UNIT 3 FUNCTIONAL ULTRASTRUCTURE OF THE CELL

Structure

3.1 INTRODUCTION

In the preceding units, you have learnt about the evolution of cell and the characteristic features of procaryotic and eucaryotic cells. Besides, you have familiarised yourself with various tools and techniques to study the organisation of the cell. A cell consists of various cytoplasmic organelles. The present unit deals with the structure and functions of the organelles of eucaryotic cell, i.e. endoplasmic reticulum, Golgi apparatus, nucleus, mitochondria, chloroplast etc. Detailed functions of some of double membraned cell organelles like nucleus, ribosomes and mitochondria will be discussed later in the course.

In this unit, we shall study the structure and functions of endoplasmic reticulum, lysosomes and peroxisomes. The processes of endocytosis and exocytosis tend to delete or add to membrane components, but the surface area of the membrane remains constant through recycling of membrane components. Plastids are the important components of plant cells which contain respiratory and coloured pigments. They also act as store house of macromolecules. Cytoskeletal system of the cell constitutes microfilaments and microtubules concerned with the movement in and around the cell and keeps the cell in shape.

You have studied the basic structure of the cell in Units 1 and 2. You also know the basic differences between animal and plant cell.

Objectives

After studying this unit, you will be able to:

- identify the various organelles of a eucaryotic cell in the light micrographs and electron micrographs and state their functions,
- describe the structure and function of cilia, flagella, smooth and rough endoplasmic reticulum, Golgi apparatus, mitochondria, chloroplast and nucleus, and
- explain recycling of membrane components in a cell with suitable examples.

3.2 ENDOPLASMIC RETICULUM (ER)

Eucaryotic cells have two major compartments— nucleus and cytoplasm. Cytoplasm was known to have no structure until the discovery of electron microscope. That cytoplasm is permeated by a membranous network called **endoplasmic reticulum** (ER), was revealed only after the introduction of electron microscope. Endoplasmic reticulum is a three dimensional network of membrane channels which constitutes more than half of the total membrane of the cell. ER is a highly folded and convoluted structure and forms a single continuous sheet enclosing one continuous sac. The interior of the sac is called "**cisternal** space" or "**ER lumen**". This is separated from the cytoplasm also called cytosol by a single membrane which mediates the communication between these two compartments. ER provides the cell with a compartment for storage of substances to be kept separate from cytosol. In addition, it has a key role in the biosynthesis of macromolecules.

ER is a double membranous organelle which consists of interconnecting flattened sacs called **cisternae** or interconnected **tubules** or **vesicles**. Cisternae are temporary storage sites for nutrients (Fig. 3.1 a).

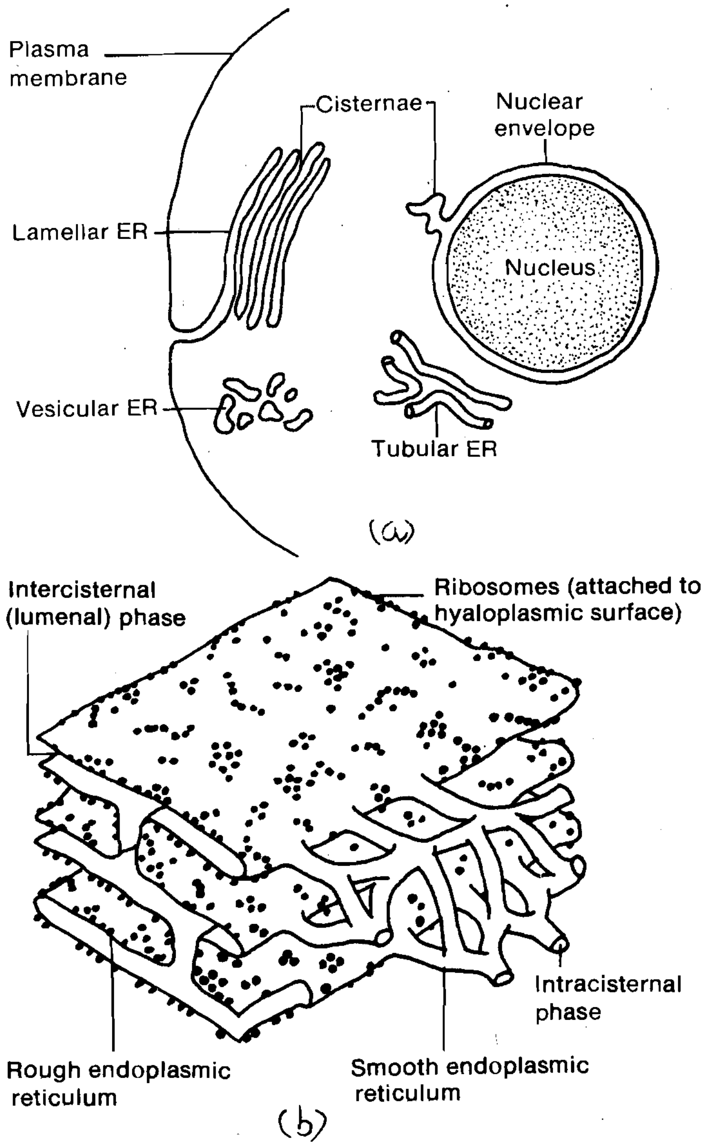

Fig. 3.1 : a) Three physical forms of ER, lamellar, vesicular and tubular. The lamellar type of ER is in the form of flattened membrane sacks, the vesicular type of ER is in the form of vesicles, and tubular type of ER is in the form of tubules.
b) Endoplasmic reticulum shows the continuity of ER types that exists between adjacent membranes and cisternae of both rough and smooth ER. Rough ER membranes are characteristically sheet like, whereas smooth ER membranes are characteristically tubular.

Rough and Smooth Endoplasmic Reticulum (RER and SER) : ER is differentiated into two regions, **granular** or **rough endoplasmic reticulum** (RER) and **agranular** or **smooth endoplasmic reticulum** (SER). These two regions also differ considerably in shape: rough ER is organised in stacks of flattened sacs called cisternae and smooth ER consists of a mesh work of fine tubules (Fig. 3.1 b). In RER, the outer surface in the cytoplasmic site of the membrane is studded with small particles called **ribosomes** whereas in SER, the ribosomes are absent. Ribosomes are the sites of protein synthesis. Thus, it is evident that RER is more abundant in cells which are actively engaged in synthesis and export of proteins, for example, pancreatic acinar cells and plasma cells. SER is found in those cells which are specialised in lipid metabolism and which secrete steroids such as the cells of adrenal cortex, the testes and ovary. Smooth ER is also present in liver cells where it helps in detoxification of drugs and poisons.

