UNIT 1 CELL STRUCTURE AND FUNCTION

Structure

1.1 INTRODUCTION

All organisms, whether simple or complex, plants or animals, are composed of cells. For example, a bacterium or an amoeba is made up of just one cell, while a complex organism like an adult human is composed of hundreds of billions of cells (over 10^{14} cells). The sum total of the properties of cells in an organism is represented by its appearance, behaviour, activities and functions. It becomes thus, important to study cells for understanding all forms of life. In this unit, you shall learn about the structure of a cell. We shall also describe the function of various components which are present within a cell. However, our aim in describing a cell and its organisation in this course is to introduce you to various biomolecules like carbohydrates, lipids, nucleic acids, proteins, enzymes and vitamins, which we shall describe in the units to follow. Some of these biomolecules, also known as compounds of life, form part of the structure of cell, and some of these are sources of energy for the cell. A few of them also store energy for the cell and take part in the cellular reactions. The cell is able to synthesise other molecules, needed by the living system, from these compounds. Therefore, the study of the organisation of cells will help us to understand the biological importance of these molecules.

Objectives

After studying this unit you should be able to:

- describe the biochemical composition of a living organism,
- distinguish between the major types of cells,
- explain the structural organisation of cells,

- label the intracellular organelles, and
- describe the functions of various organelles of a cell.

1.2 THE CELL - AN OVERVIEW

The present day study of cells combines many scientific disciplines, like biochemistry, biophysics, genetics, microscopy and physiology. A great deal has been understood about cells, especially in the last 35 years, regarding how they are constructed, how they function, and how they work together in complex organisms. Still, much remains to be learned. The term 'cell' was first used by Robert Hooke in 1664 to denote the little box-like structures, which he observed in cork tissue under a primitive microscope. A contemporary of Hooke, Antonie van Leeuwenhoek, discovered sperm cells, red blood cells and a variety of microorganisms, again using a microscope consisting of a single lens. However, these initial observations led to nearly two centuries of microscopic study of cells, and, with the gradual introduction of more and more powerful microscopes, the cell nucleus was also discovered. Thus, the cellular nature of all plants and animals came to be recognised. By 1830's, it was proposed that all organisms are constructed of cells. This statement is now known as the cell doctrine or cell theory, about which you shall study in Section 1.3.

Consequent to this doctrine, biologists established that new cells are formed by cell division and by the end of the nineteenth century, the hereditary material in cells, the chromosomes, were recognised. As the biochemical, physiological and genetic properties of cells were studied, it was established that in both unicellular and multicellular organisms, it is the fundamental structural unit, which stores the genetic material and the biochemical organisation, that accounts for the existence of life. It is naturally essential for a person to know about cells so that one is able to understand a wide variety of issues like health, drugs, illness, medical treatment, reproduction, environmental problems, evolution and life in general.

We shall first outline the biochemical composition of a cell and then describe the types of cells in the next section.

1.2.1 Biochemical Composition

As life evolved on this planet, nature selected only a few elements, and life eventually came to be based essentially on carbon compounds. Out of the nearly 50 or so elements present in most living organisms, six elements, namely, oxygen, carbon, hydrogen, nitrogen, calcium and phosphorus, constitute nearly 99 per cent by weight of a living organism. One of the reasons for nature's selection of carbon in all life forms, could be that carbon forms a wide range of complex organic compounds. Potassium, sodium, chlorine and magnesium account for nearly 0.8%, and the other elements are present in very small amounts (0.2%), and are called trace elements. The distribution of elements in a living organism is given in Table 1.1. There is a remarkable similarity in the nature of the chemical substances that are present in all living organisms. Water constitutes nearly 60-80% of the weight of the living organisms, and is rightly called the "solvent of life", as it is the principal medium in which all cellular reactions occur. The rest, i.e., the dry weight of the cells, comprises proteins, lipids, nucleic acids and carbohydrates. You will study in other units of this block, more details about these essential biomolecules. Table 1.2 gives you the average chemical composition of a cell.

Table 1.1: Elemental composition of living organisms

Elements	% by weight
Oxygen	65
Carbon	18
Hydrogen	10
Nitrogen	3
Calcium	1.5
Phosphorus	1.0
Sulphur	0.25
Potassium	0.20
Sodium	0.15
Chlorine	0.15
Magnesium	0.05
Fe, Zn, Cu, Mn, etc.	Trace amounts

Table 1.2: Chemical composition of a cell

	% of Dry weight
Protein	71
Lipid	12
Nucleic acid	7
Carbohydrate	5
Inorganic minerals and other materials	5

Before studying more about cells, attempt the following SAQ.

SAQ 1

Tick [√] mark the following statements as true or false.

a) Potassium and sodium are trace elements present in the cell. [True/False]

b) Proteins are the major constituents of a cell. [True/False]

c) All organisms are constructed of cells. [True/False]

d) Cellular reactions in a cell cannot occur in an aqueous medium. [True/False]

1.3 THE ARCHITECTURE OF CELL

All living organisms are composed of cells, and they are the basic structural and functional units of life, just like the atom is a fundamental unit in all chemical structures. This concept forms the basis for the **"cell theory"** proposed by M.J. Schleiden and T. Schwann in 1838-39. They concluded that all plants and animals are composed of individual cells. The same concept is also applicable to microorganisms. Some organisms, e.g., the bacteria and protozoa are unicellular, while others are multicellular organisms, like fungi, plants and animals. Fungi are composed of individual cells of similar structure, while plants and animals are made up of different types of cells. Cells in all living organisms, whether unicellular or multicellular, show several common structural features, and many events in them are carried out in a similar fashion. Let us first classify cell types on the basis of some major properties and then describe the common structural features present in different cells.

Based on the degree of complexity of the cell organisation, two types of cells, namely, **prokaryotes** and **eukaryotes**, are recognised. The prokaryotic cell has a much simpler internal organisation, has no true nucleus, and its genetic material, the DNA is naked, that is, it is not enclosed by a nuclear envelope. The cells of prokaryotes also do not possess any internal membrane bound organelles. The bacteria and blue green algae represent typical prokaryotic cells.

'Karyon' is a word meaning nucleus. The word 'prokaryote' (before a nucleus), therefore, designates cells that do not have a structurally delineated unit containing the genetic material (a nucleus). 'Eu' means true, hence, the word 'eukaryote' (true nucleus) designates cells that have a well defined nucleus whose chromosomal material is separated from the remainder of the cell contents (the cytoplasm) by a nuclear membrane.

The eukaryotic cells, on the other hand, have a true nucleus wherein the genetic material, DNA is enclosed within a well defined nuclear membrane and has a complex internal structure with distinct membrane enclosed organelles. The protozoa, algae, plants and animals are all eukaryotes. A comparison of the cell organisation in prokaryotes and eukaryotes is shown in Table 1.3.

Table 1.3: Comparison of cell organisation in prokaryotic and eukaryotic organisms

	Prokaryotes	Eukaryotes
Organisms	Bacteria, blue green algae	Protozoa, algae, plants and animals
Cell size	1-10 μm in diameter	10-100 μm in diameter
Metabolism	Anaerobic or aerobic	Aerobic
Organelles	Few or none	Nucleus, mitochondria, chloroplasts, lysosomes etc.
Nucleus	Absent. The genetic material consists of circular DNA without any nuclear membrane	A well-circular DNA without any nuclear membrane is present and the DNA is organised into chromosomes.
Nucleolus	Absent	Present
Cell division	Amitosis (binary fission)	Mitosis or meosis
Mitochondria	Absent. Respiratory and photosynthetic enzymes are present in the plasma	Present
Chloroplasts	Absent	Present in plant cells only
Cytoplasm	Cytoplasm has no cytoskeleton	Well-defined cytoskeleton, comprising of protein filaments, is present.

It is obvious that there are a number of differences between them. Prokaryotes, like bacterial cells are generally much smaller, less than 1μm in diameter, and are thus not visible to the naked eye. Eukaryotes, like plant and animal cells, however, are at least 10 times bigger than the bacterial cells. Also their sizes and shapes vary considerably. The approximate size and shapes of a few types of prokaryotic and eukaryotic cells are shown in Table 1.4 and Fig.1.1.

$1\mu m = 10^{-6} m$

Table 1.4: Approxiamte dimensions of biomolecules and cell components

	Dimensions (length) nm ($1 nm = 10^{-} m$)
Alanine	0.5
Glucose	0.7
Phospholipids	3.5
Haemoglobin	6.8
Myosin	160
Bacteriophage OX 174	25
Tobacco mosaic virus	300
E.coli cell	2,000
Ribosomes in *E.coli*	18
Liver cell	20,000
Mitochondria (liver cell)	1,500
Chloroplast (leaf cell)	8,000

There are over 200 types of cells in the human body, which are assembled into a variety of tissues, such as, the epithelia, connective tissues, muscle, nervous tissue, blood, germ cells, sensory cells and many more. Prokaryotic cells, being simpler in structure are important in biochemical studies, as they can be easily grown in a laboratory in very large numbers in a relatively short span of time. This is because they multiply by simple mechanisms of reproduction. The *Escherichia coli* (*E.coli*) bacterium, for instance, can divide every 20-30 minutes, and thus it happens to be the most widely studied prokaryotic cell.

