-spaces and through the lymphatic capillaries and vessels enter the subclavian veins.
3	It consists of erythrocytes leucocytes and platelets.	3	It consists of leucocytes only.
4	It appears red because of the presence of erythrocytes.	4	Due to the absence of erythrocytes it appears colourless.
5	It is rich in plasma proteins calcium and phosphorus.	5	It has fewer plasma proteins and less calcium and phosphorus.
6	It flows rapidly.	6	Its flow is very slow.

Science, Technology and Society Connections

List major hospitals of cardiology working in your province.

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 form 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 determine 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, protozoal, fungal (histoplasmosis), leukeemias, lymphomas etc.

Exercise

Select the correct answer

1. 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

2. 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. sinoatrial node

   In which order will the red blood cell passes the structures?

   A) $2 \longrightarrow 3 \longrightarrow 1 \longrightarrow 4 \longrightarrow 5$

   B) $3 \longrightarrow 1 \longrightarrow 5 \longrightarrow 2 \longrightarrow 4$

   C) $3 \longrightarrow 5 \longrightarrow 1 \longrightarrow 2 \longrightarrow 4$

   D) $5 \longrightarrow 3 \longrightarrow 1 \longrightarrow 4 \longrightarrow 2$

3. What effect would be caused by cutting the sympathetic nerve fibres to the heart?

   A) a decrease in the heartbeat rate

   B) a decrease in the length of the diastole phase

   C) a decrease in the length of the systole phase

   D) a decrease in the stroke volume

4. 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

5. Human heart is

   A) myogenic B) neurogenic

   C) cardiogenic D) digenic

6. Typical lub-dup 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.

7. 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

8. Pace maker 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.

9. During ventricular systole in a mammalian heart the

A) ventricular pressure increases B) atrioventricular valves open

C) semilunar valves close D) aortic pressure decreases

10. Lymph returns---------- to blood

A) oxygen B) carbon dioxide

C) interstitial fluid D) white blood cells

11. Lymph most closely resembles which of the following?

A) blood B) urine

C) water D) interstitial fluid

12. 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

13. 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

SECTION II : SHORT QUESTIONS

1. Which side of the human heart contains oxygenated blood?
2. What are the contraction and relaxation of human heart called?
3. Name two circulatory systems in the body of man.

4. Where are SA node, AV node, Purkinje fibre, Bundle of His located?
5. Name the artery supplying blood to the heart.
6. What is blood pressure?
7. Name the instrument used in measuring blood pressure.
8. Why is SA node called pacemaker of the heart.
9. What is a cardiac cycle?
10. What is the major feature of human lymphatic system?
11. What is an arterial pulse? How much is the normal human pulse rate?
12. Why is AV node essential for the conduction of cardiac impulse?
13. What is the function of the valves in lymph vessel?
14. What are the risks associated with atherosclerosis?
15. 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?
16. List the risk factors in your family history and life style for cardiovascular disease. Which factors can be changed? Which cannot? What can you do to lower your risk of heart disease?
17. What is the difference between the lymph capilleries and blood capilleries?

SECTION III : EXTENSIVE QUESTIONS

1. Describe the external and internal structure of human heart.
2. Write a comprehensive note on electrocardiogram.
3. Explain how the structure of each type of blood vessel is suited to its function?
4. Define blood pressure. How it is measured?
5. Discuss cardiovascular diseases. List the ways to prevent it.
6. Write notes on: Angiography, angioplasty, open-heart surgeries, and hypertension.
7. Describe the lymphatic system is man.

ANSWER MCQS

1. D 2. D 3. A 4. D 5. A 6. D 7. B 8. A 9. A 10. C 11. D 12. C 13. A

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CHAPTER 13

IMMUNITY

Major Concepts:

Number of allotted teaching periods: 12

More than 2000 years ago, the Greek historian **Thucydides** observed that occasionally someone contact a disease, recovers and never catches the particular disease again, the person has become immune (resistant) to subsequent infection. In 1796 an English country doctor **Edward Jenner** hypothesized that cowpox somehow conferred protection against smallpox.

The body's response to foreign molecules, such as the production of antibodies directed against a specific **antigen**, is called an **immune response**. The term **immune** is derived from Latin word *immunis* meaning "safe" or free of burden. **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 immunity and the defence mechanism of the body.

Defences Against Microbial Invasion

The human body has three lines of defences against microbial attack:

(1) First line of defence – the **external barriers** that keep microbes out of the body. (2) Second line of defence – the **nonspecific internal defence** (innate immunity) that combat all invading microbes. (3) Third line of defence – the specific (adaptive immunity) or **immune system** that directs its assault against specific microbes.

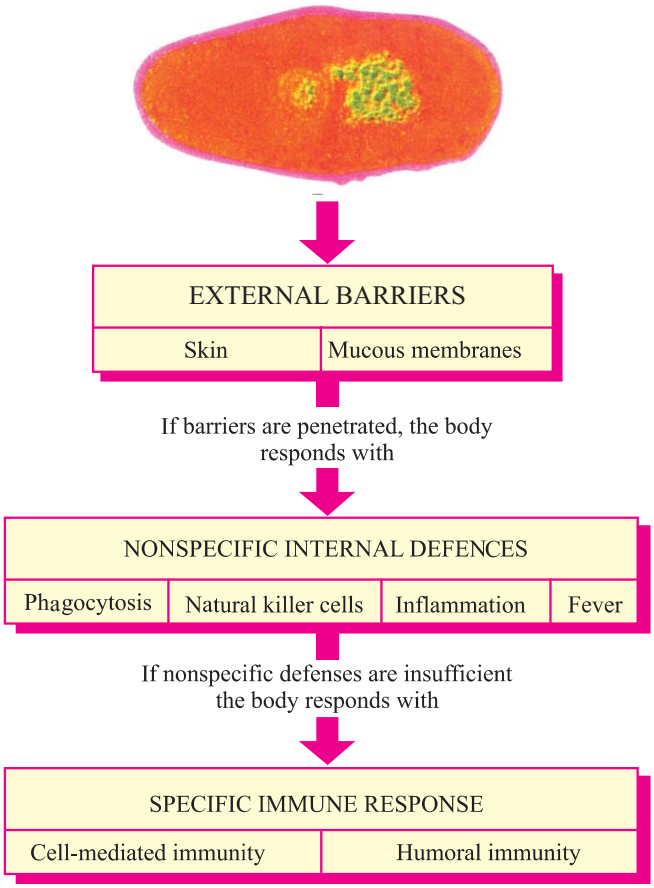


Fig 13.1 Levels of defence Against Infection

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 barriers to microbial invasion.