ER (both RER and SER) performs many mechanical functions of the cell by providing mechanical support. Large surface area of ER helps in the exchange of materials across the membrane by diffusion and active transport. ER may act as a kind of circulatory system for the distribution of various substances in the cell.

SAQ 1
Which processes do you expect to occur in the following cells? Write your answer in the space provided.

i) A cell in which there is an extensive network of RER.

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ii) A cell in which there is a lot of SER.

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3.3 GOLGI APPARATUS

Camillo Golgi in 1898 discovered a reticular structure in the cytoplasm of nerve cells with the help of metal impregnation technique using silver nitrate for which he received the Nobel Prize. This structure was named as Golgi apparatus or Golgi complex after him. Golgi complex is located near the cell nucleus.

Golgi complex is structurally similar in both plant and animal cells, but in plant cells it is more evident and is called as **dictyosomes** which are stack-like or plate-like bodies. Animal cells contain comparatively much smaller number of Golgi apparatus than plant cells.

The Golgi complex consists of (a) stack of flattened sacs or **cisternae** (b) small rounded **transport vesicles** (c) larger **vacuoles** filled with amorphous or granular material.

The cisternae, which are flattened sac like vesicles of Golgi complex, are arranged in parallel series and are separated by a space of 20-30 nm. Cisternae are gently curved so that the Golgi bodies give a bow like appearance (Fig. 3.2). The convex side facing the endoplasmic reticulum is '**forming**' or '**proximal**' face, whereas the concave side oriented towards cell surface is the '**releasing**' or '**distal**' face of the complex.

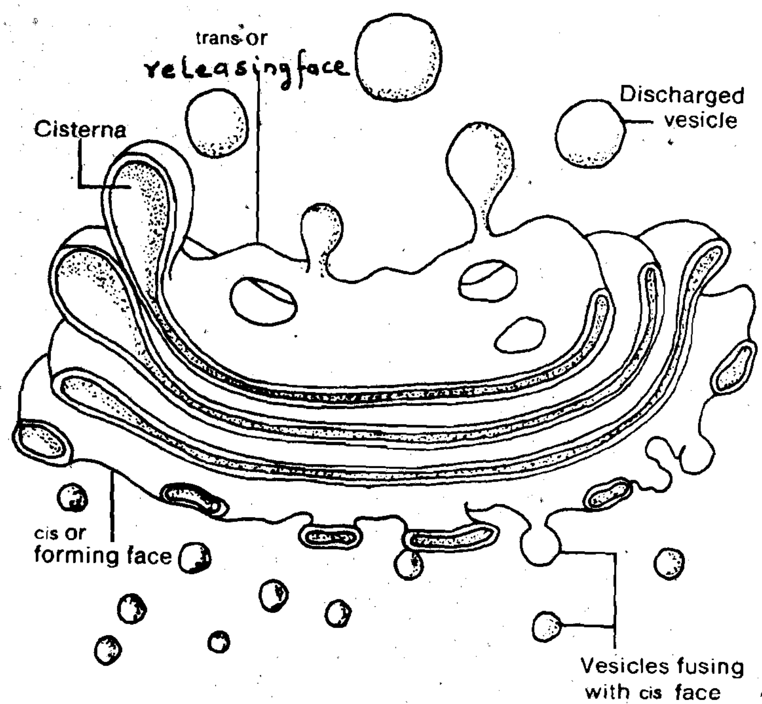

Fig. 3.2 : Golgi apparatus based on the study of electron micrograph. The cisternae exhibit a structure having two faces i.e. forming face (convex) and releasing face (concave). The forming face is generally curved and closer to the endoplasmic reticulum and the nuclear membrane. The releasing face is concave shaped and encloses a region containing large secretory vesicles.

Small vesicles called transition vesicles are frequently seen lying between rough endoplasmic reticulum and the forming face. It is thought that these vesicles are formed from the ER and migrate to Golgi, where they form new cisternae, which get fused with existing cisternal membrane, and thus the growth of the organelle occurs. New cisternae are formed at the forming face to compensate for the loss of secretory vesicles of the releasing face. The transformation of membrane from one type to another is a step which leads to the formation of a vesicle. The chemical composition of Golgi complex is intermediary between ER and the plasma membrane.

Golgi apparatus is composed of at least three types of sacks which contain different types of enzymes. The most characteristic enzymes are transferases, for example, glycosyl transferase. Besides this, acid phosphatases and other lysosomal and oxidative enzymes are also present.

Golgi apparatus performs many functions in the cell such as processing of the molecules secreted by the ER, and packaging of the molecules according to their final destination as shown below:

Endoplasmic reticulum
↓
Golgi complex
↓
Secretory granules
↓
Plasma membrane
↓
Cell exterior

In plant cells, Golgi apparatus helps in the formation of cell plate and cell wall.

SAQ 2
Golgi complex is involved in the transport and processing of many substances that are produced in ER and are discharged outside the cell. How? Write your answer in the space given below.

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Recycling of Plasma Membrane Components

During exocytosis secretory vesicles fuse with plasma membrane, adding to the membrane surface area. Yet, the surface area of plasma membrane remains constant. This is due to recycling of the membrane components. This recycling is carried out by subsequent return of the internalised membrane components and by removal of excess membrane through internalisation. For example, plasma membrane of thyroid cells can bind with ferritin, endocytosis is induced by addition of thyrotropin to the cells. Immediately after endocytosis, ferritin appears in lysosomes, and within 30 minutes it can be detected in cisternae of Golgi complex (Fig. 3.3).

Likewise, endocytosis results in the internalisation of plasma membrane. Golgi complex may reprocess and reuse the membrane components after endocytosis, and use them in secretion, lysosome formation or restoration of plasma membrane itself. That is how the Golgi apparatus functions in recycling of the membrane components.