The differences of cell types notwithstanding, the similarities among them are more profound. Actually, all cells possess the same basic properties, some of which are outlined below:

- All cells store information in genes.
- Ribosomes synthesise proteins in all cells.
- Proteins control the structure and function in all cells.

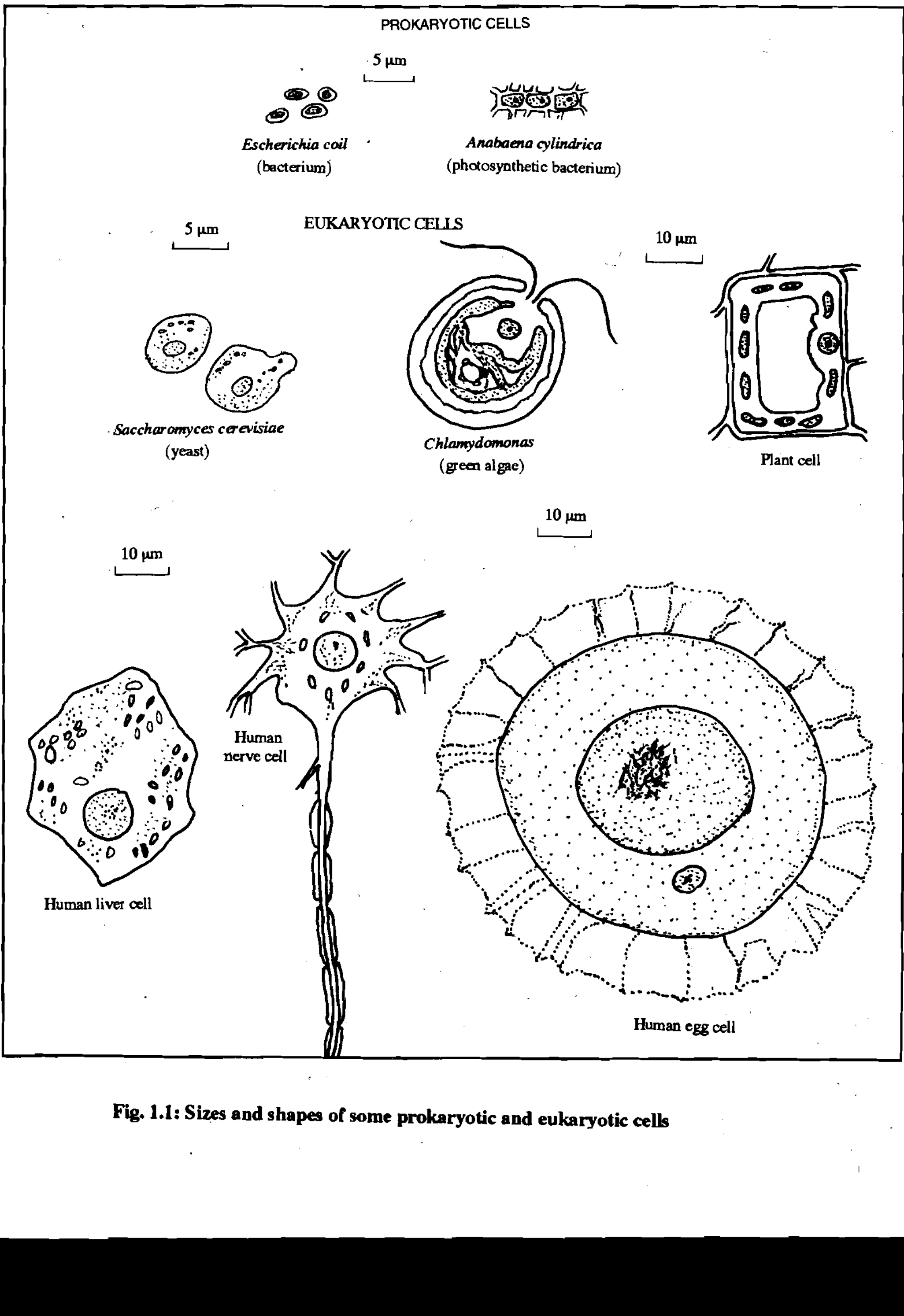


Fig. 1.1: Sizes and shapes of some prokaryotic and eukaryotic cells

- ATP is the molecule used by all cells to transfer energy.
- Plasma membrane is a common feature in all cells.

It is thus possible, due to these similarities, to generalise about the structures and functions of cells. In the following sections, we shall describe the structural features of the eukaryotic and prokaryotic cells.

1.4 THE PROKARYOTIC CELL

While we describe in detail the structure of a eukaryotic cell, it will be useful to examine the structural features of a typical prokaryotic cell as well. *Escherichia coli* is an organism found in the intestinal tract of all human beings, and represents a typical prokaryotic organism, which has been intensively investigated. An *E.coli* cell is about 2μm long and 1 μm in diameter (Fig.1.2). Its cell wall is made of a rigid framework called the **peptidoglycan**, consisting of polysaccharide chains crosslinked by peptide units. The partial structure of a peptidoglycan is shown in

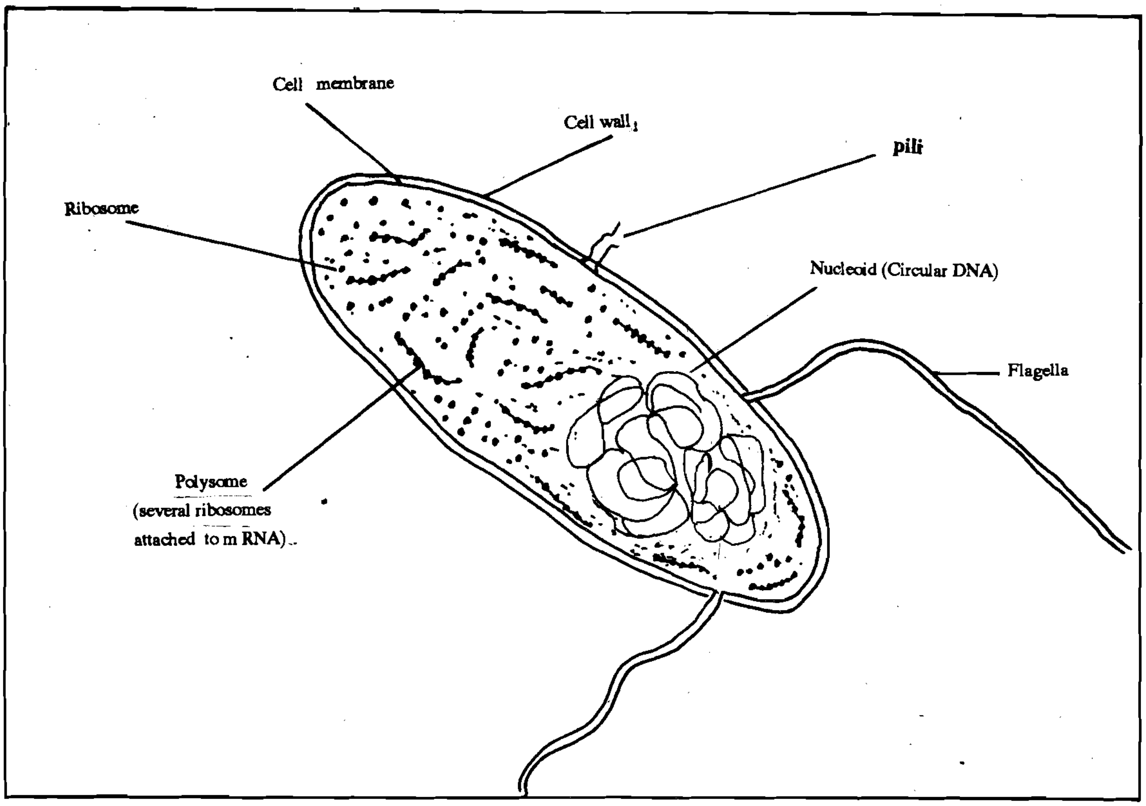
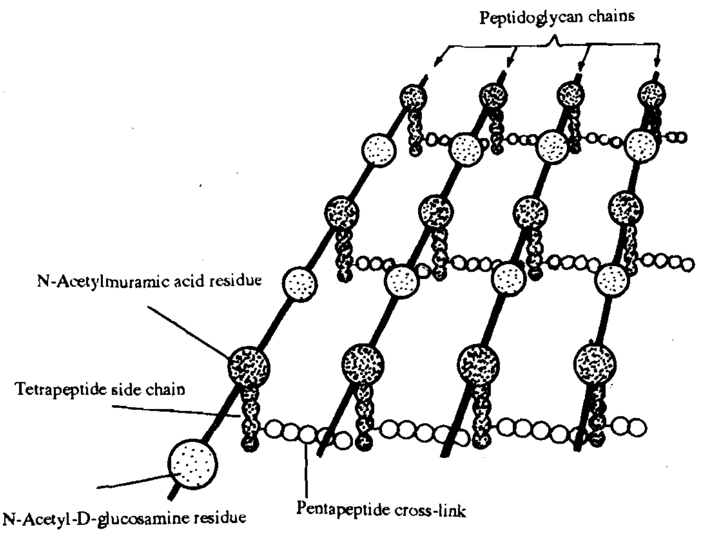