Structural Features of Human Skin

The skin is made up two-layers **dermis** and **epidermis**. The dermis is dense, irregular connective tissue. Nerve endings hair follicles, smooth muscles, glands and lymphatics extend to the dermis. The epidermis is stratified squamous epithelium separated from dermis by basement membrane. Most cells of epidermis are **keratinocytes**, which produce a protein mixture called **keratin**. Other cells of the epidermis include **melanocytes**, which contribute to skin colour and **Langerhan cells**, which are part of immune system. The major glands of skin are the **sebaceous glands.**

Sebaceous glands located in the dermis, are simple or compound alveolar glands that produce **sebum**, an oily, and white substance rich in lipids. Most sebaceous glands are connected by a duct to the upper part of the hair follicles from which the sebum oils the hair and the skin surface. This prevents drying and provides protection against some bacteria. There are two types of sweat glands i.e merocrine and apocrine.

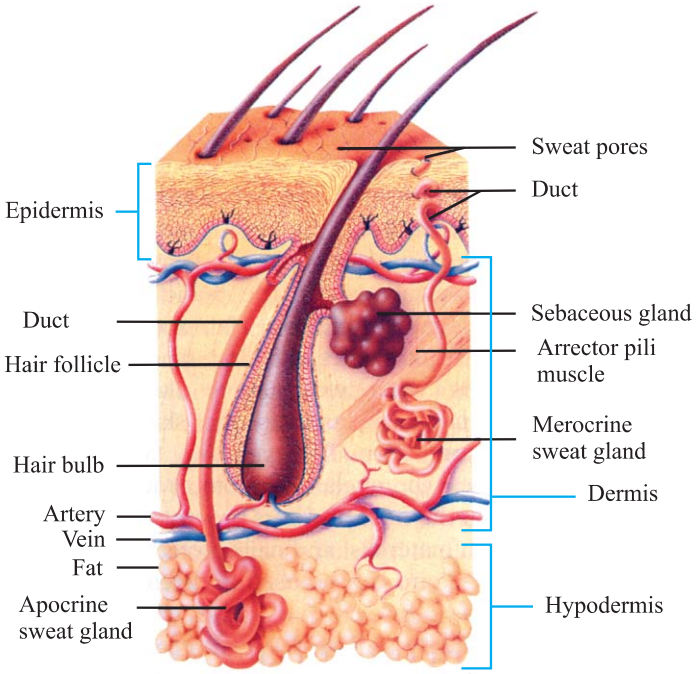


Fig: 13.2 Glands of Skin

The Intact Skin is both a Barrier to Entry and Inhospitable Environment of Microbial Growth

The outer surface of the skin consists of dry dead cells having keratin. Consequently, most microbes that land an the skin cannot obtain the water and nutrients they need. **Secretion** from sweat glands and sebaceous glands also cover the skin. These secretions contain acids and natural antibiotics such as **lactic acid** that inhibit the growth of bacteria and fungi. These multiple defences make the unbroken skin an extremely effective barrier against microbial invasion.

Digestive Tract : Role of Acids and Enzymes

The gastrointestinal tract (GIT), is covered by mucous membrane, which protects the G1T. (a) In the stomach hydrochloric acid is secreted by **oxyntic** or **parietal cell**. It kills the microorganisms (b) **Zymogen cells** or principal cells secrete gastric enzymes, which digest the microorganisms. (c) Intestinal and pancreatic juice also secrete enzymes, which digest the microorganism.

Role of Respiratory Tract

The nasal cavity cleans the air. The vestibule is lined with hairs that trap some of the large particles of dust in the air. The air comes into contact with the mucous membrane lining the nasal cavity. This mucous membrane consists of pseudostratified ciliated columnar epithelium with goblet cells, which secrete a layer of mucus. The mucus traps debris in the air and the cilia in the surface of the mucous membrane sweep the mucus posteriorly to the pharynx, where it is swallowed and eliminated by the digestive system. The trachea is lined by mucous membrane. The cilia propel mucus and foreign particles towards the larynx, where they enter the pharynx and are swallowed.

The **nasal turbulence mechanism** (see glossary) for removing particles from air so effective that almost no particles larger than 6 micrometeres in diameter enter the lungs through the nose. Of the remaining particles, many that are between 1 and 5 micrometers settle out in the small brochioles as a result of gravitational precipitation. Particles smaller than 0.5 micrometres in diameter remain suspended on the alveolar air and are later expelled by expiration

The cilia and mucus present in the bronchus and bronchioles are the system's clearing elements.

13.2 SECOND LINE OF DEFENCE - The Nonspecific Defences

Three nonspecific internal defences are mustered against microbes that penetrate the skin or mucous membranes. These defences are nonspecific because they attack wide variety of microbes, rather than targeting specific invaders as the immune response does. First, the body has a standing army of **phagocytic cells** that destroy microbes and **natural killer cells** that destroy cells of the body that have been infected by viruses. Second, an injury with

combination of tissue damage and relatively massive invasion of microbes provokes an **inflammatory response**. Third, if a population of microbes proceeds in establishing a major infection, the body often produces fever, which slows down microbial production and enhances the body's own fighting abilities.

13.2.1 KILLING CELLS OF BLOOD

Constantly patrolling your body are white cells called **phagocytes**. A phagocyte is a cell that destroys other cells by engulfing and ingesting them. This process is called **phagocytosis**. Two types of blood cells are phagocytes: macrophages and neutrophils.

Macrophages

Monocytes are formed in bone marrow. Monocytes have short life i.e. only 10-20 hours. Macrophages are derived from monocytes or the monocytes that that leave the blood are called **macrophages**. From bone marrow, through blood, macrophages are transported to the areas of the body where they are needed. Macrophage can engulf large particles, even the whole red blood cells, or occasionally even malarial parasites. Macrophages after digesting particles can extrude the residual products. Macrophages are beneath the free surfaces of

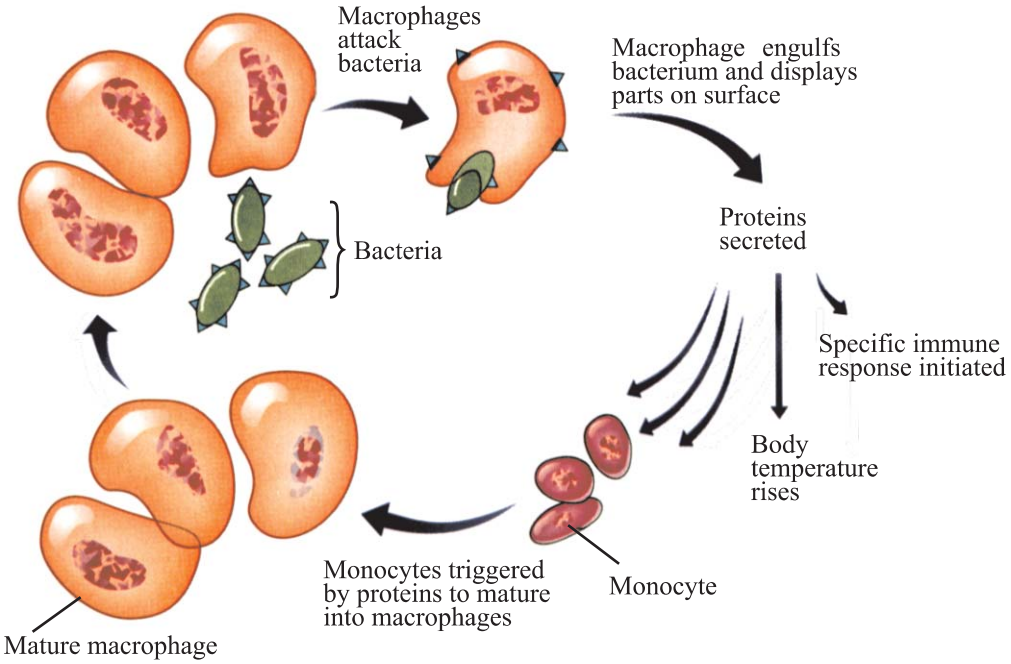


Fig. 13.3 Activation of the Immune Response

the body and provide protection by trapping and destroying microorganisms entering the tissue.