SAQ 3
A cell is very active in secretory activities. Which organelle do you expect to take part in this activity of the cell and why? Give one reason in the space provided.

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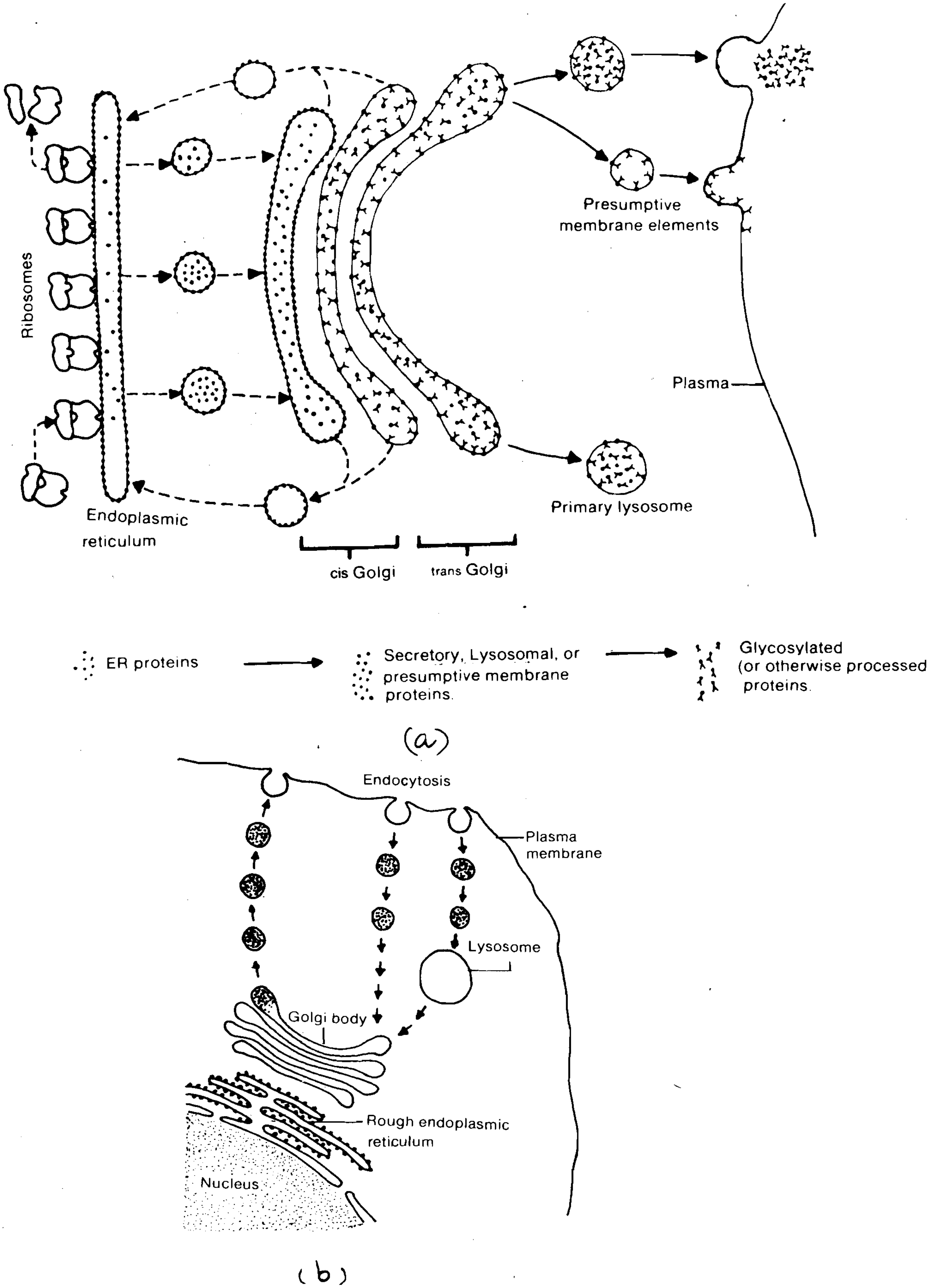

Fig. 3.3 : a) Secretion of proteins across membranes. Proteins from ER enter the forming face of the Golgi. Proteins from ER destined to be secreted out are successively purified and are discharged as vesicles from the distal face.
b) Role of the Golgi apparatus in recycling and reuse of plasma membrane components, which enter the cytosol during endocytosis.

3.4 LYSOSOMES AND PEROXISOMES

Lysosomes were first discovered by Christian de Duve. Unlike other organelles which were detected by microscope, these were first discovered biochemically. Later, electron microscope and biochemical methods shed more light on their nature and their participation in cell activities.

These particles were called **lysosomes** (lysis = dissolution, soma = body) due to their hydrolytic activity. A lysosome is a single membrane bound vesicle that either buds off from the releasing face of Golgi apparatus or arises directly from ER. The lysosomes are rich in **hydrolases, specially acid phosphatase**, of about 50 different types which digest all the significant groups of macro molecules. These enzymes are active at pH 5 within the organelle. The enzymes, which escape from lysosomes, become slow in their action because the pH of cytoplasm is 7.0. This large pH difference is a device to protect the cell from digestion.

Polymorphism in Lysosomes

Polymorphism, i.e. existence of a structure in more than one form, is an important feature of lysosomes. Several different forms of lysosomes have been identified within the cell as **primary lysosomes, secondary lysosomes, residual bodies** and **autophagic vacuoles** (Fig. 3.4).