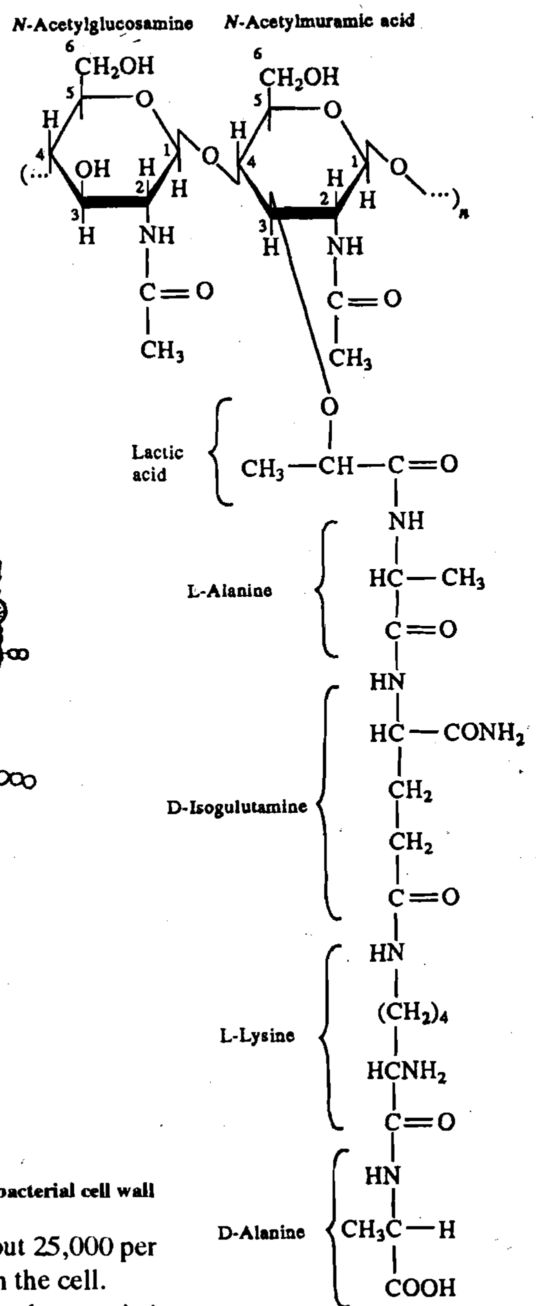
Fig. 1.2: Diagrammatic representation of an *E. Coli* cell showing pili and flagella. Flagella are long, slender whips of protoplasm by which *E.Coli* rapidly propel, and polysome is a structure formed when two or more ribosomes are bound to and engaged in translation of a single mRNA molecule

Fig.1.3. The **cell membrane** lining the inner surface of the **cell wall** is made up of phospholipids (45%) and proteins (55%). Some *E.coli* cells have small thin filamentous extensions of the cell wall called the pili. While the cell wall serves to protect the organism from the external environment, it also allows small molecules and nutrients to selectively pass through. The **cytoplasm** of the cell is enclosed within the cell membrane. Within the cytoplasm lies a single molecule of double stranded DNA in the form of an endless loop called circular DNA. The circular DNA molecule is tightly coiled to form the nuclear body (bacterial chromosome). In addition, most bacteria contain small circular fragments of DNA called the **plasmids**, which also carry genetic information independent of the bacterial chromosome.

The protoplasm (living substance) outside the nucleus in a cell is known as **cytoplasm**.



(a)



(b)

Fig.1.3: **a) Structure of the peptidoglycan chains of the bacterial cell wall**
b) Structure of the repeating disaccharide unit of the peptidoglycan of the bacterial cell wall

Cytoplasm also possesses a number of dense granular elements (about 25,000 per cell) called the **ribosomes**, which are the sites of protein synthesis in the cell. Further, the cytoplasm of many bacteria contains certain storage granules consisting of fats, starch and other nutrients. Cytoplasm is very rich in proteins, and contains all the enzymes required for the bacterial metabolism. From the foregoing description of an *E.coli* cell it should be clear that the structural organisation of the organism is fairly simple. However, the organism is still able to accomplish most of the functions that occur in a more complicated cell, such as, that of the liver.

Before you study the eukaryotic cell, attempt the following SAQ.

SAQ 2

Fill in the blanks in the following:

a) .... is the basic structural and functional unit of life forms.

b) Prokaryotic cells have extrachromosomal DNA-containing elements called ....

c) ....cell has no true nucleus.

d) The bacterial cell wall structural polysaccharide is called ....

1.5 THE EUKARYOTIC CELL

It is thought that prokaryote like cells preceded the eukaryotic cell in evolution, and that the first eukaryote evolved from some type of prokaryote, probably a billion or more years ago.

The eukaryotic cell is a complex unit and contains many structural features not seen in the simple prokaryotic cell. Fig.1.4 shows the details of various structural features seen in a typical animal and a plant cell. Let us now describe the structure of such a typical eukaryotic cell.

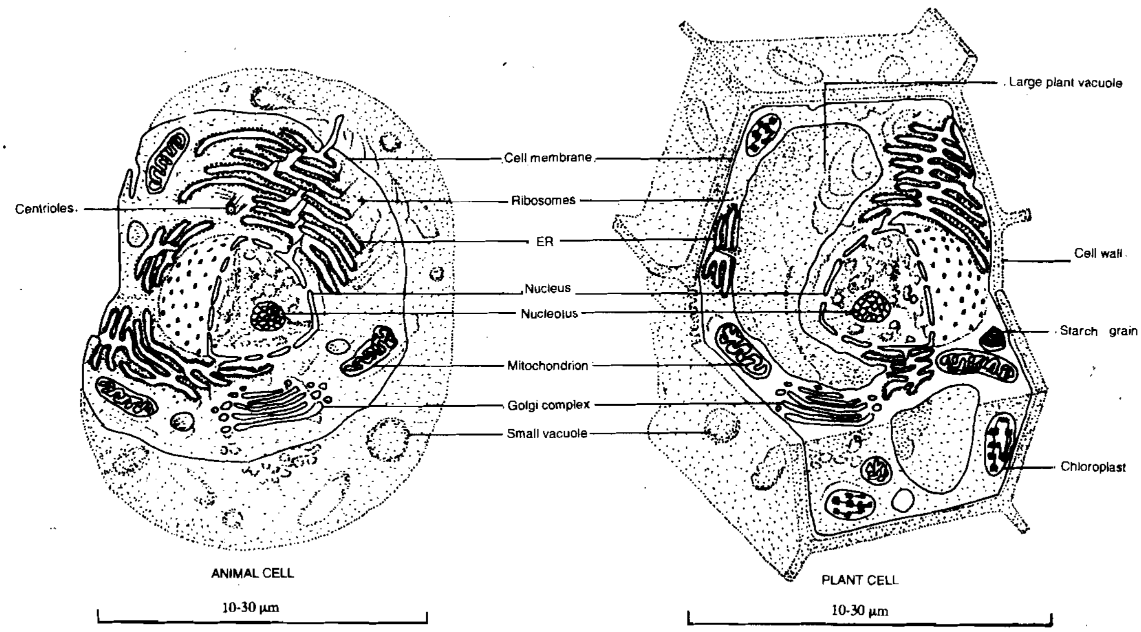


Fig.1.4: Structure of a typical eukaryotic plant and animal cell

1.5.1 Cell Membrane

All cells, whether prokaryotic or eukaryotic, are bound by a limiting membrane called the **cell membrane** or the **plasma membrane**. The cell membrane gives shape and mechanical strength to the cell and protects it from the environment. The cell membrane is composed of lipids and proteins, and in many cases about 2-5% carbohydrates are also present. These carbohydrates are linked to the proteins or lipids. In plants, the cell membrane is covered by a rigid **cell wall** whose major component is cellulose. In fungi, the cell wall is made of chitin. Among the various models proposed for the plasma membrane, the most satisfactory model that is generally accepted is the **fluid mosaic model** of S.J. Singer and G.L. Nicolson (1972). This model satisfactorily accounts for several of the observed properties of the plasma membrane. According to this model the phospholipids of the membrane are arranged in a bilayer with their polar head groups on the exterior and the nonpolar hydrophobic tails tucked inside. The different proteins of the membrane are dispersed within this phospholipid bilayer and are free to move within the plane of the membrane. Some of the proteins could also be present superficially embedded in the bilayer. The proteins of the plasma membrane are responsible for the diverse functions associated with the cell membrane, such as, selective transport, cell recognition, cell-cell communication, cell responses and motility. Fig.1.5 shows a schematic representation of the fluid mosaic model and the structure of a typical phospholipid is shown in Fig.1.6.