The macrophages secrete many different proteins. Some of these proteins trigger the maturation of monocytes into macrophages, thereby increasing their numbers. Another protein interleucin-1 signals the brain to raise the body temperature, producing fever. The higher temperature aids the immune response and inhibits the growth of invading microorganisms.

Neutrophils

These are a type of granular leukocytes, which are mobile and squeeze between cells of capillary walls. They move like *Amoeba* forming pseudopodia . The life of neutrophils once released from the bone marrow is 4-8 hours circulating in blood and 4-5 days in tissue. In serious infections, life span is shortened to few hours, because they proceed rapidly to infected area to perform their duty and they often die after a single phagocytic event. Neutrophils also release lysosomal enzymes that kill microorganisms and also cause damage and inflammation.

Natural Killer Cells

Natural killer cells are another class of white blood cells. In general, natural killer cells do not directly attack invading microbes. Instead, natural killer cells strike at the body's own cells that have been invaded by viruses. Virus infected cells usually bear some viral proteins on their surfaces. Natural killer cells recognize and kill cancerous cells. Natural killer cells do not eat their victims; they strike from the outside. Their weapons are proteins that they secrete into the plasma membrane of the infected or cancerous cell. Killer cells also secrete enzymes that break up some of the molecules of the target cell, as a result the target cell soon dies.

13.2.2 PROTECTIVE PROTEINS

The **complement system** often simply called complement is a number of plasma proteins. Once a complement protein is activated, it activates another protein, and the result is a set series of reactions. Complement is activated when microbes enter the body. It "complements" certain immune responses and this accounts for its name. For example, it is involved in and amplifies the **inflammatory response** because **complement proteins** attract **phagocytes** to the scene.

Another series of reaction is complete when complement proteins (perforin-1) result in a membrane attack complex that produces **holes** in the bacterial cell walls and plasma membranes of bacteria. When K^+ ions leave,

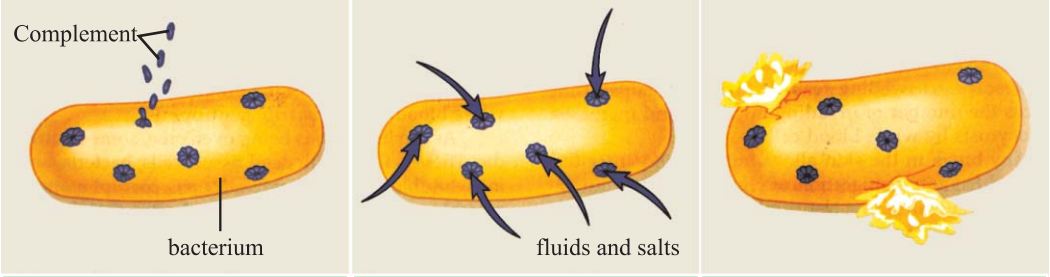


Fig. 13.4 Action of the complement system against a bacterium

fluids and salt enter bacterial cell to the point that it bursts.

How the Interferons Inhibit the Ability of Viruses to Infect Cells?

Cells of immune system secrete a remarkable number of regulatory proteins known as **cytokines**. When infected by viruses, cells respond by secreting cytokines called interferons. Interferons are a heterogeneous group of lipoproteins. They inhibit the growth of viruses by blocking the translation of viral proteins. Because **interferons** are produced within a few hours of the initiation of viral replication, they may act in the early phase of viral diseases to limit the spread of virus.

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 infections microorganism or by physical injury, even just a scratch or an insect bite triggers this response. Inflammation can be localized or systemic. **Local inflammation** is an inflammatory response confined to a specific area of the body.

Inflammation literally means "setting on fire". The fig. 13.5 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 defences. Histamine for instance induces neighbouring blood vessels to dilate and blood vessels start leaking. Blood flood to the damaged area increases, and blood plasma passes out of the leaky vessels into the interstitial fluid of the affected tissues. The major results of the inflammatory response are to disinfect and clean injured tissues. The white blood cells mustered into the

area engulf bacteria and the remains of the body cells killed by them or by the physical injury are left. Many of the white blood cells die in the process. The **pus** that collects around a wound consists largely of microbes, tissue debris,

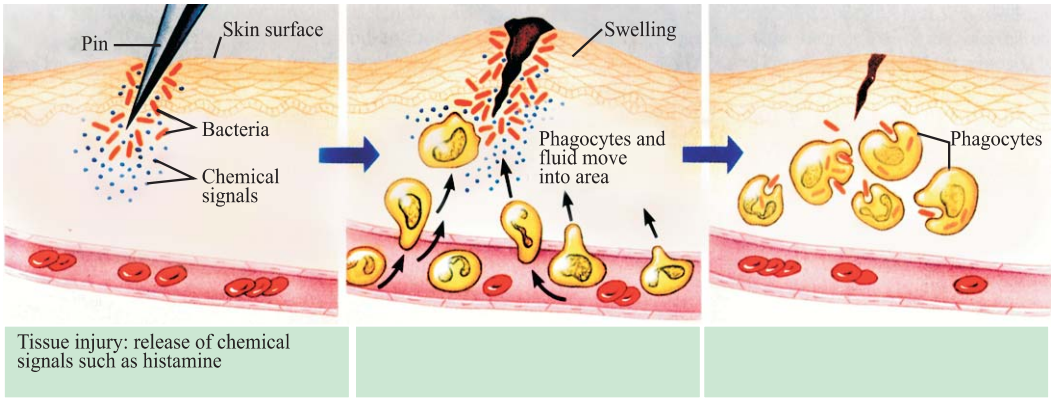


Fig. 13.5 The Inflammatory Response

and living and dead white blood cells. The inflammatory response also helps to prevent the spread of infection to the surrounding tissues.

The body may react with one or several inflammatory weapons for instance the number of white blood cells circulating in the blood may increase. Another response is **fever**.

13.2.4 TEMPERATURE RESPONSE

Fever, which means a body temperature above the usual range of normal, can be caused by abnormalities in the brain itself or by toxic substances that affect the temperature-regulating centers. Some causes of **fever** are bacterial diseases, brain tumors, and environmental conditions that may terminate in heatstroke.