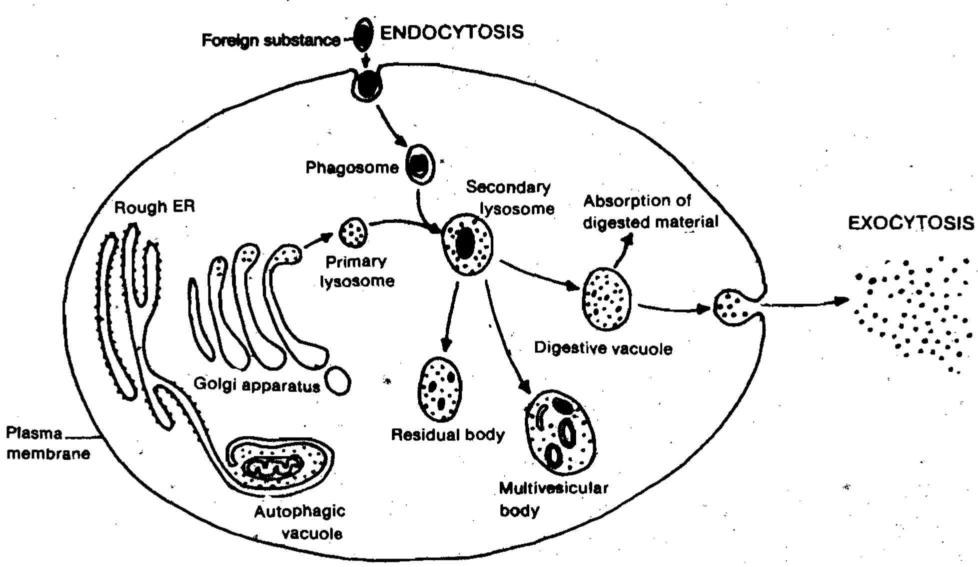

Fig. 3.4 : Figure showing the polymorphism of lysosomes. Primary lysosomes containing digestive enzymes fuse with the phagosome to form secondary lysosome. Digestion products are released by exocytosis. Primary lysosome may fuse with some organelles like mitochondria to form autophagic vacuole. Incomplete digestion of foreign substances form residual bodies.

Primary lysosomes: These are newly formed organelles. They are believed to be derived from the maturing face of Golgi complex whose digestive enzymes have not yet taken part in hydrolysis.

Secondary lysosomes are formed from fusion of primary lysosomes with the vesicles containing variety of substrates known as 'phagosome'. After fusion, their membrane undergoes a change and enzymes are activated so that the substrate is digested. After activation they may continue hydrolysis repeatedly. The secondary lysosomes which fuse with vesicles containing extracellular substrate brought into the cell by endocytosis are known as heterophagic lysosomes or heterophagosome whereas lysosomes fusing with vesicles containing particles isolated from cell's own cytoplasm like mitochondria, microbodies, and fragments of endoplasmic reticulum are known as **autophagic vacuoles**. During pathological conditions or during cell growth, autodigestion of cellular organelles is a normal event.

Residual bodies: Incomplete digestion of foreign substances leads to the formation of residual bodies. Residual bodies are huge, irregular in shape and are electron dense. In some cells they remain for a long time and play a role in the aging process. In some other cells, the content of the residual bodies leave the cell by exocytosis.

Lysosomes are responsible for the intracellular digestion of a variety of substances such as food molecules, disease causing organisms, etc. This process is called heterophagy. Lysosomes are also responsible for digestion of cell's own cytoplasmic constituents. This process is called **autophagy**. It is important that lysosomes do not **rupture and release their contents inside living cells** as they would start digesting the cell and cell will die.

SAQ 4
Which form of lysosomes are found in abundance during pathological conditions and why? Give your answer in about 30 words.

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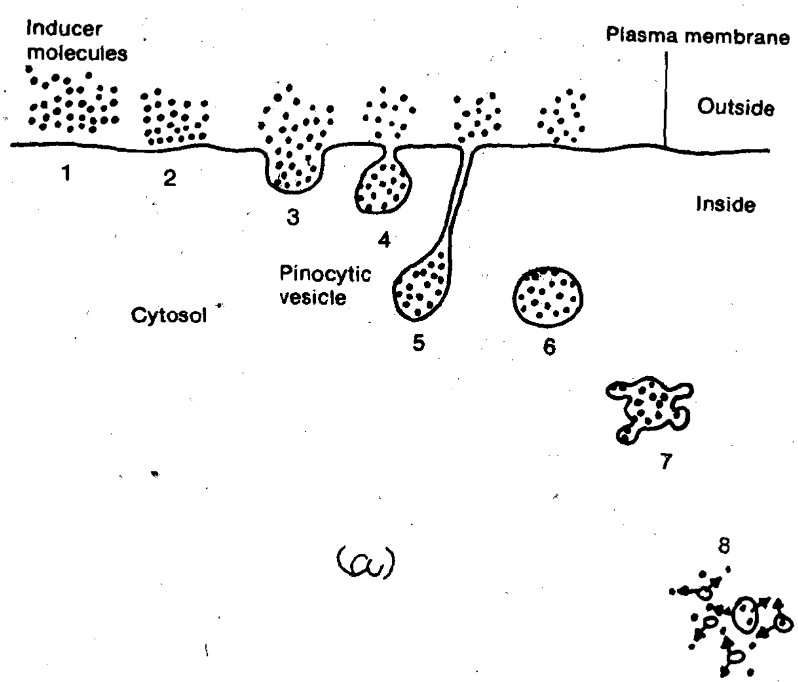
Endocytosis and Exocytosis
Endocytosis is the process by which substances are brought into the cell from outside by formation of membrane bound vesicles. These extra cellular substances are enclosed in a small portion of plasma membrane which invaginates and pinches off to form an intracellular vesicle. The intake of fluids by formation of vesicles is called as **pinocytosis** (pinein = drink). Pinocytosis is induced by the presence of appropriate concentrations of inducer molecules which can be proteins, amino acids or certain ions in the medium surrounding the cell (Fig. 3.5a). The ingestion of large particles by formation of larger vesicles is known as **phagocytosis** (phagein = to eat) (Fig. 3.5 b). The process of phagocytosis is associated with heterophagic activity of the lysosomes such as the destruction of worn blood cells in the liver, spleen and bone marrow. Exocytosis is the reverse sequence where the membranous intracellular vesicle fuses with plasma membrane and releases its content to the extracellular surroundings. The best understood form of exocytosis is secretion by the cell. As you have studied earlier, Golgi apparatus plays an important role in the formation of cytoplasmic intracellular vesicles. The membrane of these vesicles is incorporated into plasma membrane and the vesicle's contents are discharged to the exterior.



