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.

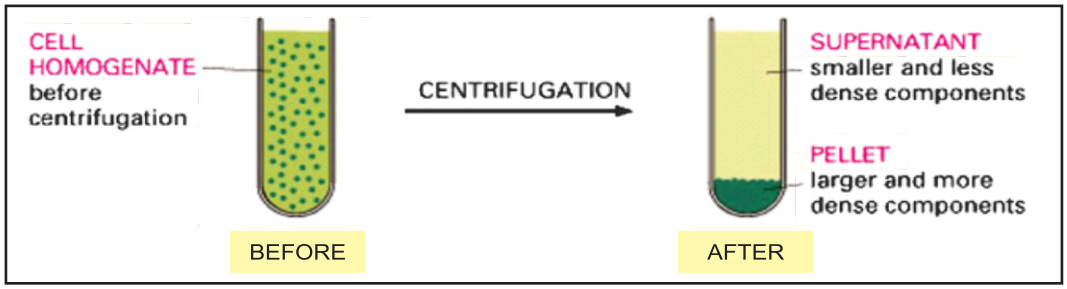

Fig 1.1: Centrifugation of cells

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.

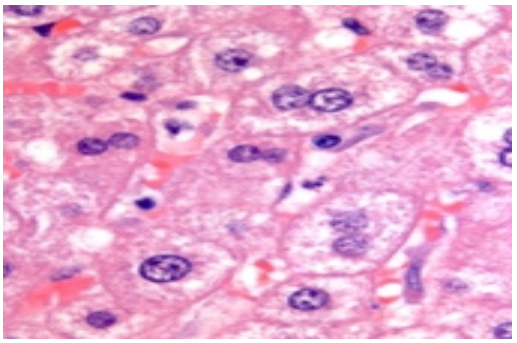

Fig. 1.2: Differential staining

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.

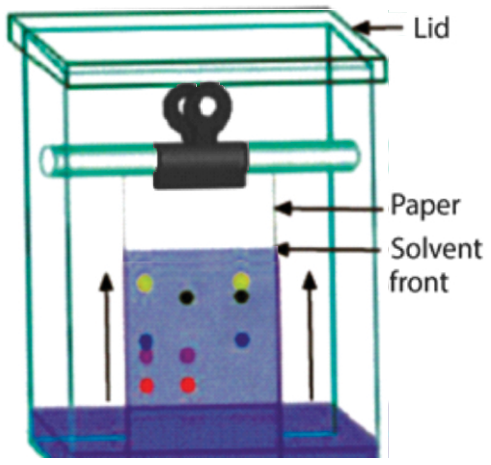

Fig. 1.3: Chromatography chamber

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.

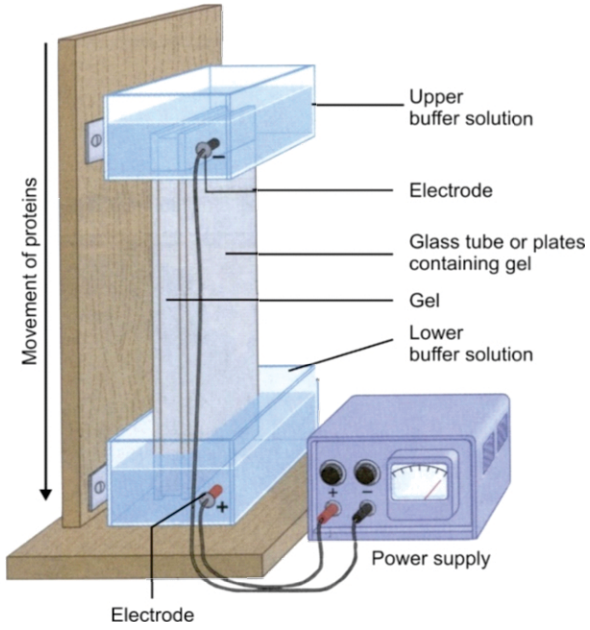

Fig. 1.4: Gel electrophoresis

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

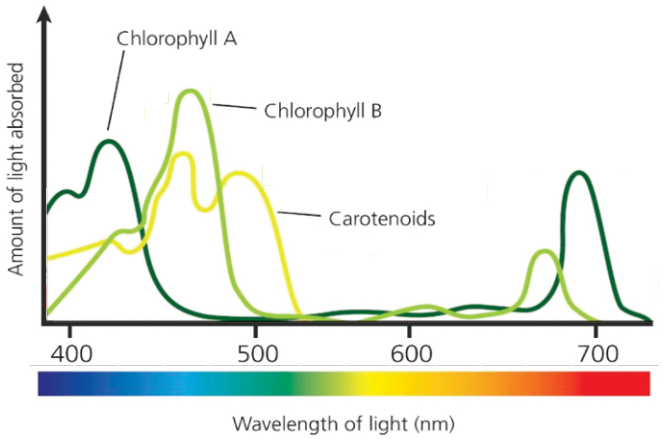

Fig. 1.6: Absorption spectrum

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.