Effect of Pyrogens: Many proteins, breakdown products of proteins, and certain other substances, especially lipopolysaccharide and toxins released from bacterial cell membrances, can cause the set-point of the **hypothalamic thermostat** to rise. Substances that cause this effect are called **pyrogens**. It is pyrogens released from toxic bacteria or pyrogens released from degenerating tissues of the body that cause fever during disease conditions. When the set point of the hypothalamic temperature-regulating center becomes increased to a higher level than normal, all the mechanisms for raising the body temperature are brought into play, including heat conservation and increased heat production. Within a few hours after the set-point has been increased to a higher level, the body temperature also

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.

approaches this level.

The Ways Fever Kills Microbes

Certain white blood cells in responding to the infection, release hormones collectively called **endogenous pyrogens** (self produced fire makers). **Pyrogens** travel in the blood stream and raise the thermostat's set point, triggering behaviours that increase body temperature: shivering increased fat metabolism or feeling cold so more clothing is put on. Pyrogens also cause other cells to reduce the concentration of iron in the blood.

Fever has both beneficial effects for the body's defences and detrimental effects on the invading microbes.1) Many bacteria require more iron to reproduce at temperature of 38^0C or 39^0C than at 37^0C, so fever and reduced iron in the blood combine to slow down their rate of reproduction. (2) Simultaneously, fever increases the activity of phagocytic white blood cells that attack bacteria, they rely producing a shorter and less serious infection. (3) When viruses invade certain cells of the body they synthesize and release a protein called interferon. It travels to other cells and increases their resistance to viral attack. Fever increases the production of inteferons. (4) The higher body temperature may directly inactivate the virus particles,

Skills: Initiating and Planning

- **Justify the inflammatory response in arthritis as an example of a misdirected immune response.**

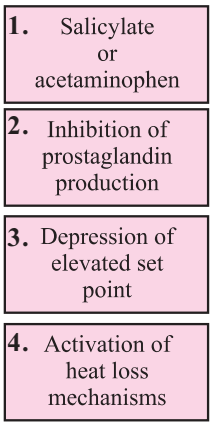
In this disease, autoantibodies are formed against IgG (antibody or immunoglobin of class G). These autoantibodies are called rheumatoid factors. The agent that induces these autoantibodies is unknown. Within the inflamed joints, the synovial membrane is infiltrated with T cells, plasma cells and macrophages and the synovial fluid contains high levels of macrophage- produced inflammatory cytokines.

Skills: Initiating and Planning

- **Justify why the physician prescribe antipyretic drugs, when fever is a nonspecific defense against microbial infections**

Antipyretic Therapy

Antipyretic 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.



Pharmaceutical Intervention in Fever

13.3 THE THIRD LINE OF DEFENCE – The Specific Defences

The third line of defence or specific defence mechanism or immune system recognizes and defends against invading microbes and against cancer cells. Specific defence mechanisms depend on the lymphatic system and its cells. Substances that stimulate specific immunity are antigens (large molecules) and haptens (small molecules). Specific immunity historically has been divided into two types: **Humoral immunity** and **cell-mediated**. Early investigators of the immune system found that, when plasma from an immune animal was injected into the blood of a nonimmune animal, the nonimmune animal became immune. Because the process involved body fluids (humors), it was called **humoral immunity**. 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**.

It was also known that immunity results from the activities of lymphocytes called B and T cells. B cells give rise to cells that produce proteins called **antibodies**, which are found in the plasma. Because antibodies are responsible, **humoral immunity** is now called **antibody mediated immunity**.

Monocytes, T cells and B cells as Components of Immune System

The human blood cells consists of: (a) Polymorphonuclear neutrophils (b) Polymorphonuclear eosinophils (c) Polymorphonuclear basophils(d) Monocytes (e) Lymphocytes

Monocytes

From bone marrow or lymphoid tissues monocytes are transferred (10 to 20 hours transit time) through the capillary into tissues. Once in the tissue they swell and attain a larger size to become tissue **macrophages** and in this form, they can live for months or even for years unless they are destroyed by performing phagocytic function. Macrophages secrete about 100 different compounds including **interferons** and enzymes that destroy bacteria. When macrophages are stimulated by bacteria, they secrete **interleukins**, which activate B cell and helper T cells. Interleukins also promote a general response to injury, causing fever and activating other mechanisms that defend the body against invasion.

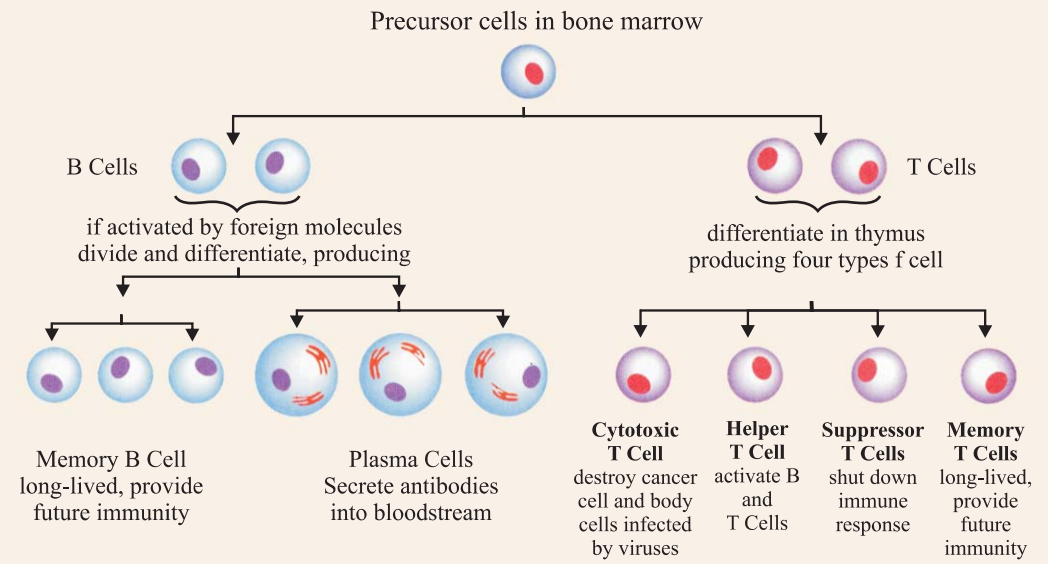


Fig. 13.6 The Major Cells of Immune System and Their Roles in the Immune System

T Cells and B Cells

Immune responses depend on two main groups of white blood cells: phagocytes and lymphocytes. **Phagocytes** include neutrophils and macrophages (monocytes). **Lymphocytes** spend most of their time in tissues and organs of lymphatic system. Three main types of lymphocytes are: T lymphocytes or T cells, B lymphocytes or B cells and natural killer (NK) cells.

T Cells are Responsible for Cellular Immunity

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 'T' in cells stands for *thymus derived*). The thymus

makes T cells immunocompetent that is capable of immunological response. Two main categories of T cells have been identified. The first group, known as **CD8** cells because they have surface marker designated **CD8**, include cytotoxin T cells and suppressor T cells. **Cytotoxic T cells** also known as **killer T cells** recognize and destroy cells with foreign antigens on their surface. Among their target cells are virus-infected cells, cancer cells and foreign tissue grafts. T cells kill their target cells by releasing a variety of cytokines and enzymes. **Suppressor T cells** release **cytokines** that inhibit the activity of other T cells and B cells. **Helper T cells** also known as **CD4** cells because they have a surface marker designated **CD4**. Helper T cells secrete substances that activate or enhance the immune response.