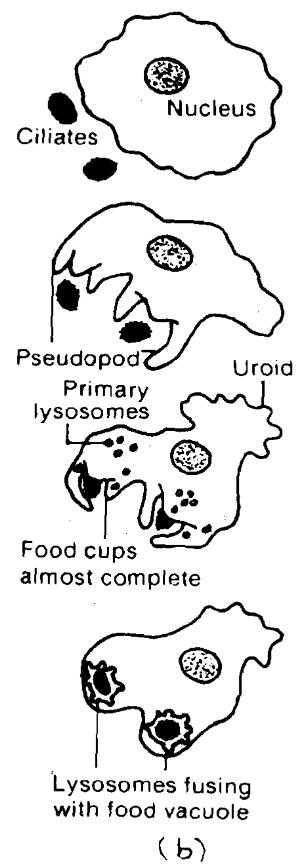


Fig. 3.5 : a) Stages of pinocytosis. 1-2 binding of inducer molecules to plasma membrane, 3-5 invagination of the membrane, 6-8 detachment from plasma membrane and fragmentation into smaller vesicles.
b) Different stages of phagocytosis. In the presence of food e.g. ciliates shown in fig (i) the cell forms pseudopodia (ii) which entrap the prey in vacuole (iii) the fusion of primary lysosomes with these vacuoles is followed by digestion of prey (iv).

Microbodies: Peroxisomes and **glyoxysomes** are microbodies formed from ER which superficially resemble the lysosomes. Peroxisomes are spherical bodies limited by a single membrane. The centre of peroxisomes is occupied by a fine granular core called 'nucleoid'.

Peroxisomes contain oxidising enzymes which are synthesised by ribosomes. These enzymes are uric acid oxidase, D-amino acid oxidase, hydroxyl acid oxidase which produce hydrogen peroxide on oxidation, while peroxisomal catalase, the enzyme found in lysosomes, destroys hydrogen peroxide. Since hydrogen peroxide is toxic to the cell, catalase plays a protective role by breaking down hydrogen peroxide. Hence, peroxisomes play an important role in detoxification. In green plants, peroxisomes carry out a process called photorespiration.

Glyoxysomes are a form of peroxisome which contain enzymes like isocitrate lyase, and malate synthetase which are specific to gloxylate cycle. They also have several Krebs cycle enzymes about which you will study later. Glyoxysomes are the essential components of plant cell.

3.5 MITOCHONDRIA, CHLOROPLAST AND NUCLEUS

Energy transducing: There are different sources of energy like radiant energy, chemical compounds etc. Whatever be the source, it must be converted into a useful form, i.e. adenosine triphosphate (ATP). This transformation is called as energy transformation.

Mitochondria, chloroplast and nucleus are important organelles of the cell. All these organelles share a common characteristic, i.e., they are enclosed with double membranes. Mitochondria are the main energy transducing organelles in animal cells. In plant cells this function is performed by chloroplasts. Both these organelles have structural similarities.

Nucleus is the "central and commanding" organelle of the cell. It is an important distinguishing feature of procaryotic and eucaryotic cell.

You will study about the structure and function of mitochondria, chloroplast and nucleus in the following sub-sections.

3.5.1 Mitochondria

Energy currency (ATP) : The free energy derived from the oxidation of foodstuffs and from light is transformed into a special form before it is used for movement, active transport and biosynthesis etc. This special carrier of free energy is ATP.

Mitochondria, earlier called bioblasts, are found in the cytoplasm of eucaryotic cells and are characterised by specific morphological, biochemical and functional properties. Mitochondria (mito—thread, chondrion— granules) are generally rod shaped elongated structures. They are commonly known as the " power house" of the cell, as they are the sites of ATP (energy currency) production in the cell. Mitochondria are considered to be capable of movement, changing in both shape and position within the cell.

A mitochondrion consists of two membranes (outer and inner) and two compartments (outer and inner). The outer three layered membrane and is separated by a space of 6-8 nm from the inner membrane. The inner membrane has a number of infoldings which are called **cristae** or **mitochondrial crests** (Fig. 3.6). Cristae vary in number and shape. Generally they lie parallel to one another, or are stacked on top of each other forming incomplete compartments as in liver cells. The number of cristae depends on metabolic activity of the cell. Mitochondria themselves are often found concentrated in region of high metabolic activity such cells of cardiac muscles, flight muscles of insect and bird etc.

The fluid filled space between the outer and inner membrane is called the **intermembrane space**. The space surrounded by inner membrane is called **mitochondrial matrix**. It is dense and is made-up of proteinaceous material. The matrix is generally homogeneous but sometimes, may contain a fine filamentous material or small dense granules which are the sites for binding of Mg^{2+} and Ca^{2+} ions. Matrix is continuous within the mitochondria as the cristae do not divide the inner chamber into separate sections. Matrix contains ribosomes, RNA and one or more molecules of circular DNA; an important characteristic of mitochondria. It is because of the presence of DNA, RNA and ribosomes that mitochondria are self replicating and can synthesise some of their own proteins and membrane material.

The enzymes involved in TCA cycle and fatty acid oxidation are found in the matrix. Oxidation and reduction reactions are specifically associated with the inner membrane of mitochondria which brings about the conversion of ADP to ATP.

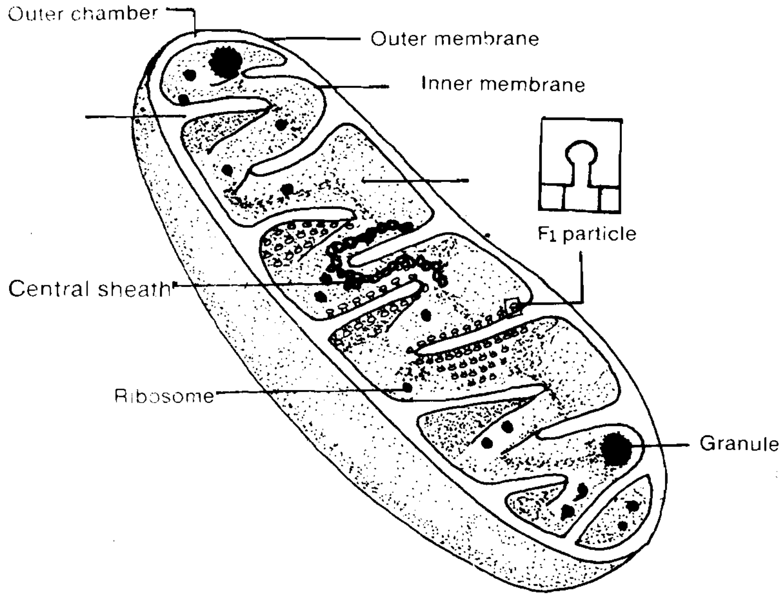


Fig. 3.6 : Three-dimensional diagram of a mitochondrion (longitudinal section). The cristae are the folds of the inner membrane. On their matrix side they have the F_1 particles. The inset shows an F_1 particle with the head piece and stalk.