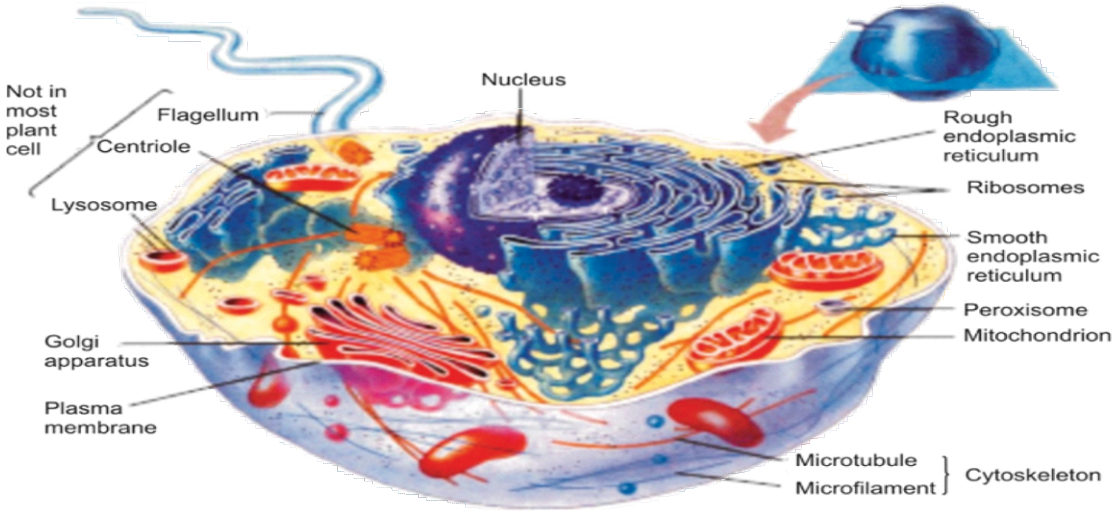

Fig. 1.7: Electron microscopic structure of an animal cell

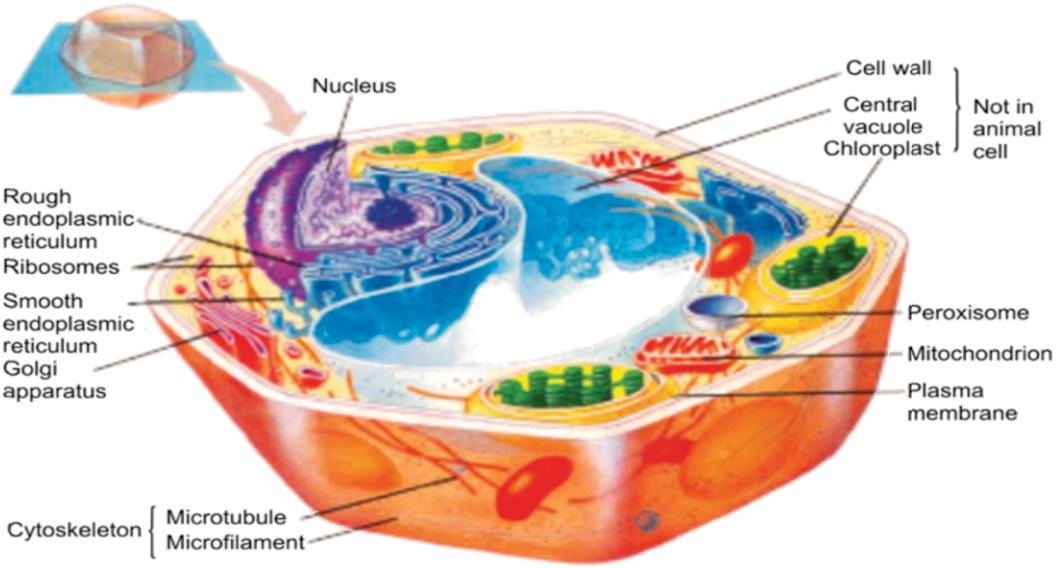

Fig. 1.8: Electron microscopic structure of a plant cell

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.