Most plant cells are enveloped by a thick, rigid **cell wall**, that gives the cell its shape and protects it both from mechanical injury and from osmotic pressure. It is made up of cellulose fibres embedded in a matrix of other polysaccharides and proteins. Materials that make up the cell wall are synthesised inside the cell, then packed just inside the plasma membranes, released from the cell and ultimately deposited in the cell wall.

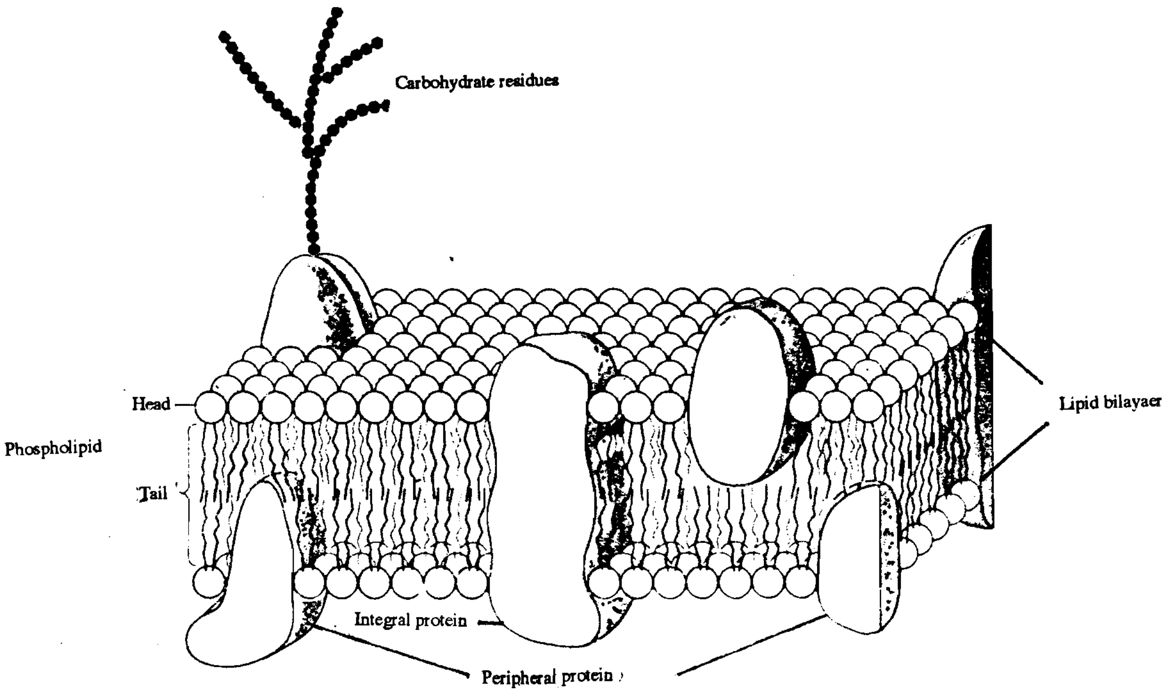


Fig.1.5: Fluid mosaic model of bi... ...ger and Nicolson)

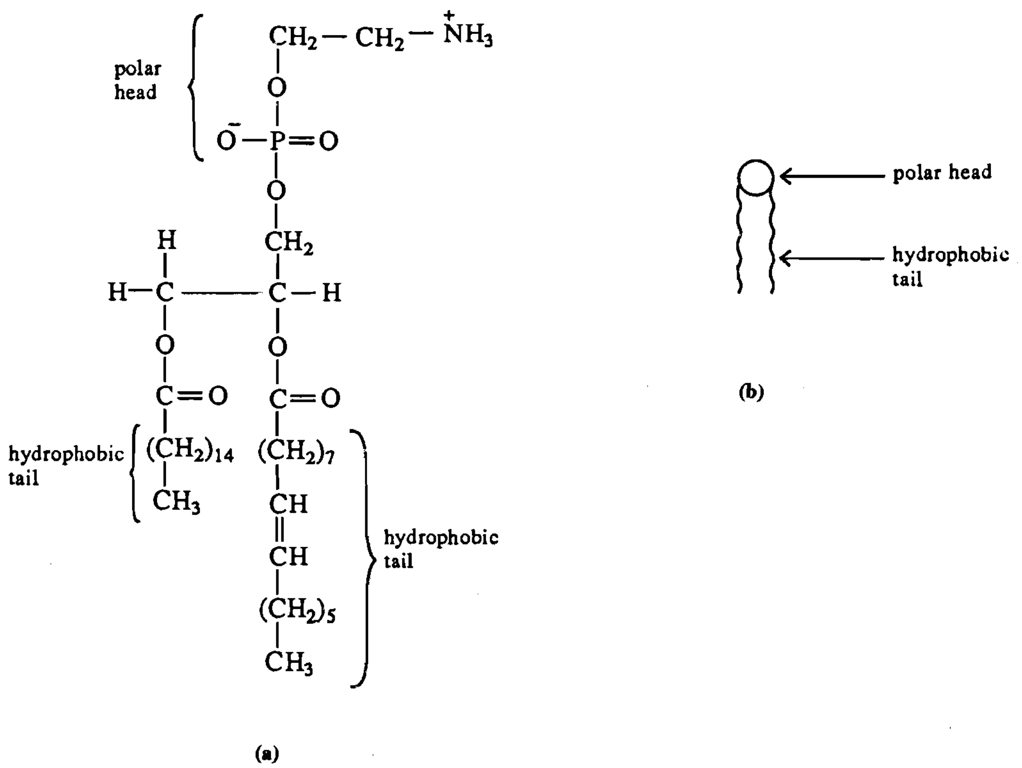


Fig.1.6: a) Structure of a phospholipid
b) Diagrammatic representation of a phospholipid showing the polar and nonpolar ends of the molecule

A major function of the cell membrane is to maintain the characteristic integrity of the cell by forming a selective barrier between the cell and its surroundings. It regulates the movement of various molecules into and out of the cell. For this purpose,the cell membrane is endowed with various transport processes. In general, nonpolar molecules are transported more readily across the membrane than polar or charged molecules. While some substances can diffuse by passive diffusion across the membrane (e.g. water), substances like glucose are transported by facilitated diffusion, involving specific proteins in the membrane. Most biomolecules are, however, transported into and out of the cell in an active process involving expenditure of energy.

In passive diffusion the molecules simply move or diffuse across a membrane and the rate of flow depends directly on the concentration gradient across the membrane.

Facilitated diffusion is the transport of molecules or ions across a membrane by carrier proteins in the membrane, driven by a concentration difference for the substance on the two sides of the membrane.

Active process or transport is similar to facilitated diffusion except that the molecules or ions move across the membrane against a concentration gradient which requires energy input.

An important part of the structure of a eukaryote is the nucleus. We shall now describe this organelle.

Within a cell, certain activities are confined to definite structures or **organelles**. Photosynthesis, for example, takes place in chloroplasts while respiration is confined to mitochondria. Organelles are, thus, membrane bound specialised regions within a cell.

1.5.2 The Nucleus

In all eukaryotic cells, the nucleus represents the most prominent and conspicuous organelle of the cell, and is generally seen as a large dense body by special staining procedures, since in a living cell it generally appears structureless. The nucleus is surrounded by a double membrane with pores, which allow selective passage of materials into and out of the nucleus. The nucleus being the "control centre" of the cell, it contains chromatin, composed of DNA, which is associated with a set of five basic proteins called the **histones**. Histones are small proteins with molecular weights ranging from 11,000 to 21,000, and these contain a very high content of the basic amino acids, namely lysine and arginine (about 25%). Eukaryotic cells contain considerably more DNA than prokaryotes. Thus, while the *E.coli* cell has an aggregate DNA content of 4×10^6 base pairs, that of yeast has 1.35×10^7 base pairs, and the human cell has 2.9×10^9 base pairs. Much of the DNA in a eukaryotic cell does not code for proteins, and is regarded as "junk" DNA, the function of which is not clearly understood as yet. The nuclear DNA is distributed between two or more chromosomes, the number of which varies among different eukaryotes, and is characteristic of every organism. The yeast cell, for example, has 12-18 chromosomes, while the human cell has 23 pairs of chromosomes. The nucleus is filled up with nucleoplasm, which contains several of the enzymes involved in the synthesis of nucleic acids. The nucleus also contains a roughly spherical body, the **nucleolus**, within which the RNA component of ribosomes is synthesised. The nucleus and its associated chromosomes undergo profound changes at the time of cell division, during which, the genetic material is duplicated and identical copies of it are shared between the two daughter cells.