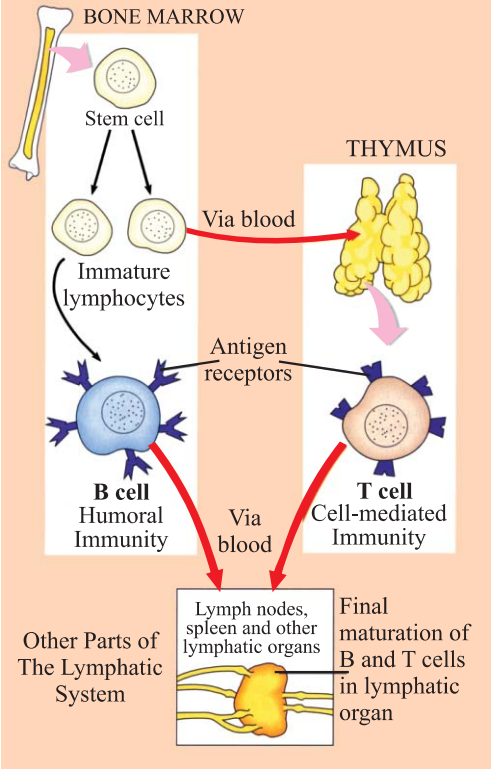


Fig: 13.7 The Development of B cell and T cells

B Cells

B cells are differentiated in bone marrow (hence the name B cells) Each B cells carries receptors needed to bind with a specific type of antigen. After binding with specific type of antigen the B cells develop into **plasma cells**, the cells that are specialized to secrete antibodies. A plasma cell can produce more than 10 million molecules of antibody per hour.

13.3.1 INBORN AND ACQUIRED IMMUNITY

The two basic types of immunity are (a) inborn or innate immunity (b) acquired immunity. If microorganisms breach the first line of defence i.e. skin and mucous membrane then the **innate part** of the immune system is available to destroy the invaders. Because the components of the innate or inborn immunity are fully active, they can function immediately upon entry of the microorganisms. The ability of the innate immune system to kill microorganisms is not specific. 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**.

Table 13.2 Main Component oif Innate and Acquired Immunity

Immunity	Humoral immunity	Cell-mediated immunity
Innate	Complement, neutrophils	Macrophages, natural killer cells
Acquired,	B cells, Plasma cells	Helper T cells, cytotoxic T cells

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: This 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. Because memory cells, produced on exposure to the first infection, are able to stimulate the production of massive quantities of antibody when exposed to the same antigen again, this type of immunity is most effective and generally persists for a long time, sometimes even for life.

Artificial Active Immunity (Vaccination): This is achieved by injecting (or less commonly 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 the antigen. Often a second, booster injection 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.

Critical Thinking

Why do you think it is important that there are phagocytes constantly circulating in the blood stream and in the body tissues?

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

Passive immunity 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

Here 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 for some rhesus.

13.3.2 CELL-MEDIATED AND ANTIBODY MEDIATED IMMUNITY

Cell-Mediated Immune Response

The activation of helper T cells by interleukin-1 and the binding of antigen to these activated helper T cells unleash a chain of events known as the **cell-mediated immune response**. The main event of this response is that **cytotoxic T cells** (cell poisoning cells) also known as natural killer (NK) cells, recognize and destroy infected body cells. When a helper T cell has been activated it produces a variety of chemical substances collectively called **lymphokines**. One type of lymphokine attracts macrophages to the site of infection and another inhibits their migration away from it. Another type of a lymphokine stimulates T cells that are bound to foreign antigens to undergo cell division many times. This cell division produces enormous quantities of T cells capable of recognizing the antigens specific to the invader. Each type

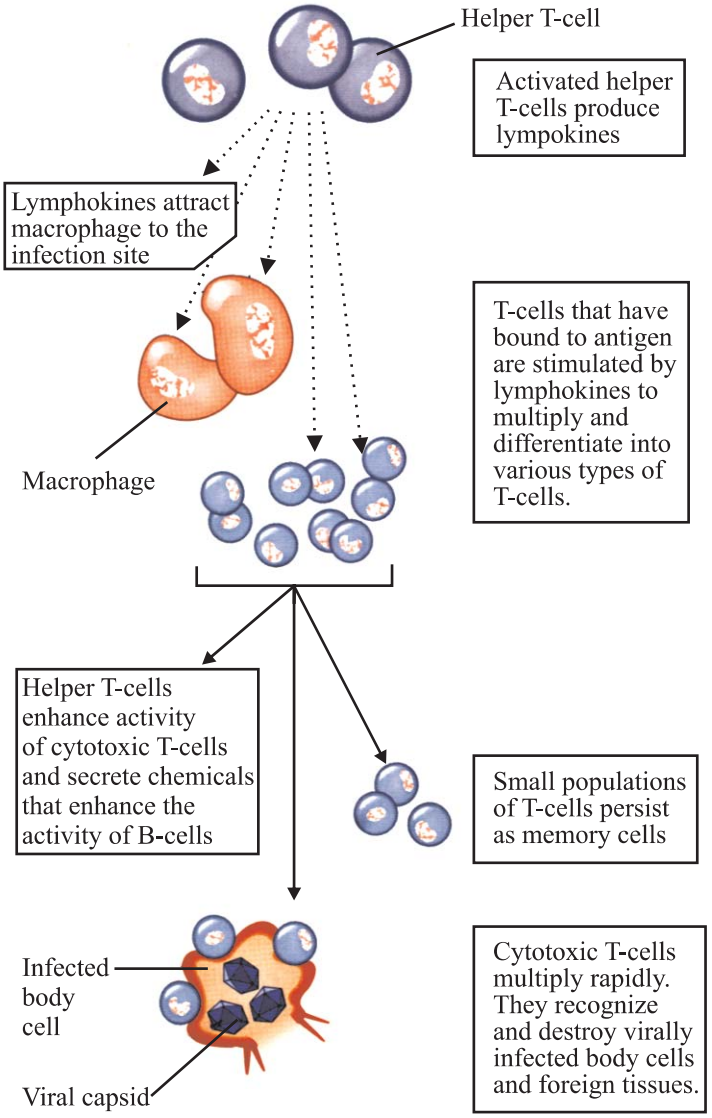


Fig. 13.8 Cell Mediated Immune Response

of activated T cell does have a specific job. Because the entire cell binds to the infected cells (by means of specific cell-surface proteins), this response is called **cell-mediated**.

The Antibody Mediated Immune Response

When helper T cells are stimulated to respond to foreign antigens they activate the cell-mediated immune response and activate a second, more long range defence called the **antibody mediated immune response**. Depending

upon the types of antigen present, the helper T cells may stimulate either or both of the immune response.