Cristae appear to be covered with mushroom-like particles, called as **F_1 particles, elementary particles** or **oxysomes**. These particles are small stalked sphere-like structures containing an enzyme, ATPase, that is involved in oxidative phosphorylation. You will study about this in more detail in Block 3. F_1 particles cannot be seen in the intact mitochondria as they are an integral part of the inner membrane.

Since the inner membrane of the mitochondria is the site of ATP production in the cell, greater the number of cristae, the larger the surface area for ATP production.

The structure of mitochondria changes according to the physiological activity occurring in the organelle. If the external ADP content is low or the respiratory chain is inhibited, the mitochondria are seen in **orthodox state** or inactive state. In this state, matrix occupies a larger area of the mitochondria and consequently the outer chamber becomes small.

However, if ADP is added to the medium, there is a sudden contraction of the inner compartment. This is called the **condensed state**, i.e. when mitochondria are actively involved in phosphorylation and electron transport. In the condensed state, the cristae are more randomly distributed and the intermembrane space remains greatly enlarged.

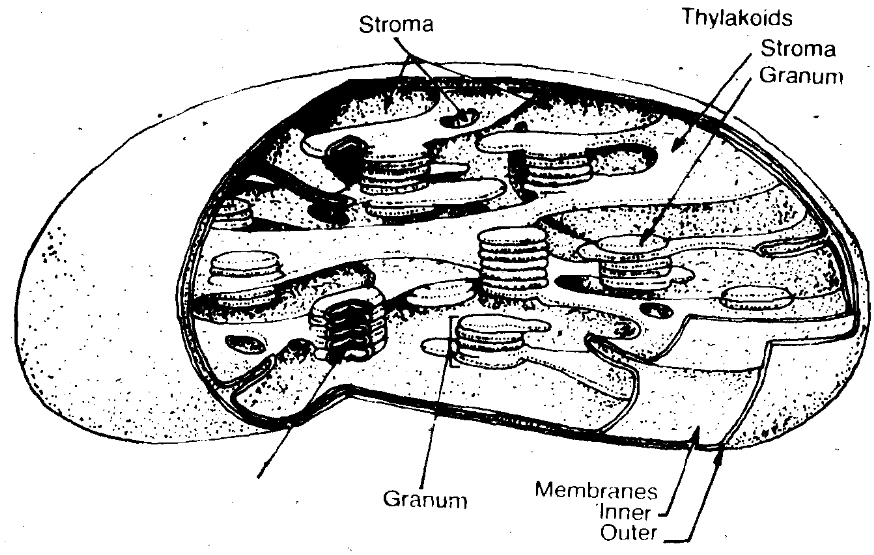
3.5.2 Chloroplast

Plastids are the organelles found in plant cells only. Like mitochondria they are bounded by two membranes. Plastids self replicate as they contain their own genetic material, i.e. DNA, RNA and ribosomes. There are many types of plastids such as **chloroplasts, chromoplasts** and **leucoplasts** depending on the colour pigment they contain.

Chloroplasts, that are mainly found in the cells of leaves of green plants and the most common ones are biologically important plastids. Chloroplasts are limited by a smooth outer membrane which regulates the transport of materials between the cytoplasm and the interior of the organelle. The **inner membrane** runs parallel to the outer membrane and is provided with extensive foldings. The inner membrane gives rise to a series of internal parallel membraneous sheets called lamellae. Lamellae are suspended in a fluid-like matrix called **stroma**. Stroma contains about 50% of soluble protein, ribosomes, DNA and the machinery for protein synthesis (Fig. 3.7).

Most of the lamellae in the chloroplasts are organised to form sac like structures called **thylakoids**. They are flattened vesicles arranged as a membranous network within the stroma. Thylakoids may be stacked like a pile of coins forming the '**grana**'.

A typical chloroplast has between 40-60 grana and each granum may have 2-100 small, flattened thylakoids. When thylakoids are unstacked they are called **stroma**. Fifty per cent of the total chloroplast proteins and the various components involved in the main steps of photosynthesis are present in thylakoids (Fig. 3.7).



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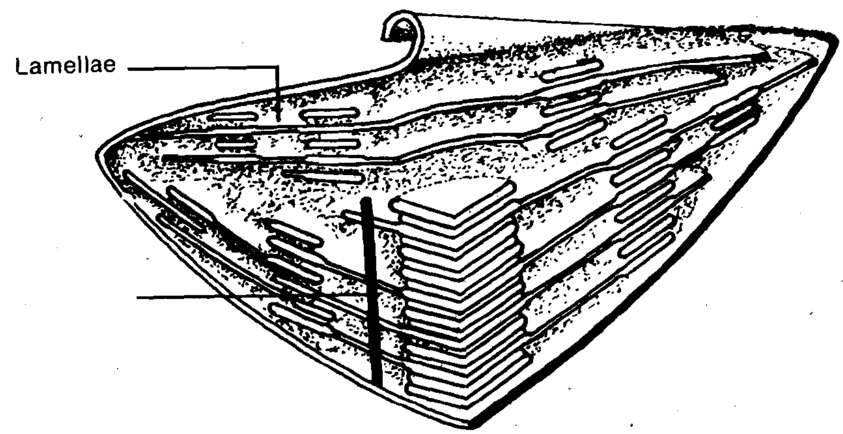

(b)

Fig. 3.7 : a) Structure of chloroplast. The inner membrane of a chloroplast is fused to form stacks called thylakoids within which photosynthesis takes place. Thylakoids are stacked on top of each other in columns called grana.

b) Cross-section of a chloroplast showing the arrangement of lamellae and grana.