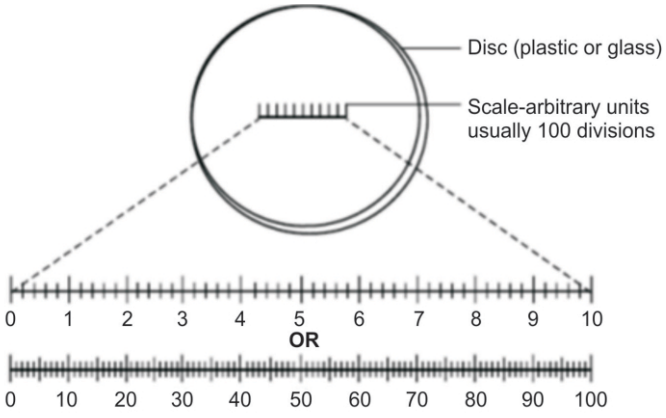

Fig. 1.9: Ocular micrometre

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.

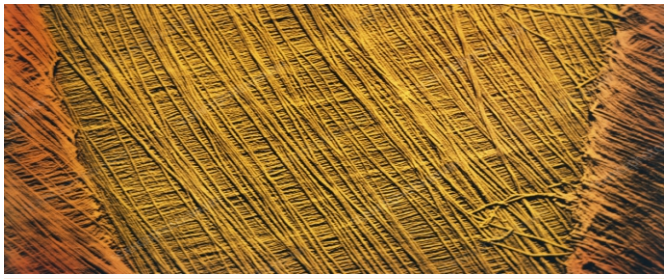

Fig. 1.10 : Crisscross arrangement of cellulose

> **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.

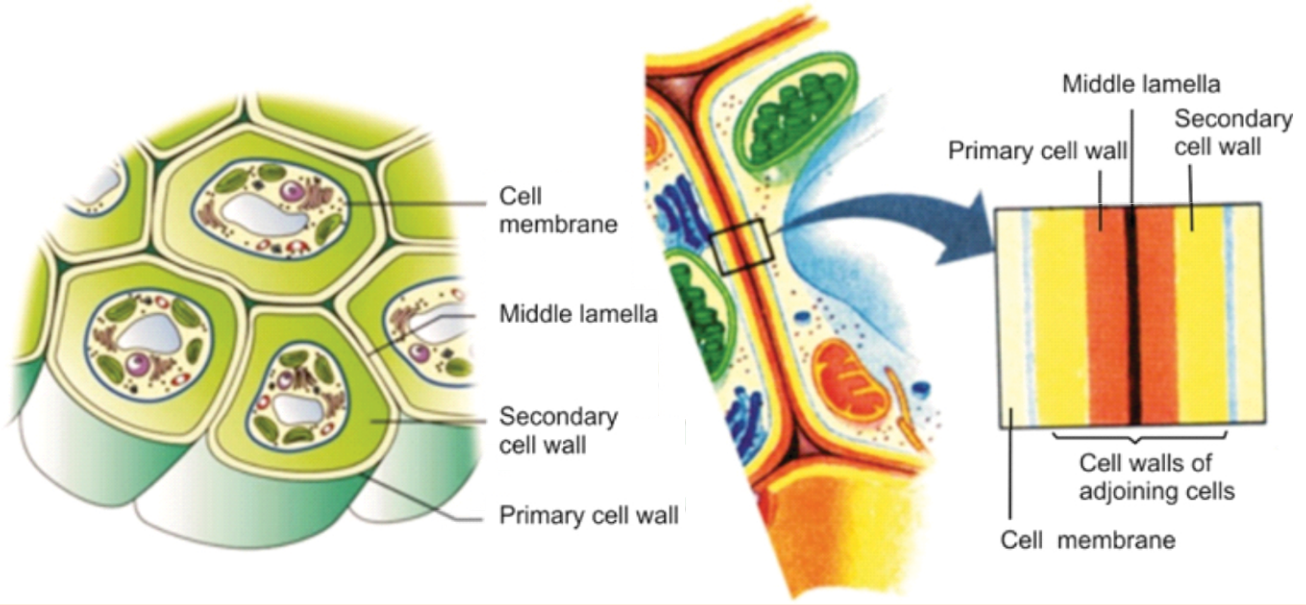

Fig. 1.11: Plant cell wall

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.