The key players in antibody–mediated immunity are the lymphocytes called **B cells** or **B-lymphocytes**. The B cells are named after a digestive organ in birds called Bursa of Fabricus, in which these lymphocytes were first discovered. However, B-cells mature in the bone marrow of the humans. The antibody response is sometimes called the **humoral response**, which refers to the fact that B cells secrete antigen that specific chemicals into the blood stream – one of the body fluids called "**humours**" long ago.

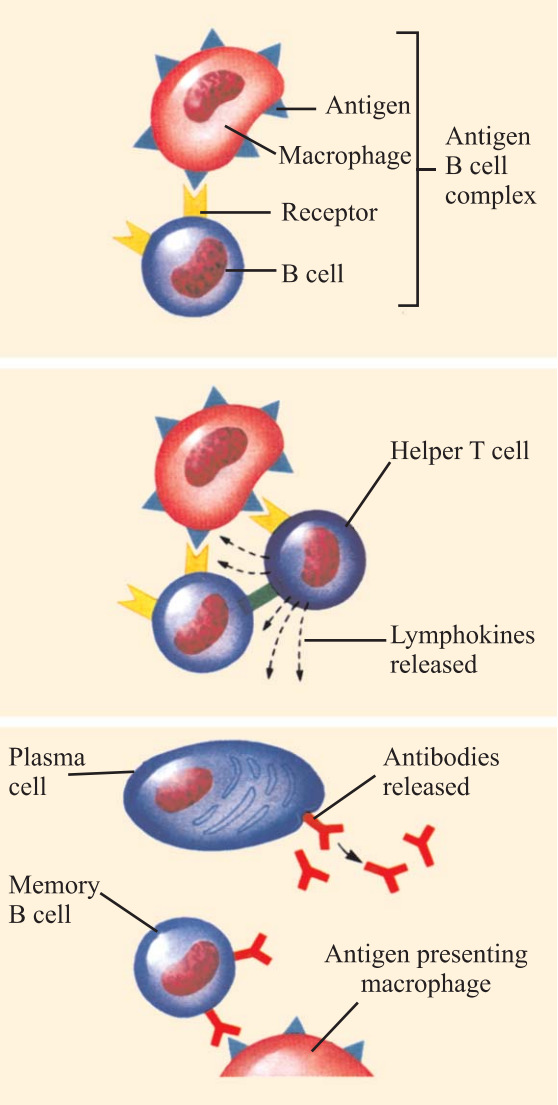


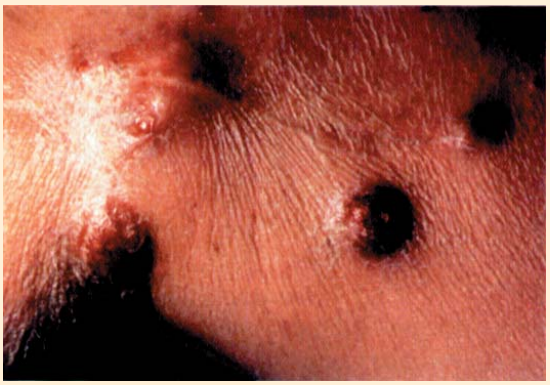
Fig.13.9 Antibody-mediated response

On their surface B cells have about 100,000 copies of a protein receptor that binds to antigens. Because different B cells bear different protein receptors, each recognizes a different, specific antigen. At the onset of a bacterial infection for example, the receptors of one or more B cells bind to bacterial antigens. The B cells may bind to either free bacteria or bacterial antigens displayed by macrophages. These antigen-bound B cells are detected by helper T cells, which then bind to the antigen –B cell complex (fig. 13.9). after binding, the helper T cells release lymphokines that trigger cell division in the B cells. After about 5 days and numerous cell divisions, a large clone of cells is produced from each B cell that was stimulated to divide.

Malignant Melanoma

The presence of tumour infiltrating lymphocytes (TIL) amid the tumour cells in the stroma and overlying epidermis is a constant feature of melanoma, the deadliest skin cancer. These lymphocytes are mostly cytotoxic cells. They can kill melanoma cells. This specific killing can be facilitated by monoclonal antibodies against CD4, CD8, T cells receptors and against class 1 human leukocyte antigens. This indicates that these cytotoxic cells can recognize melanoma cells through the T cells receptors in a human leukocyte antigen class 1. Therefore, these cells and their products are important in killing in melanoma. TILs are not strong enough to control certain types of tumors such as those of malignant melanona.

Gene therapy is the treatment of genetic disorder by the insertion of normal genes into the cells of a patient. In 1991 doctors injected genetically engineered cells into the thigh of a melanoma patient in an attempt to use gene therapy to help his immune system to destroy the cancer. Researchers first remove TIL cells from the patient and inserted a gene that codes for the protein tumor necrosis factor (TNF). This protein kills tumor cells by preventing them from establishing a blood supply. The engineered TIL cells were then returned to the patients bloodstream to seek out and invade the malignant melanoma tumors. As each genetically altered TIL cell finds and enters a tumor, it is able to attack the tumor with the TNF. The engineered TIL cells, in effect, becomes a factory that makes the tumor-killing protein inside the tumor itself.



Malignant Melanoma

Science, Technology and Society Connections

Describe malignant melanoma as due to the inability of tumor-infiltrating lymphocyte (TIL) to control the tumor of skin cancer and correlate it with the scientific advancements of inserting a gene of tumor necrosis factor in the lymphocyte.

Then the B cells begin producing and secreting copies of the receptor proteins that respond to the antigen. These receptor proteins are called **antibodies** or **immunoglobulins**. The secreting B cells are called **plasma cells**. After B cells become plasma cells they live only for a few days but secrete a great deal of antibody during the time. Antibodies do not destroy a virus or bacterium directly, but rather it destruct them by the mechanism of complement or macrophages.

Memory Cells

A person who overcomes a disease often remains immune to future encounter with that specific disease for many years. Retaining immunity is the function of **memory cells**. Plasma cells and cytotoxic T cells do the immediate job of fighting disease organisms, but they usually live only for a few days. **B** and **T memory cells**, on the other hand, may survive for many years. If foreign cells bearing the same antigens re-enter the body, they will be recognized by the appropriate memory cells. These memory cells will multiply rapidly, generate huge populations of plasma cells and cytotoxic T cells, and produce a second immune response. In the first encounter with a disease microbe, only a few B and T cells respond. Each of these however leaves behind hundreds or thousands of memory cells. Further, memory cells respond to antigen much more rapidly than their progenitor B and T cells could. Therefore, the second immune response is very rapid.

Structural Model of an Antibody Molecule

A typical antibody is a Y-shaped molecule in which the two arms of the Y are binding sites. This shape emits the antibody to combine with two antigen molecules, and allow formation of antigen-antibody complexes. The tail of the Y performs functions such as binding to cells or activating the complement system.

The antibody molecule 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, or **C region**, of the heavy chains, the amino acid sequence is constant within a particular immunoglobulin class.