The pigments, chlorophyll, carotenoids and plastiquinone are present in the thylakoid membranes involved in photosynthesis. Chlorophyll is the green coloured pigment present in chloroplasts. The function of chlorophyll is to trap the light energy required for the formation of two products: ATP and NADPH essential for the reactions involved in CO_2-assimilation. Chromoplasts are the plastids that synthesise and store the coloured pigments like carotenoids. Carotenoids, which include carotene and xanthophyll, are responsible for the yellow, orange or red colouration in plants. They also act as the precursor of vitamin A in animal tissues. Leucoplasts are colourless plastids which act as storage organelles and are classified on the basis of the material stored, e.g. amyloplasts store carbohydrate in the form of starch.

Some Relationships between Mitochondria and Chloroplast

a) Both, mitochondria and chloroplast originate and develop in the same way. They are formed by fission of pre-existing organelles, as for example, **proplastids** develop to form the mature chloroplast.

b) Both are **semiautonomous organelles** as both contain DNA, RNA and ribosomes. All these components are required for protein synthesis. Mitochondrial DNA (mtDNA) present in matrix is circular in shape. DNA of chloroplast is much bigger than mtDNA. Though ribosomes are also present, but the genetic information of the chloroplasts is limited.

c) The symbiont hypothesis suggests that there are many similarities between procaryotes and mitochondria and chloroplasts, e.g. the presence of DNA and ribosomes. It was thought that mitochondria and chloroplasts may have been procaryotic intracellular parasites which in course of time established symbiotic relationship with eucaryotic cells.

3.5.3 Nucleus

Nucleus is the dominant organelle controlling all the activities of the eucaryotic cell. As you have studied in Unit 1, the procaryotes have nuclear regions in the cytoplasm as opposed to eucaryotes, that have a prominent well defined nucleus. Some cells have more than one nucleus, as for example, rat liver cells have 2-3 nuclei per cell. There are variations in the size and shape of the nucleus. However, some cells lack nucleus at maturity such as RBCs and sieve tube cells (transport cells in vascular plants).

Nucleus was considered to have a single membrane till the use of electron microscope. Under EM, nucleus is found to be composed of two membranes known as "**nuclear envelope**". The outer and inner membranes are separated by a narrow space called the **perinuclear space**. The outer membrane remains in contact with endoplasmic reticulum and the inner membrane surrounds the nuclear contents. At certain places, the nuclear envelope is interrupted by the presence of small structures called "**pores**". The pores are enclosed by circular structures called **annuli**. The pores and annuli together constitute the **pore complex** (Fig. 3.8). Both the membranes of the envelope are in continuity around these pores, The pores help in the exchange of material between nucleoplasm (nuclear fluid) and cytoplasm. Without these pores RNA could not leave the nucleus. The nuclear envelope is a dynamic structure. It is not just a physical barrier, but regulates the passage of ions and small molecules. During a cell division, the nuclear envelope disappears and reappears during nuclear reorganisation.

Nucleoplasm contains a number of structures like nucleolus, chromatin and chromatin network (chromosomes). The nucleolus is a spherical structure which is not separated from the rest of the nucleoplasm by a membrane. It is produced from and is associated with a specific nucleolar organising region (NOR) on a chromosome. In the nucleolus the rRNA is synthesised and the ribosomal subunits, rRNA and proteins are partially assembled. The nucleoli are larger and more numerous in cells that are actively involved in protein synthesis.

During the resting stage of the cell, the chromosomes are uncoiled in a loose, indistinct network called "**chromatin**". Chromosome contains DNA, RNA and protein. The types of protein present are histones and non-histones (see Unit 1).

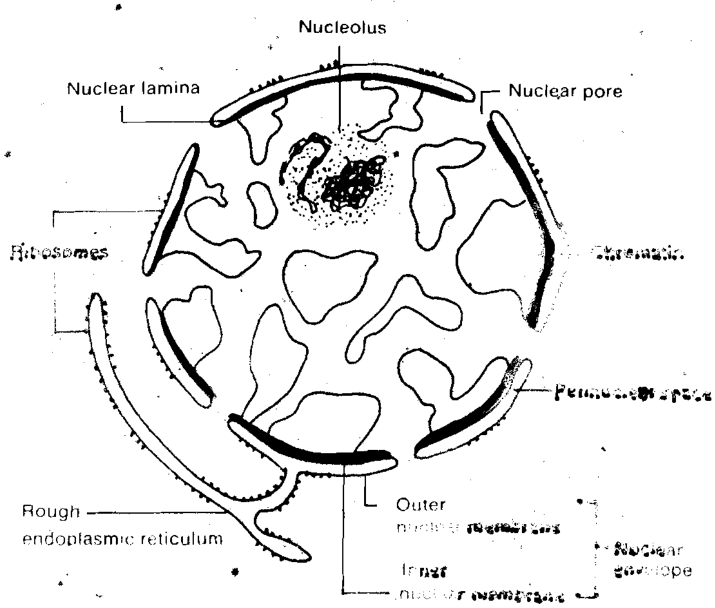

Fig. 3.8 : The nucleus is composed of a double membrane called nuclear envelope which encloses a fluid called nucleoplasm. In cross-section, the individual nuclear pores are seen to extend through the two membrane layers of the envelope.

SAQ 5

a) In the cells of an intestine a lot of energy is required for the transport of materials from the lumen of the intestine into the cells. Which organelle do you think would be very much concentrated in these cells and why? Write your answer in the space provided.

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b) Nuclear membrane is interrupted by nuclear pores at several places. What is their significance? Write your answer in the space given below.

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3.6 CYTOSKELETAL SYSTEM

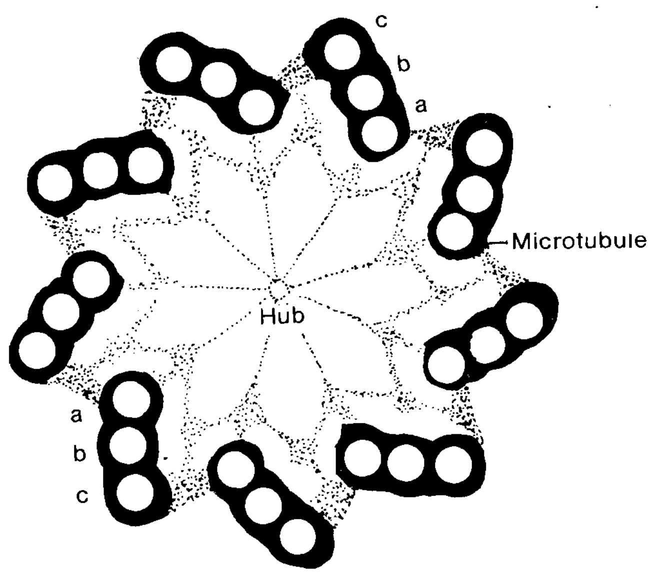
Eucaryotic cells have distinct shapes and a high degree of internal organisation. Moreover, they are capable of changing their shape, of repositioning their internal organelles and in many cases, of migrating from one place to another. These properties of shape, internal organisation and movement depend on complex networks of protein filaments in the cytoplasm that serve as the "bone and muscle" of the eucaryotic cell, which constitutes the cytoskeletal system of the cell. Cytoskeleton maintains the cell shape and helps in the cell movements.