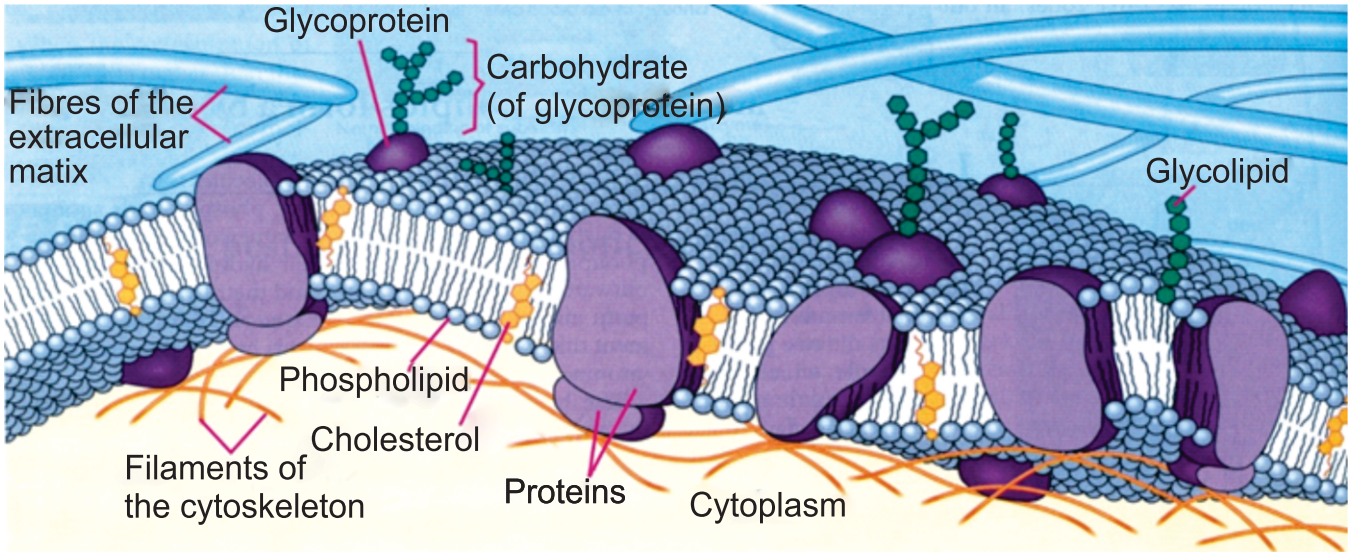

Fig. 1.12: Fluid mosaic model of plasma membrane

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**.

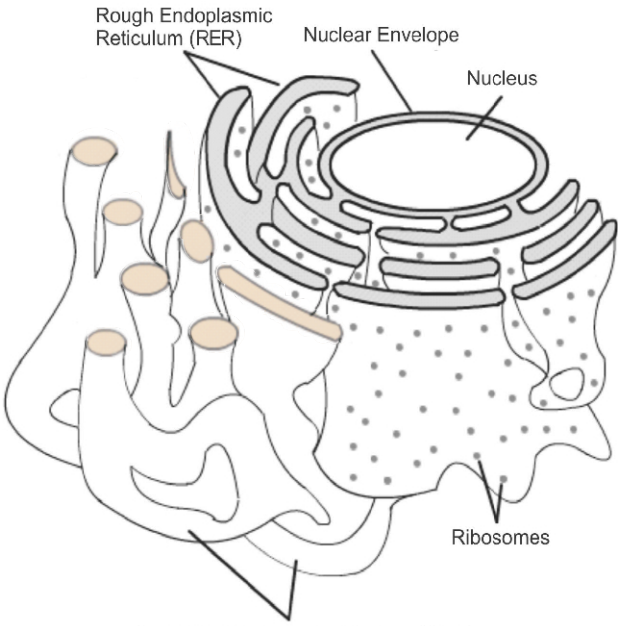

Fig.1.13: Endoplasmic reticulum

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.

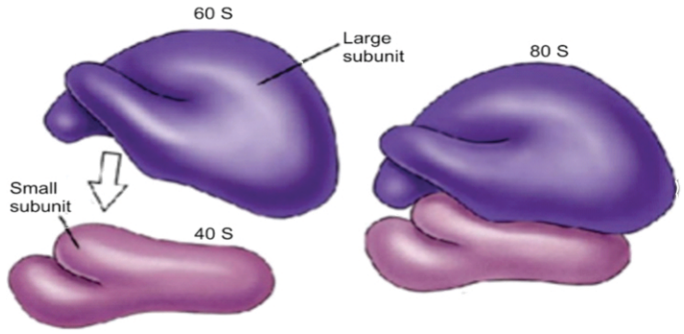

Fig.1.14: Eukaryotic 80S ribosome

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.

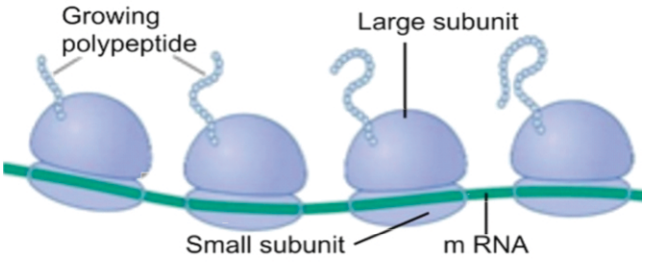

Fig.1.15: Polysome

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.