The **C region** may be thought of as the handle portion of a door key. Like the pattern of bumps and notches at the end of a key, the variable segment, or **V region**, has a unique amino acid sequence. In B-cell receptors the variable region of the immunoglobulin protrudes from the B cell, whereas the constant region anchors the molecule to the cell.

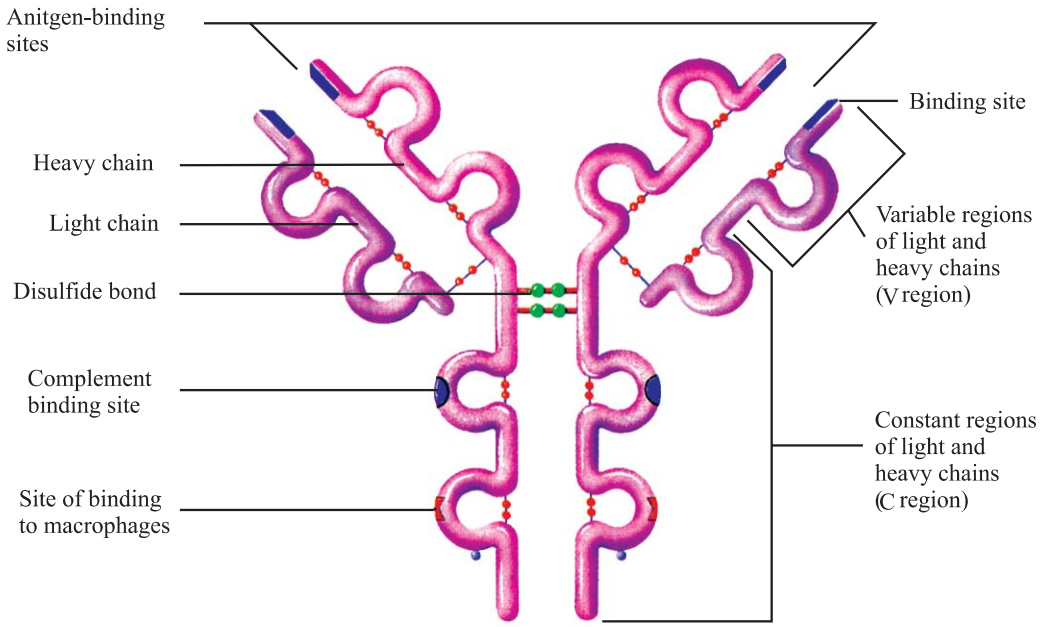


Fig: 13.10 Structure of the Antibody (IgG)

Monoclonal Antibodies

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 gonorrhea, syphilis), hepatitis, rabies, cancer, *Chlamydia*, streptococcal throat infections, herpes viruses, leukaemias (cancers of white blood cells), lymphomas. 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, Technology and Society Connections

Describe the discovery of monoclonal antibodies and justify how this accomplishment revolution many aspects of biological research.

13.3.3 DISORDERS OF IMMUNE SYSTEM

Many people suffer from allergic reactions to substances that are not harmful in themselves and to which many other people do not respond. Common allergies include those to pollen, dust, mold spores, and bee stings.

Allergies are Inappropriately Directed Immure Responses

Allergies are actually a form of immune response. A foreign substance, such as a pollen grain, enters the bloodstream and is recognized as an antigen by a particular type of B cell. This B cell proliferates, producing **plasma cells** that pour out IgE antibodies attach to the plasma membranes of histamine-containing cells located in the respiratory and digestive tracts.

When pollen grains encounter the attached IgE antibodies, they tigger the release of histamine, which causes increased mucus secretion, leaky capillaries, and other symptoms of inflammation. Because pollen grains most often enter the nose and throat, the major reactions occur in these locations, resulting in the runny nose, sneezing, and congestion typical of "heavy fever". Antihistamine drugs block some of the effects of histamine, relieving the symptoms of allergies. Food allergies cause equivalent symptoms, including cramps and diarrhea, in the digestive tract.

An Autoimmune Disease is an Immune Response against Some of the Body's own Molecules

A person's immune system does not normally respond to the antigens borne on the body's own cells. Occasionally, however something goes awry, and "anti-self" antibodies are produced. The result is an autoimmune disease, in which the immune system attacks some component of one's own body. Some types of anemias, for example, are caused by antibodies that destroy a person's red blood cells.

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.

Role of T-cells and B-cells in 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 a tissue **rejection reaction**.

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 T_H cells (helper T cells) come into contact with the graft tissue's major histo compatibilty 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 T_H 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 T_H 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 play a role. The responsive T_H 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 antibodymediated cellular cytotoxicity. The latter is accomplished by K or killer cells.

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.

Functions of B cells and T cells

Antibody-Mediated Immunity (B Cells)	Cell- Mediated Immunity (T Cells)
1. Host defence against infection (opsonize bacteria, neutralize toxins and viruses)	1. Host defence against infection (especially *M tuberculosis*, viruses, and fungi)
2. Allergy, e.g., hay fever	2. Allergy, e.g., poison oak
3. Autoimmunity	3. Graft and tumor rejection
	4. Regulation of anitbody response (help and suppression)

Skills: Initiating and Planning

- **Explain why a transplant recipient is given immune suppressant drugs and determine what implications does this have 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 Titbits

Certain sites in the body are immunologically privileged. A few immunologically privileged locations exist in which foreign tissue is accepted by a host. The brain and corneas are examples. Corneal transplants are highly successful because the cornea has almost no blood or lymphatic vessels associated with it and so is out of reach of most lymphocytes. Furthermore, antigens in the cornea circulatory graft probably would not find their way into the circulatory system, and so would not stimulate an immune response.

Exercise

SECTION I : MULTIPLE CHOICE QUESTIONS

Select the correct answer

1. 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
2. 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
3. Vaccines are
   A) the same as monoclonal antibodies
   B) treated bacteria or viruses or one of their proteins
   C) major histocompatibilty complex (MHC) proteins
   D) not destroyed by heating
4. In addition to the immune system, we are protected from disease by
   A) body temparature B) hormones
   C) antigens D) mucous membrane and cilia
5. Fevers
   A) decrease interferon production
   B) decrease the concentration of iron in the blood
   C) decrease the activity of phagocytes
   D) decrease the reproduction of invading bacteria

6. T and B cells are

A) lymphocytes B) macrophages

C) natural killer cells D) red blood cells

7. Foreign molecules that evoke an immune response are called

A) pathogens B) antibodies

C) lymphocytes D) histamines

8. When B-cells are presented with antigen they differentiate into

A) T-cells B) helper T-cells

C) plasma cells D) bursa cells

9. Memory cells are

A) modified T-cells B) B-cells

C) killer T-cells D) suppressor cells

10. 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

SECTION II : SHORT QUESTIONS

1. List the ways of defence of the human body against invading microbes.
2. Define: immunity, immunology, microbes, monocyte, macrophages, allergy, T cells, B cells, cell mediated immunity, antigen, lymphocytes, antibody mediated immunity, autoimmune diseases, vaccine, vaccination.
3. What is the relationship between the lymphatic and immune system.
4. Write the level of defence against infection.
5. Name the parts of antibody molecule.
6. What are the memory cells?
7. How does an antibody differ from an antigen?
8. Name the disorders of immune system.
9. What is the difference between an antibody-mediated immune response and a cell-mediated immune response?