DNA is the genetic material that is passed on from one generation to another. You will study about DNA in Unit 4.

A DNA molecule with proteins bound to it, is known as a **chromosome**.

We shall now describe an organelle,where two important biomolecules, viz., proteins and lipids, are synthesised.

1.5.3 The Endoplasmic Reticulum

The cytoplasm of most eukaryotic cells contains a very complex network of internal membranes,called the endoplasmic reticulum, which forms channels and vesicles within the cell. The endoplasmic reticulum, responsible for the synthesis of different proteins and lipids, is of two types, the **smooth endoplasmic reticulum,** which simply consists of membrane material and the **rough endoplasmic reticulum**, which is studded with a number of ribosomes. The ribosomes associated with the rough endoplasmic reticulum are actively involved in the synthesis of proteins that are meant to be exported out of the cell or that become part of the membranes. The smooth endoplasmic reticulum,lacking the ribosomes, is mainly involved in the synthesis of lipids.

Ribosomes are cytoplasmic particles composed of RNA and protein molecules. They form the basis of the system responsible for protein synthesis. Ribosomes are assembled in the nucleolus and move through the pores of the nuclear envelope to the cytoplasm, where they are present in hundreds of thousands of numbers, all working to synthesise the proteins of the cell. We shall describe protein biosynthesis in Unit 14.

SAQ 3

Match the following in group A with group B.

	A		B
a)	Singer and Nicolson	1)	Cell membrane
b)	Selective barrier	2)	Basic protein
c)	Histones	3)	Ribosomes
d)	Protein synthesis	4)	Fluid mosaic model

In subsection 1.5.3, we explained that ribosomes on the rough endoplasmic reticulum are mainly responsible for protein synthesis. But how are these proteins identified in the cells so that they could be despatched to sites were they are needed? This feat is achieved by Golgi bodies. So let us know more about this important organelle.

1.5.4 Golgi Bodies

Eukaryotic cells possess, within the cytoplasm, a complex organisation of a cluster of membrane-surrounded vesicles called the Golgi bodies, named after the Italian cytologist, Camillio Golgi, who first discovered these. The Golgi bodies appear within the cell as stacks of flattened vesicles. Many of the proteins synthesised by the cell have to reach their individual destinations, such as, membranes, lysosomes and other organelles, or these have to be secreted out, as in the case of hormones. One would thus wonder as to how the cell can accomplish this task. This, in a cell is achieved in a remarkable fashion by the Golgi bodies. The latter receive the newly synthesised proteins from the rough endoplasmic reticulum, and put identifying marks on them, just as the pin code numbers are put on an address. The Golgi bodies carry out this process by introducing certain specific and different chemical signals in the form of certain carbohydrate residues on the proteins, in a process called **glycosylation**. Such glycosylated proteins are recognised at different sites within the cell. The Golgi bodies, thus, play a key role in chemically modifying newly synthesised proteins, and sort them out to make them reach their appropriate destinations. Fig.1.7 depicts diagrammatically how the Golgi bodies receive three different proteins made in the endoplasmic reticulum, and sort them out and process them to become part of the lysosomal enzymes or be secreted out of the cell or become a part of the plasma membranes.

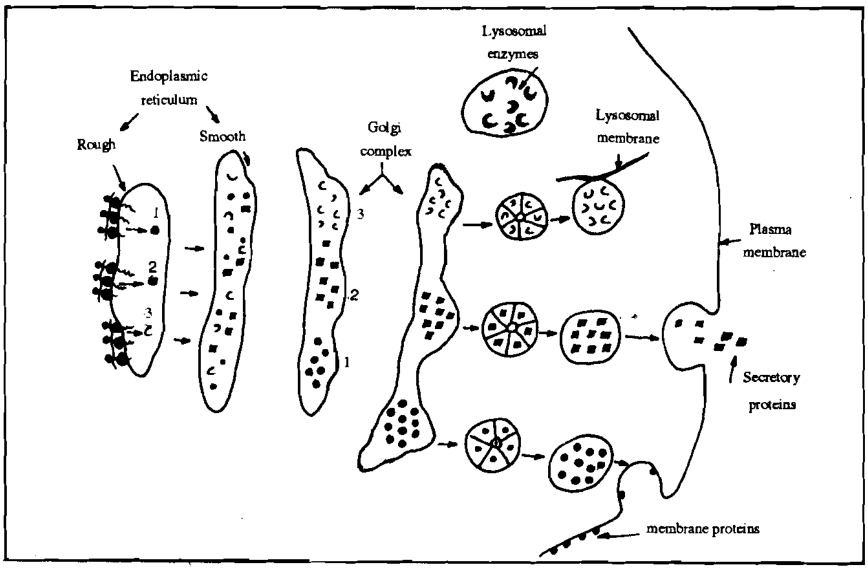


Fig.1.7: Role of the Golgi complex in protein processing

SAQ 4

Tick [√] mark the correct statement from the following:

The Golgi bodies are cell organelles,

a) involved in sorting and processing of proteins [ ]

b) containing Golgi proteins [ ]

c) which synthesise lipids [ ]

d) containing hydrolytic enzymes [ ]

We shall now describe an organelle responsible for selective and controlled breakdown of biomolecules such as proteins, nucleic acids and carbohydrates, within the cell.

1.5.5 Lysosomes

Within the cytoplasm of the cell, several hydrolytic enzymes (lytic enzymes) capable of hydrolysing proteins, nucleic acids and carbohydrates, are present within specialised membrane bound vesicles called the lysosomes. Some 40 enzymes are known to be present within lysosomes and some of these include acid phosphatase, cathepsins and nucleases. The lysosomes are actually formed by budding from the Golgi bodies. Their main function appears to be involved in the selective breakdown of cellular macromolecules within the cytoplasm. The lytic enzymes are thus, especially contained within these bag-like structures so that indiscriminate hydrolysis of substances is prevented. Lysosomes are abundant in leucocytes (white blood cells) that ingest invading microorganisms. Lysosomal enzymes are also involved in the scavenging of aged and damaged cells. In several diseased states and also by intoxication with toxic chemicals, the lysosomal membranes are damaged, which leads to leakage of lysosomal enzymes. This results in certain clinical disorders. In certain genetic disorders, such as, glycogen storage disorders and Hurler's disease, the lysosomal enzymes, associated with the breakdown of glycogen and mucopolysaccharides, are missing or deficient. This leads to intracellular accumulation of these polysaccharides, leading to severe consequences. In many instances, disorders associated with lysosomal enzyme deficiencies often lead to severe mental disorders

In the following subsection, you will study the organelle responsible for the removal of toxic byproducts of metabolic reactions, so that the cell does not get damaged.

1.5.6 Peroxisomes and Glyoxisomes

A number of metabolic reactions, such as, the oxidation of amino acids and lipids result in the production of hydrogen peroxide. As hydrogen peroxide is extremely toxic to the cell, such oxidative reactions are confined within the cell to small membrane bound organelles called the peroxisomes. In plants, the corresponding organelles are called the glyoxisomes.

These organelles also possess the enzyme catalase, which decomposes toxic hydrogen peroxide.

$$RH_2 + O_2 \longrightarrow R + H_2O_2$$

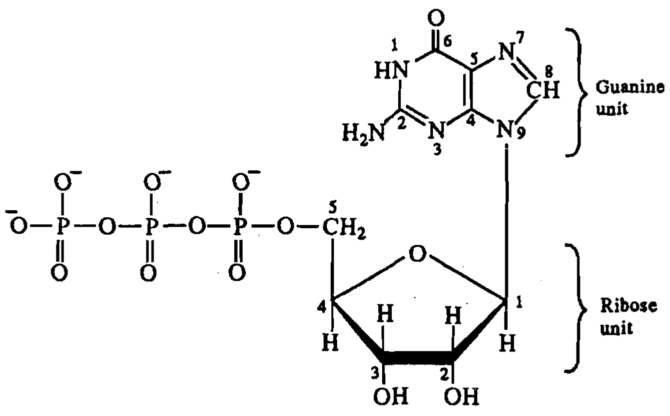
$$2H_2O_2 \xrightarrow{\text{catalase}} 2H_2O + O_2$$

Peroxisomes are formed within the cell from the smooth endoplasmic reticulum by a process of budding. Peroxisomes found in the kidney and liver cells are important in the oxidation of various toxic chemicals that are ingested by the organism. Thus, within the cell, all reactions leading to formation of toxic hydrogen peroxide are confined to peroxisomes so that it is instantly decomposed within these organelles.