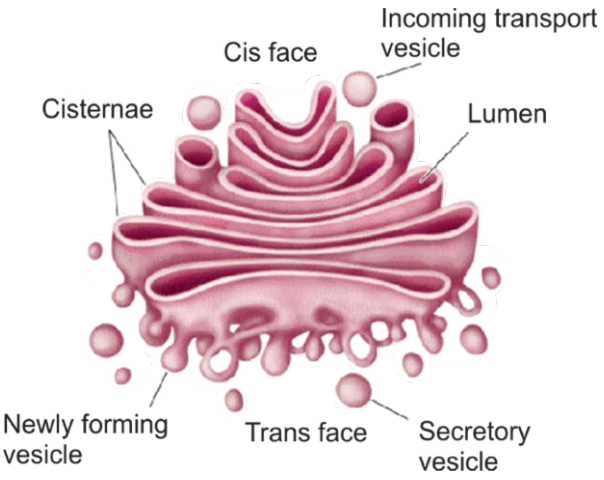

Fig. 1.16: Golgi complex

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.

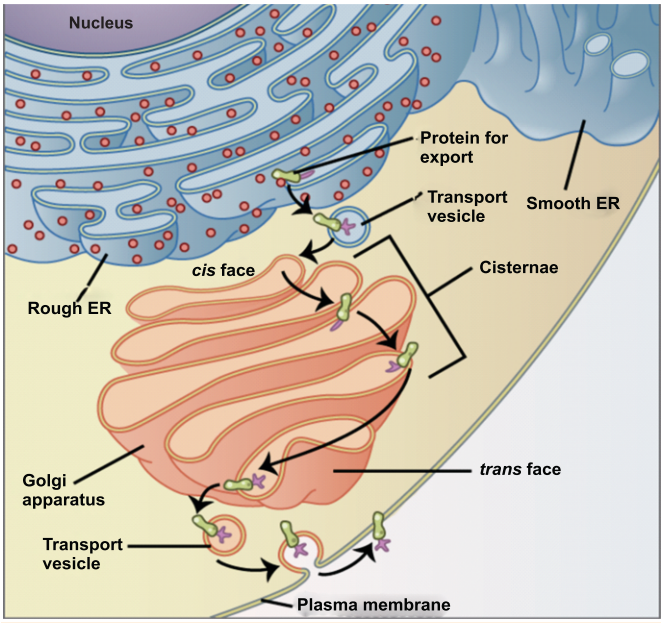

Fig. 1.17: Role of Golgi complex in a glandular cell

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.