10. Why is passive immunity temporary?
11. List the benefits of fever.

SECTION III : EXTENSIVE QUESTIONS

1. Name the specific and non-specific line of defence of the human body against microbes. Explain your answer.
2. How do natural killer cells and cytotoxic T cells destroy their targets?
3. Describe humoral immunity and cell-mediated immunity.
4. How do immune system construct so many antibodies?
5. Draw and label the structure of an antibody. What parts bind only to antigens? Why does each antibody bind only to a specific antigen?
6. How do memory cells contribute to long lasting immunity to specific diseases?
7. How does vaccine confer immunity to a disease?
9. Explain the process by which a T cell is able to recognise an antigen.
10. How are active immunity and passive immunity achieved?

ANSWER MCQS

1. C 2. A 3. B 4. D 5. B 6. A 7. B 8. C 9. B 10. B

SUPPLEMENTARY READING MATERIAL

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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.

anaphyylaxia: It is an acute system (multi-system) and severe type I hypersensitivity allergic reaction in humans and other mammals. Minute amount of allergens may cause a life-threatening **anaphylactic reaction**. Anaphylaxis may occur after ingestion, skin contact, and injection of an allergen or in some cases inhalation.

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-kI): 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.

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: this asteroid larva develops from the bipinnaria larva.

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.

C_4 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 C_3 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 consideration 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.
DNA sequencing: procedure by which the sequence of nucleotides in DNA is determined.
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.

estrogens (es'troh-jens): female sex hormones produced by the ovary; promote the development and maintenance of female reproductive structures and of secondary sexual characteristics.

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.

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. Fibers 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.

f in it cells are rapidly frozen and then fractured with a sharp metal blade. The technique allows membranes to be split and the surfaces inside to be examined

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.

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.

hermaphordite (her-maf'roh-dite): an organism that possesses both male and female sex organs.

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.

heterospory (het" ur-os'pur-ee): production of two types of n spores, microspores (male) and megaspores (female).

hexose: a monosaccharides containing six carbon atoms.

histones (his"tones): small, positively charged (basic) proteins in the cell nucleus that bind to the negatively charged DNA.

homeostasis: maintenance of normal internal conditions in a cell or an organism by means of a self regulation mechanism.

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.
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

karatconjunctivitis: corneal ulcers 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.

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.
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 proteion; transcribed from DNA.

metabolism: the sum of all the chemical processes that occur within a cell or organism; the transformations by which energy and matter are made available for use by the organism.

metamerism: condition in which the body is divided into a series of similar segments; characteristic of annelids and arthropods.

metamorphosis (met"ah-mor'fuh-sis): transition from one developmental stage to another, such as from a larva to an adult.

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.)

mutation: any change in DNA; may include a change in the nucleotide base pairs of a gene, a rearrangement of genes, within the chromosomes so that their interactions produce different effects, or a change in the chromosomes themselves.

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.

myocardial infarction (**MI**): heart attack; serious consequence occurring when the heart muscle receives insufficient oxyegen.

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.

nasal turbulence mechanism: The removal of particles by turbulent precipitation i.e. the air passing through the nasal passageway hits many obstructing vanes: the chonchae, also (called 'turbinates' because they cause turbulence of the air) the septum and the pharyngeal wall. Each time air hits one of these obstructions, it must change its direction of movement, the particles suspended in the air, having more mass and momentum than air, cannot change their direction of travel as rapidly as can the air. Therefore they continue forward, striking the surfaces of constructions, and are entrapped in mucous coating and transported by cilia to the pharynx to be swallowed.

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.

neurotoxicity: It occurs when the exposure to natural or artificial toxic substance, which are called neurotoxin, alters the normal activity of the nervous system in such a way as to cause damage to nervous tissue.

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

organic compound: a compound composed of a backbone made up of carbon atoms.

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.

ovule (ov'yool): the structure (i.e., megasporangium) in the ovary that develops into the seed following fertilization.

ovum (pl. ova): female gamete of an animal.

oxidation: the loss of one or more electrons by an atom, ion, or molecule.

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 ll, 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.

pH: the negative logarithm of the hydrogen ion concentration of a solution (expressed as moles per liter). Neutral pH is 7; values less than 7 are acidic, and those greater than 7 are basic.

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).

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.

plasma cell: cell that secretes antibodies;

differentiated B lymphocyte.

plasmids (plaz'midz): small circular DNA molecules that carry genes separate from the main bacterial 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.

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).

renin: an enzyme found in gastric juice which cause coagulation.

rennin: 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.

reproduction: process by which new individuals are produced.

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.

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.
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.
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
cytoplasm; may function in storage, digestion, or water elimination.
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: unique hydraulic system of echinoderms; functions in locomotion and feeding.
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.

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.

INDEX

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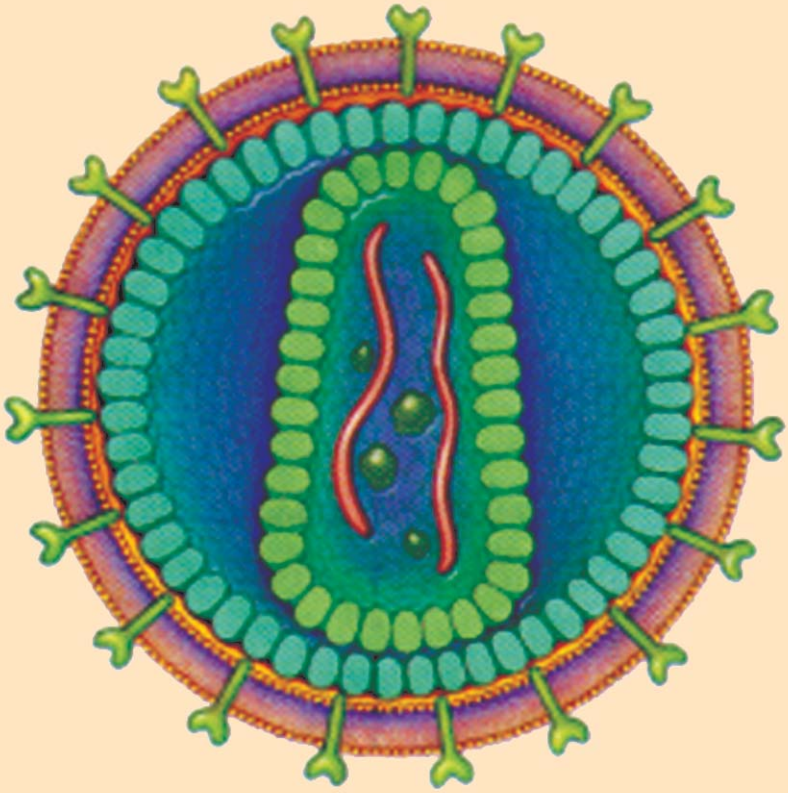

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