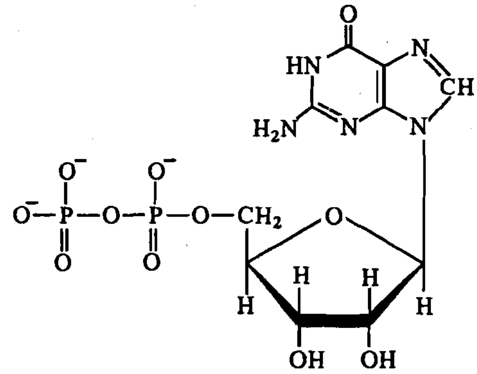
In the foregoing sections, we have described some organelles of a eukaryotic cell and also the specialised work they perform. We shall now explain how the cell maintains its shape and also keeps various organelles in their proper positions.

1.5.7 The Cytoskeleton

All eukaryotic cells have distinct shapes, and are also capable of assuming different shapes. The internal organelles of a cell are also capable of migrating from one location to another in a precise manner. Thus, the cell must be endowed with some mechanism to keep the internal structures in their proper places, and also to control their movements. The cell is able to achieve this task by an internal scaffolding system called the cytoskeleton. The cytoskeleton is, in fact, termed as the "bone and muscle" of the eukaryotic cell, and is composed of a network, consisting of two major types of protein filaments called the **microfilaments** and **microtubules**. The cytoskeleton, not only provides a rigid framework for the cell, but also provides numerous points of attachment to various structures within the cell. The microfilaments comprise of the proteins, actin and myosin, the same contractile proteins that are found in skeletal muscle cells. Since the microfilaments are made of contractile proteins, various organelles and structures associated with these filaments exhibit intracellular movement following changes in the contractile proteins. The changes in the proteins are influenced by calcium ions and by GTP and GDP, two energy rich compounds:



Guanosine triphosphate (GTP)



Guanosine diphosphate (GDP)

The microtubules are hollow tubular structures formed by a special arrangement of two proteins called the *alpha* and *beta* tubulins. The microtubules play a leading role during cell division. At that time the chromosomes attached to the mitotic spindle, composed of microtubular fibres, move apart due to contractions of the microtubule proteins. The motility of eukaryotic cells, the movement of flagella and cilia, the movement of the microvilli of the intestinal brush border cells, are all associated with microtubules. The movement of leukocytes in the blood stream and the transport of molecules along the axonal fibres are also due to contractions of the proteins constituting the microtubules. The cytoskeleton is, thus, an important structural feature of the cell, which is essential for the various kinds of movements associated with the cell and its internal structures. This is achieved by the special proteins that constitute the cytoskeleton, by a process of polymerisation and depolymerisation, resulting in changes in shape and thus resulting in movement.

To check your progress of understanding a cell, attempt the following SAQ.

SAQ 5

Fill in the blanks in the following:

a) Lysosomes are organelles containing ....enzymes.

b) Hydrogen peroxide is decomposed by the enzymes ....

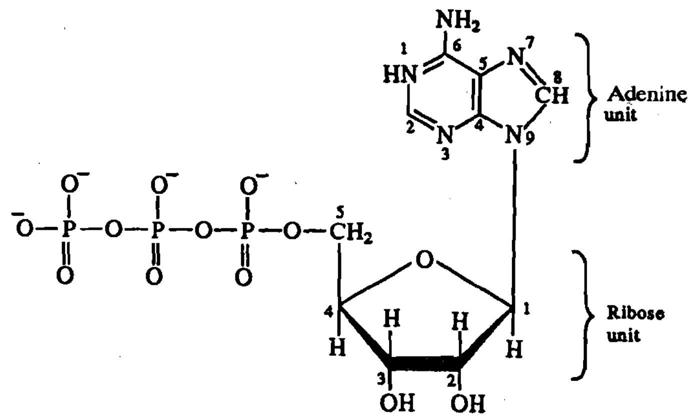
c) The proteins .... and .... are present in microfilaments.

d) The mitotic spindle is made of .... consisting of α and β tubulins.

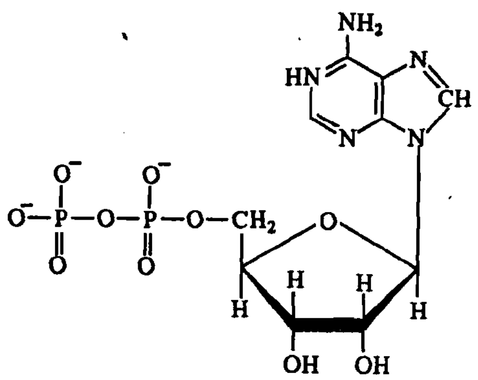
In the following subsection, we shall describe the socalled "power houses" of the cell, and also those compounds where all the energy is stored.

1.5.8 The Mitochondria

An important function of the cell is to derive energy from the different oxidisable nutrients, such as, carbohydrates and fats supplied to it. The cell is able to perform this function by carrying out oxidation of these nutrients during metabolism, and the energy released during such oxidations is transformed and stored in compounds called the "energy rich compounds". ATP and GTP are two such compounds, and are referred to as the energy currencies of the cell.



Adenosine triphosphate (ATP)



Adenosine diphosphate (ADP)

Cells are dynamic living units that are maintained in balance with their surroundings only through the expenditure of energy. Disruption of the source of energy results in the death of the cell.

Mitochondria are highly specialised organelles in eukaryotic cells. These perform the enrgy transducing process, and are often referred to as the "power houses" of the cell. Mitochondria are the largest organelles in a cell with a diameter of 0.5 – 1μm, and their numbers vary from one cell type to another. The rat liver cell for instance, has about 800 mitochondria, which occupy nearly 25% of the total cell volume. Mitochondria are of different shapes, e.g., spherical in the liver cells, cylindrical in the kidney cells or thread like in fibroblasts, and in some cells namely yeasts, are even highly branched. Within the cell, mitochondria are frequently found to be located in regions where there is a high demand for ATP.

The structure of mitochondria has been examined in great detail with the aid of the electron microscope, and it is now possible to describe the details of the organisation of a mitochondrion. Fig.1.8 gives a diagrammatic representation of the structure of the mitochondrion and its membranes. Mitochondria have a characteristic double membrane system with an outer membrane enveloping an inner membrane. The two membranes are separated by an inter membrane space. The inner membrane forms extensive invaginations projecting into the mitochondrial matrix space. These invaginations, called **cristae,** help to increase the total surface area of the inner membrane. The inner surface of the inner membrane (cristae) has a number of small stalked door knob like structures called the **coupling factors**. The coupling factors are responsible for the synthesis of ATP.

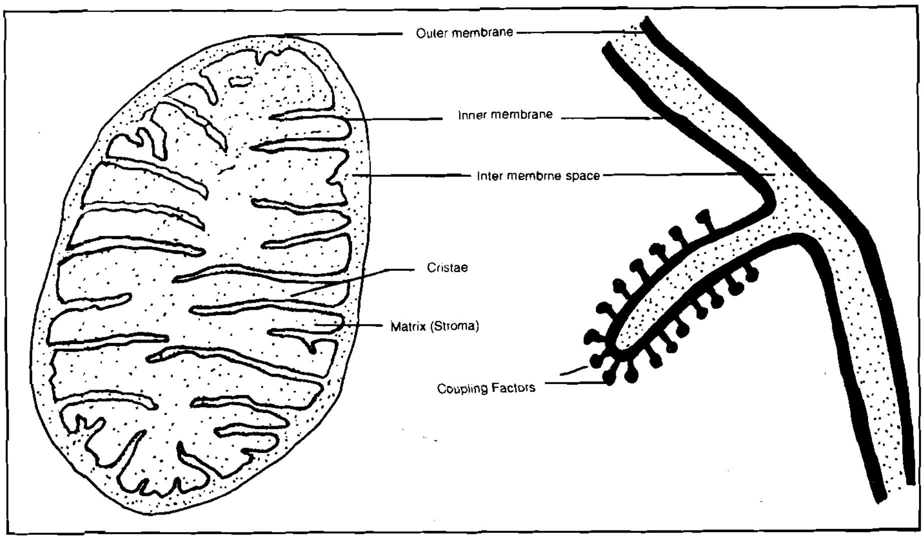


Fig.1.8: Diagram of a mitochondrion and part of its membrane

The composition of the two mitochondrial membranes is entirely different. The outer membrane is rich in lipids and contains nearly 50% of lipids, the rest being proteins. The inner membrane, on the other hand, is rich in proteins (80%) and has only 20% lipids. The outer mitochondrial membrane is permeable to most low molecular weight compounds, such as, ATP, ADP, NAD and other metabolites. The inner mitochondrial membrane, however, is impermeable to most of the metabolites, and these are transported into and out of the mitochondria by special protein carrier systems, called the **transporter systems.**

The inner mitochondrial membrane has about 60 different proteins associated with it. The outer membrane is associated with some enzymes. The mitochondrial matrix has all the enzymes of the TCA cycle and fatty acid oxidation enzymes. It also contains DNA, ribosomes and RNA. Mitochondria in a cell are self replicating structures, and these can synthesise some of their own proteins.