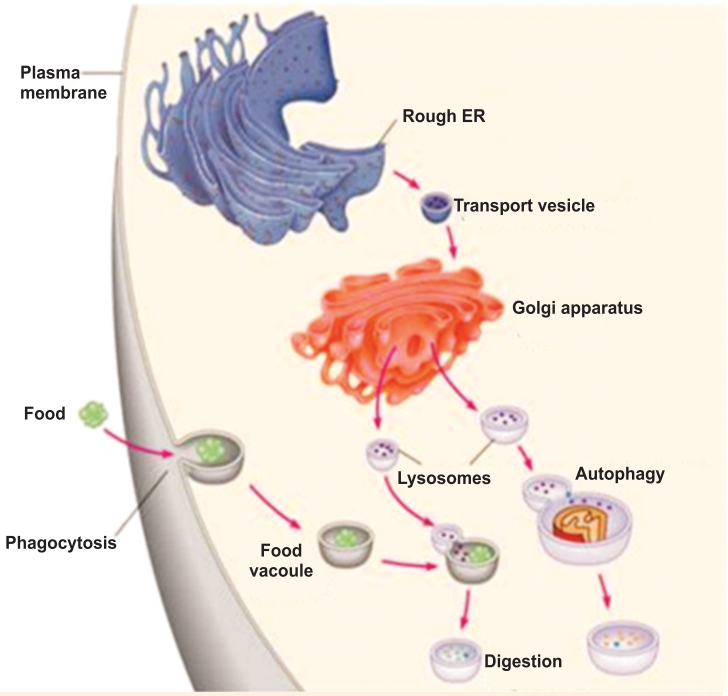

Fig. 1.18: Formation and functions of Lysosomes

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.**

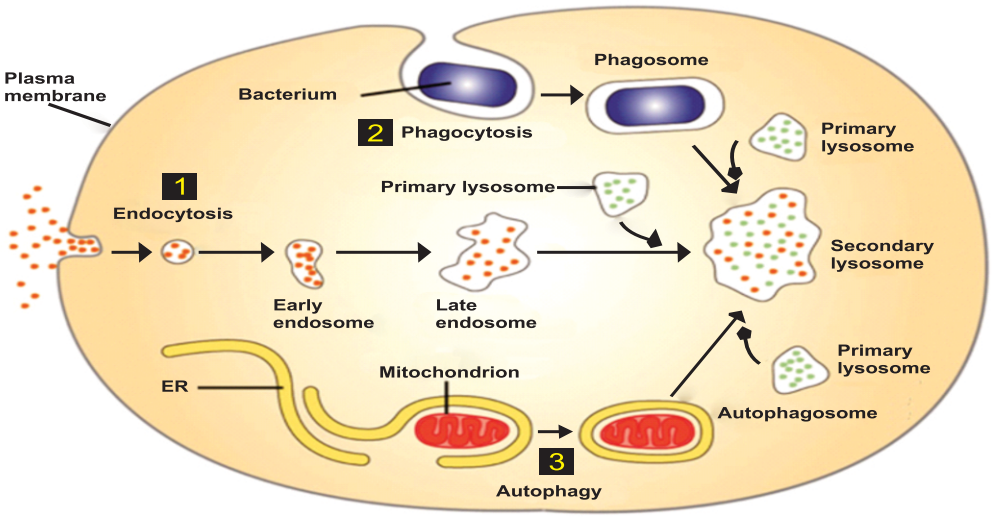

Fig. 1.19: Functions of Lysosomes

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.

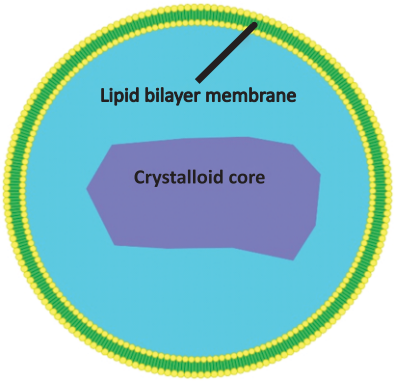

Fig. 1.20: Peroxisomes

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.

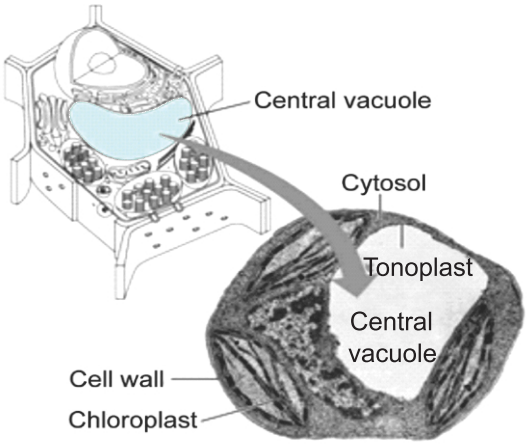

Fig. 1.21: Vacuole of a mature plant cell

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.

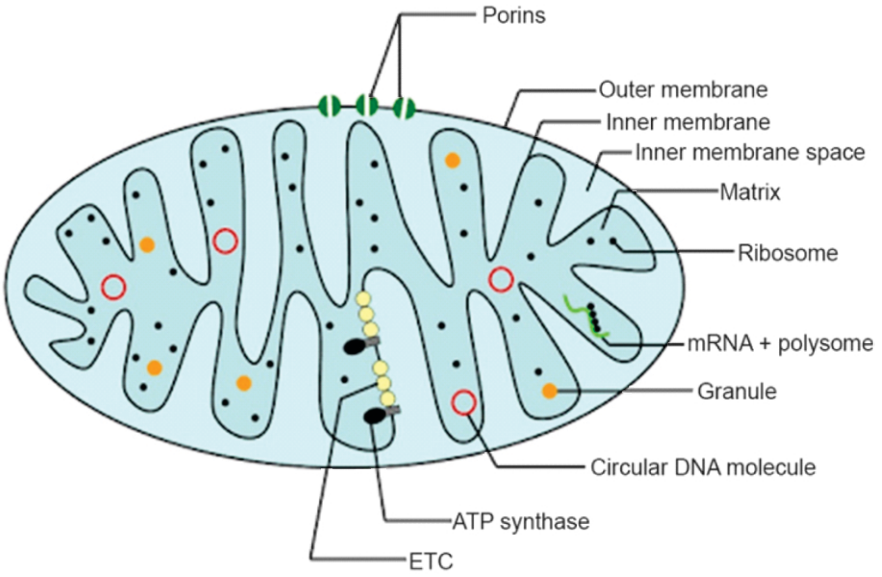

Fig. 1.22: Mitochondrion structure

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.

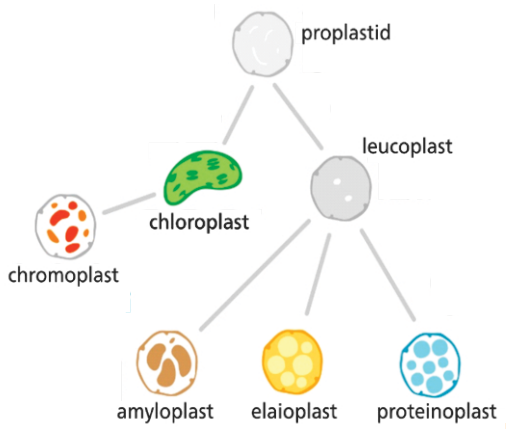

Fig. 1.23: Types of plastids

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.