The coupling factors, also called the F_1ATPase, present on the inner mitochondrial membrane facing the matrix side, are a very complex association of a number of proteins. This factor utilises the energy gradient generated during electron transport to synthesise ATP by phosphorylating ADP with phosphate. We shall describe more about the functional aspects of the mitochondria in Block 3 of this course.

SAQ 6

Match the following regarding mitochondria in group A with those in group B:

A	B
a) Coupling factors	1) High protein content
b) Inner membrane	2) High lipid content
c) Outer membrane	3) Power house of cells
d) Mitochondria	4) ATP synthesis

In subsections 1.5.9 and 1.5.10, we shall describe two organelles, which are present in eukaryotic plant cells only. Let us explain what roles they perform.

1.5.9 The Chloroplast

One of the most distinguishing features of all eukaryotic plant cells is that in addition to mitochondria, they contain special light harvesting organelles known as the chloroplasts. These are the largest organelles in a plant cell, and are about 10μm long, 2-3 μm thick (Fig.1.9 & 1.10).

About 50% of the dry weight of the chloroplasts is protein, and the rest is mostly lipids. The lipid material of the chloroplasts consists of chlorophylls, carotenoids and phospholipids. Chloroplasts, like mitochondria, possess a bilayer membrane.

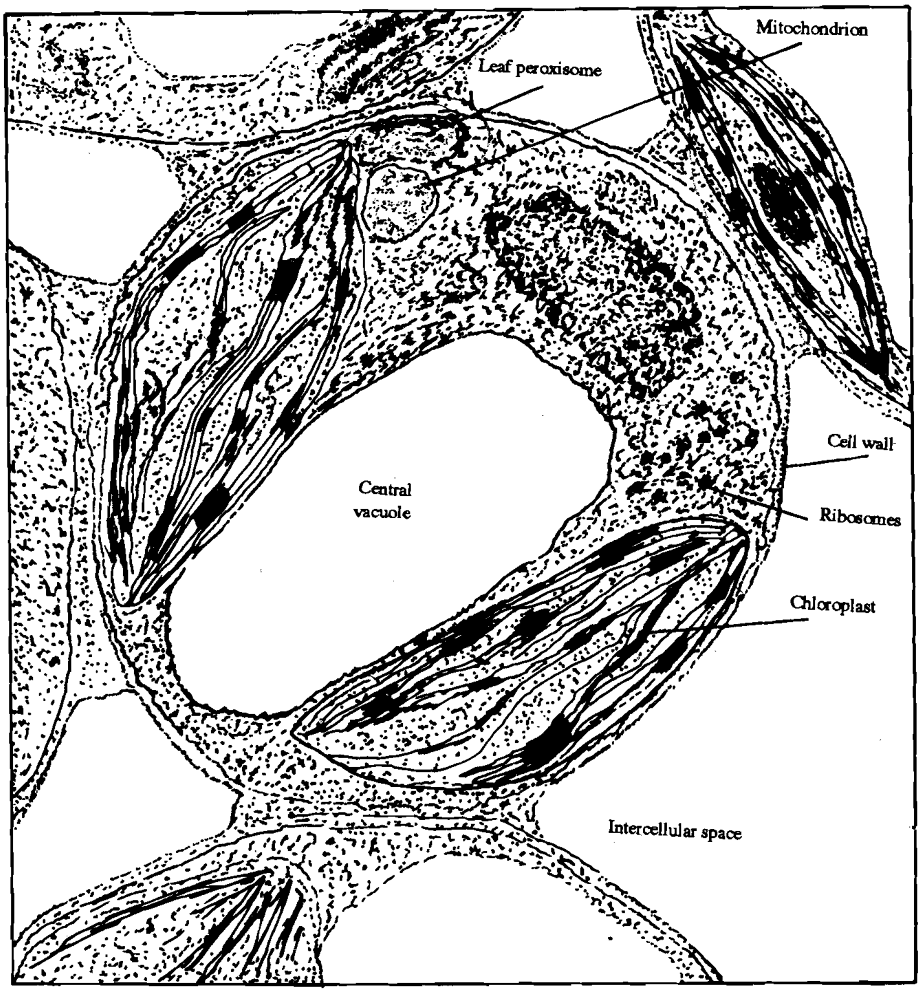


Fig.1.9: An electron micrograph of a leaf cell, showing a large internal vacuole and chloroplasts

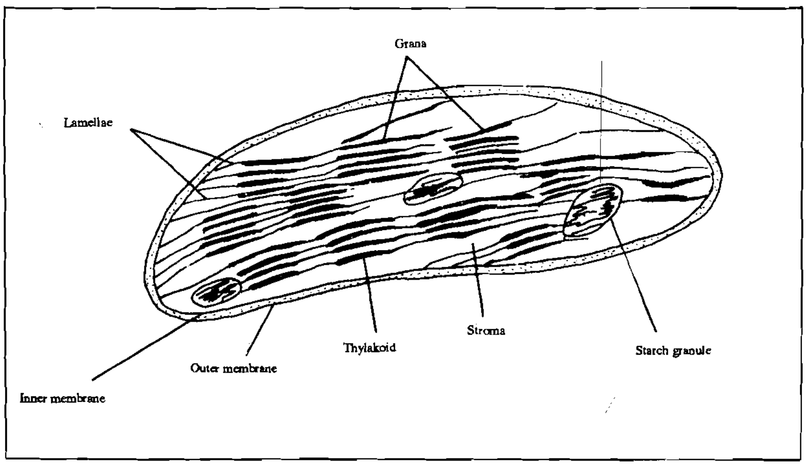


Fig.1.10: Schematic drawing of a chloroplast

The inner membrane is folded into very closely packed membranes called the **lamellae**. The lamellae flatten out at regular intervals into structures called the **thylakoids**, which are frequently found stacked one above the other to form **grana**. The matrix between the thylakoids is called the **stroma** and contains all the proteins and other factors involved in the photosynthetic fixation of CO_2 (Calvin cycle enzymes). The stroma also contains DNA and some of the chloroplast DNA is synthesised within the organelle. The thylakoid membrane contains all the factors associated with the photosynthetic electron transport leading to the generation of NADPH and ATP, which are utilised for the reduction of CO_2 into sugars and starch. Some of the major electron carrier proteins of the thylakoid membrane are the chlorophylls, constituting the light harvesting photosystems, plastoquinones, plastocyanins, ferridoxins and cytochrome b6. The chlorophyll pigments of the thylakoid membrane are organised into two distinct photosystems called the photosystems I and II. These two light harvesting systems respond to different regions of the visible light spectrum. While photosystem I is sensitive to far red light, photosystem II is sensitive to both far and near red light. Both systems function in a coordinated manner to utilise light to generate both ATP and NADPH. In marine bacteria and algae, chlorophylls are not present in separate organelles but are found in association with the cell membrane itself. Plant chloroplasts also possess a large number of starch granules. The chloroplast membranes are in a number of respects functionally similar to the mitochondrial membranes, as both are basically energy transducing membranes.

SAQ 7

Tick [√] mark the following statements as true or false:

a) Photosystems are present on the inner mitochondrial membrane [True/False]

b) Chlorophylls are constituents of photosystems I and II. [True/False]

c) Light energy is needed for electron transport in the thylakoid. [True/False]

d) Chloroplast and mitochondrial membranes are functionally identical. [True/False]

1.5.10 Vacuoles

A very conspicuous feature in most plant cells is the presence of one or more large vesicles called vacuoles which are separated from the rest of the cytoplasm by a thin membrane called the **tonoplast**. Vacuoles are small in young cells, but grow larger as the cells grow older, and can occupy as much as 50% of the cell volume. Vacuoles are filled with cell sap, and are used for storing and transport of nutrients, metabolites and waste products. In certain plants, vacuoles serve a special function of storing compounds like rubber, alkaloids, organic acids and other metabolites.

Animal cells and many types of unicellular eukaryotes contain **centrioles**, which are cylindrical in structure, about 0.15 m in diameter and 0.3 to 0.5 m long. They are mainly composed of microtubules and occur in pairs. It is beleived that they play a role in cell division (mitosis). However, their importance is, as yet, uncertain.

1.6 METHOD FOR FRACTIONATION OF SUBCELLULAR ORGANELLES

In order to study the composition and the metabolic role of the various subcellular organelles in a cell, it becomes necessary that each of the organelle is isolated from the cell. In fact, in biochemical work, the isolation of the individual organelles from the cell is the first step in metabolic studies. The difference in the densities of organelles helps in isolating them from each other. Hence, by a process of

differential centrifugation, the organelles of a cell may be separated from one another. The procedure, as applied to a typical liver cell, is depicted in Fig.1.11.

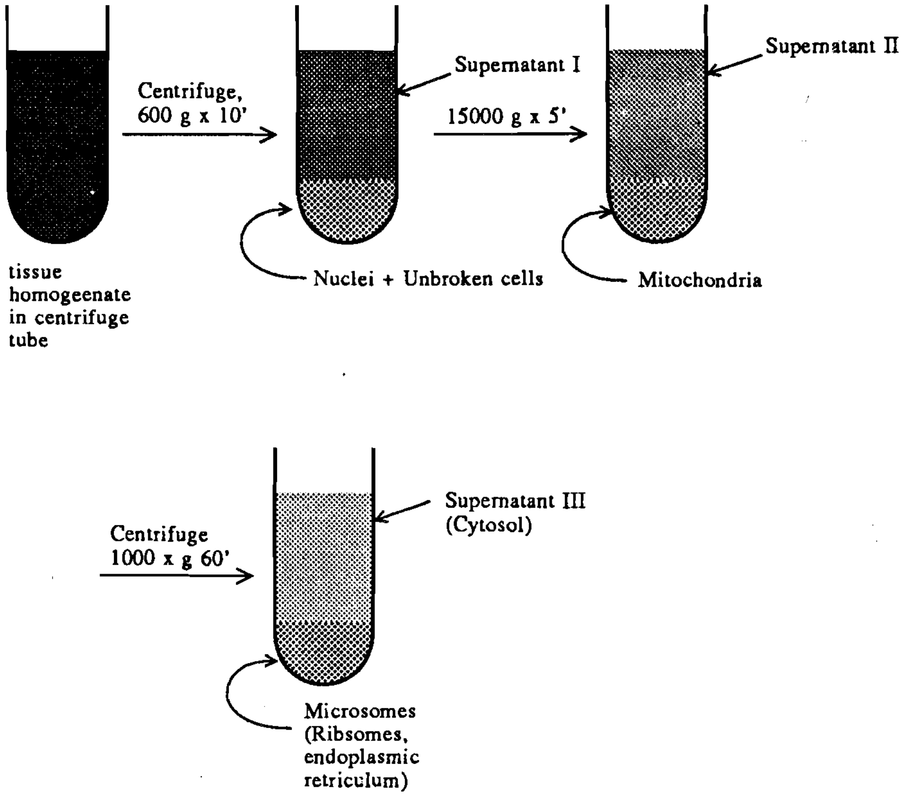


Fig.1.11: Isolation of subcellular fractions by differential centrifugation

In this technique a tissue e.g., the rat liver, is homogenised in a medium, such as, isotonic sucrose (0.25*M*) at 277K using a tissue homogeniser. The tissue homogenate is then subjected to centrifugation at different speeds, for specified time intervals, so that increasing gravitational force is exerted and the organelles are separated on the basis of their size and weight. Thus, the nuclei are the first to sediment at 600 × gbeing the heaviest organelle. The mitochondria, being the next dense material, separate at 15,000 × g, while microsomal fraction, comprising of ribosomes and fragments of endoplasmic reticulum, get separated at a speed of 100,000 × g. Subcellular fractions, thus obtained, are metabolically active. For example, mitochondrial oxidative phosphorylation can easily be demonstrated with isolated mitochondria.

SAQ 8

Fill in with the appropriate word or number given in the brackets:

a) Mitochondria sediment at .... × g. (5000, 15000, 100000)

b) Photosystem I is sensitive to .... light. (far red, near red, uv light)

c) Golgi bodies modify proteins by .... (hydrolysis, glycosylation, attachment)

d) Pentapeptide cross links are found in .... (proteins, DNA, bacterial cell wall)

1.7 SUMMARY

- Lipids, proteins, nucleic acids and carbohydrates constitute the four major classes of carbon compounds found in all organisms, and the cell is a fundamental structural and functional unit of an organism.
- Living organisms are classified as prokaryotes or eukaryotes, depending on their cell type. The prokaryotic cell has a very simple structural organisation, while the eukaryotic cell is more complex and possesses a number of well-defined intracellular organelles.
- The DNA of a eukaryotic cell is organised into a number of chromosomes within a well-defined nucleus. Prokaryotes possess within the cytoplasm a single circular molecule of DNA.
- The structure of a cell is designed primarily to facilitate distribution of various cellular functions to different structural elements. The cell membrane protects the cell from its environment, and functions to selectively transport various molecules across it. Plant cells and some bacterial cells also have a cell wall, in addition to the cell membrane.
- The various organelles in a cell have their own identity and perform distinct functions. The ribosomes associated with the endoplasmic reticulum are the chief sites of protein synthesis in a cell. The Golgi bodies are the key elements involved in the processing of newly synthesised proteins.
- Certain enzymatic reactions in a cell occur within specialised structures, such as, the lysosomes and peroxisomes.

  Microtub
  ules and microfilaments, the structural elements of the cell cytoskeleton, provide a rigid framework to the cell, and these are responsible for the movement of metabolites and structures within the cell.
- The mitochondria and chloroplasts are important energy transducing organelles of eukaroytic cells and generate ATP through oxidation of substrates and by capturing light energy, respectively.
- Animal cells lack chloroplast and vacuoles. The various organelles of a cell can be fractionated by differential centrifugation.

1.8 TERMINAL QUESTIONS

1. Define an organelle.
2. What are the functions of the cell membrane in a eukaryotic cell?
3. What would be the consequences if peroxisomes were absent in cells?
4. What are lysosomes and what is their role?
5. How is DNA, the genetic material, organised in prokaryotes and eukaryotes?
6. What is the role of the Golgi bodies in the formation of membrane proteins?
7. How do microtubules and microfilaments differ?
8. Compare the thylakoid and mitochondrial membranes.
9. How would you isolate liver mitochondria?

1.9 ANSWERS

Self Assessment Questions

1.	a) False	b) True	c) True	d) False
2.	a) The cell	b) plasmids	c) Prokaryotic	d) peptidoglycan
3.	a) 4	b) 1	c) 2	d) 3
4.	a			
5.	a) hydrolytic	b) catalase	c) actin, myosin	d) microtubules
6.	a) 4	b) 1	c) 2	d) 3
7.	a) False	b) True	c) True	d) False
8.	a) 15,000xg	b) far red	c) glycosylation	d) bacterial cell wall

Terminal Questions

1. An organelle is a membrane bound intracellular structure with well defined functions.
2. Cell membrane protects the cell from its environment, acts as a barrier for selective transport of molecules, and is involved in cell recognition, cell-cell communication, cell responses and motility.
3. Hydrogen peroxide, resulting from certain oxidative reactions in the cell, is extremely toxic and is produced only within peroxisomes, where it is also destroyed. In the absence of peroxisomes, the resulting hydrogen peroxide would prove fatal to the cell.
4. Intracellular degradation of certain macromolecules, such as, proteins, nucleic acids and lipids cannot occur indiscriminately within cells. Hence, such enzymatic hydrolytic reactions occur in lysosomes, since the lytic enzymes are specifically contained in them.
5. DNA in prokaryotes is present as a single circular molecule in the cytoplasm, while in eukaryotes it is present within a well- defined membrane enclosed nucleus, and is organised into chromosomes.
6. Proteins destined to become part of the cell membranes are synthesised on the ribosomes of the rough endoplasmic reticulum, and are glycosylated in the Golgi bodies. These marked proteins are then transferred to the membranes.
7. The two cytoskeleton elements, although made essentially of contractile proteins, differ in the nature of the proteins. Microfilaments are made of actin and myosin, while the microtubules are made up of *alpha* and *beta* tubulins.
8. The thylakoid membrane of the chloroplasts harvests light energy, and couples it to drive the synthesis of ATP and generate NADPH. The mitochondrial membrane, however, uses NADH, generated during substrate oxidation, to generate ATP. The thylakoid membrane has both chlorophyll and electron carrier proteins, while the mitochondrial membrane has only electron carrier proteins.
9. Liver homogenate is centrifuged at 600 × g, and the supernatant from this is again centrifuged at 15,000 × g. The pellet (sediment) from this step contains mostly mitochondria.