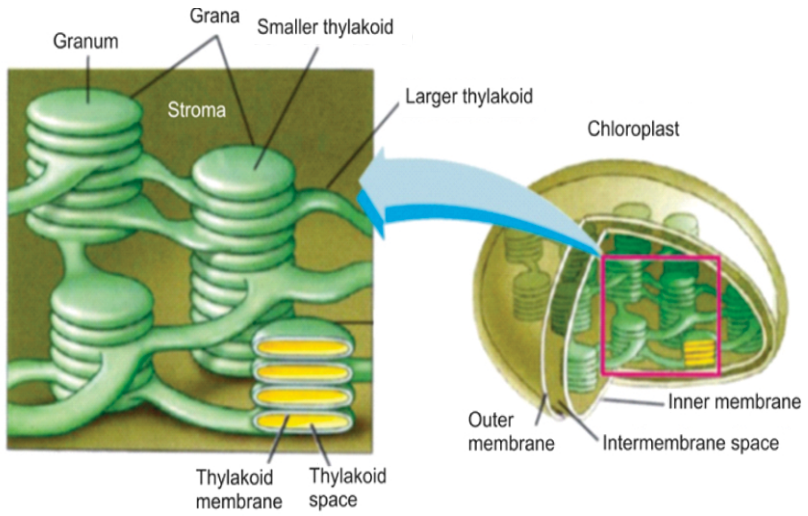

Fig. 1.24: Chloroplast

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.

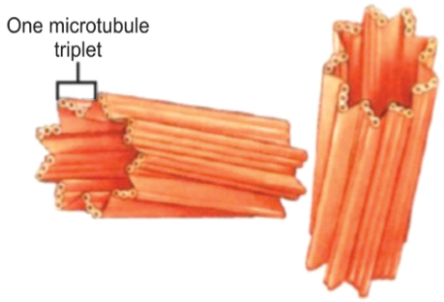

Fig. 1.25: Centrioles

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.

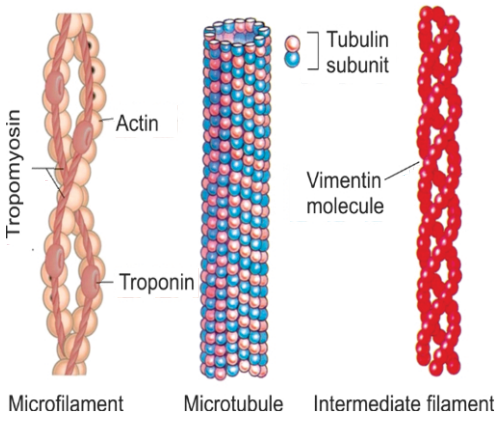

Fig. 1.26: Three types of cytoskeleton

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).

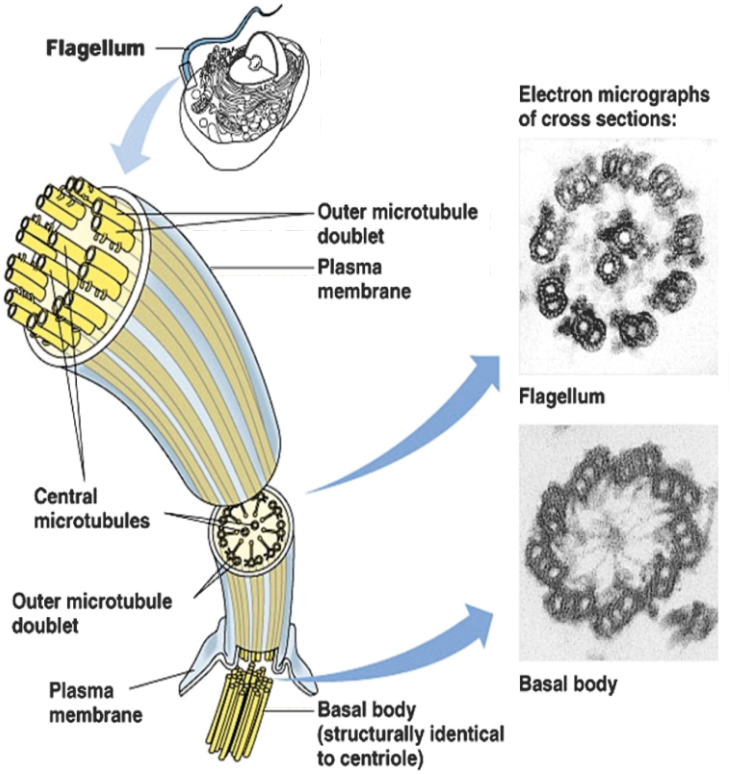

Fig. 1.27: Structure of a eukaryotic flagellum or cilium

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.

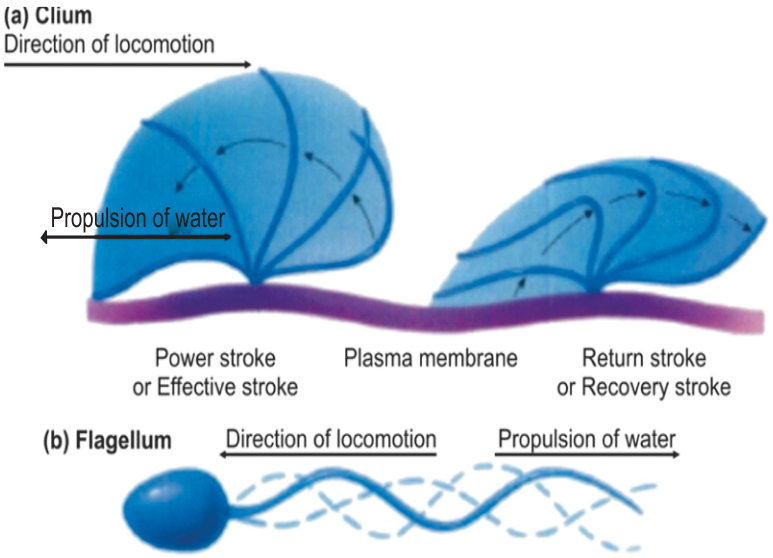

Fig. 1.28: Movement of cilia and flagella

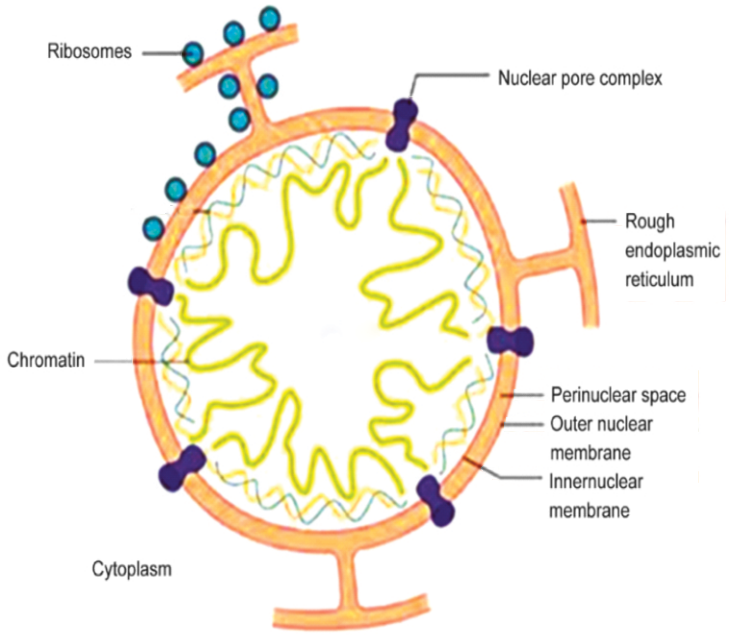

Fig. 1.29: Nucleus

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.

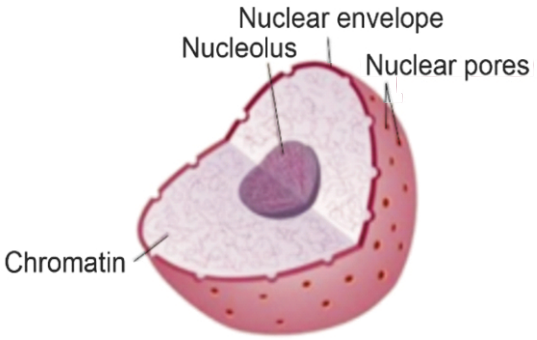

Fig. 1.30: Nucleolus

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.

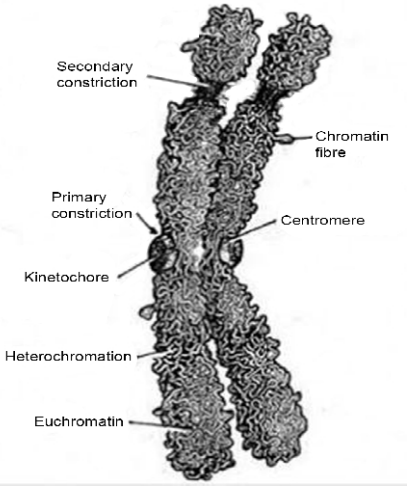

Fig. 1.31: A pair of chromosome

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?