You will study about the structure and function of centriole, cilia and flagella, microtubules and microfilaments, the basic elements of cytoskeleton in this section.

Centrioles and Basal Bodies: Centrioles are usually found near the cell nucleus and occur in pairs. Nine sets of identical triplets of microtubules arranged in a radial manner is an important characteristic of centriole (Fig. 3.9). Basal bodies are structurally similar to centrioles but they produce cilia and flagella unlike centrioles.

Cilia and Flagella

Cilia and flagella are the locomotor organelles that helps to propel a cell towards or away from the materials surrounding the cell. Cilia are generally shorter in size and are more in number than flagella. Flagella usually occur alone or in small groups. The structure of flagella and cilia are similar. Each contains a circle of nine pairs of microtubules with two single microtubules in the centre called as axoneme. Proteins unite the microtubules with axoneme and with each other (Fig. 3.9).



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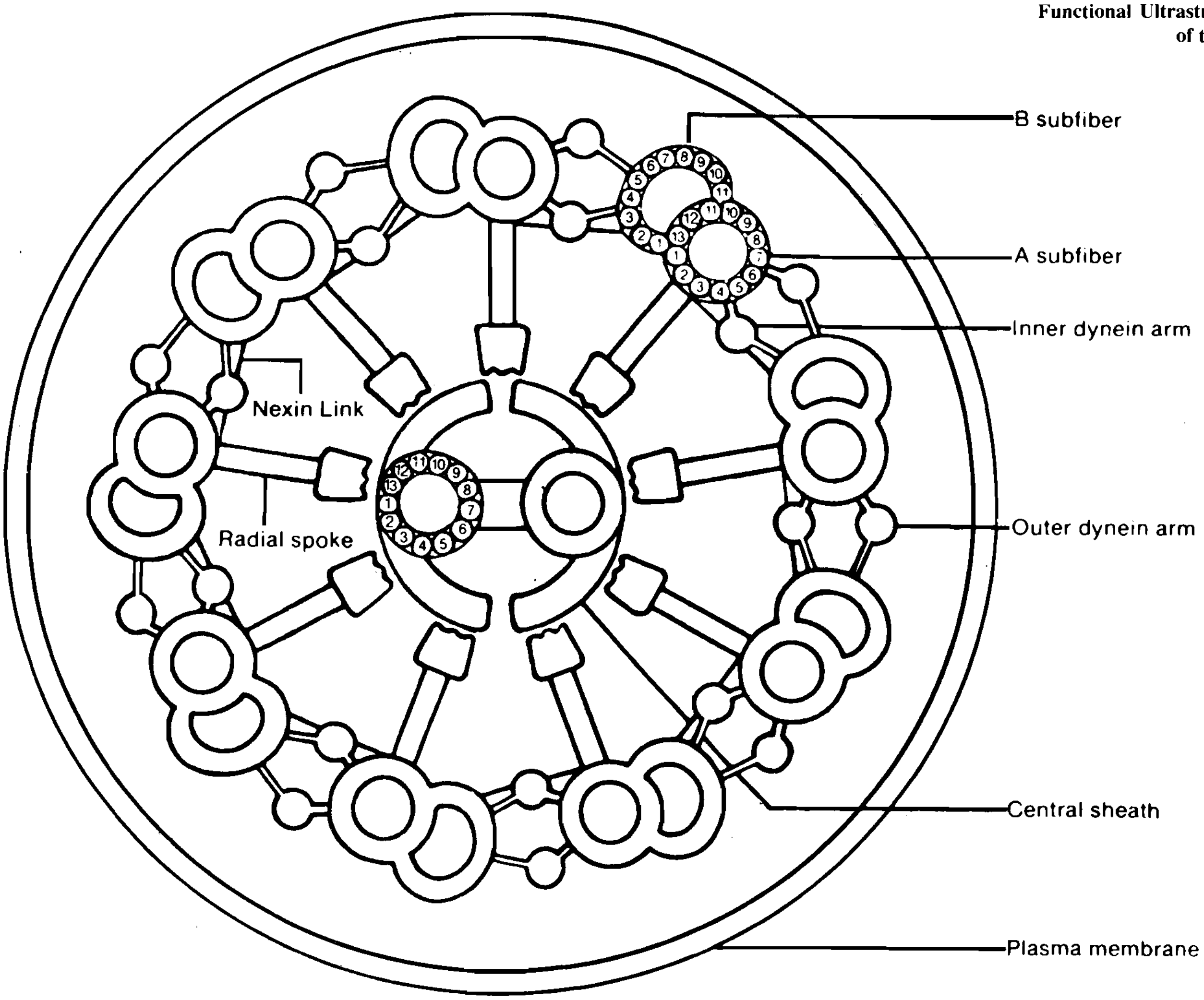

(b)

Fig. 3.9 : a) Diagram of centriole: A centriole has nine sets of identical triplets, each triplet consists of 3 microtubules, one complete (a) and two incomplete (b, c) and the triplets are arranged parallel to one another and in cross-section appear to be arranged like the vanes on a pinwheel. There is no membrane surrounding the centriole. Strands of material extend inwards from each 'a' tubule and join together at the central hub. These strands, when seen in cross-section, give the centrioles the appearance of a 'cartwheel'. b) Diagram of a cilium or flagellum seen in cross-section. Cilia and flagella contain the '9+2' arrangement of microtubules. Nine double microtubules surround the central sheath of two singlet microtubules. One microtubule of each doublet of a subfibre is composed of 13 protofilaments. The B subfibre is incomplete consisting of 11 protofilaments. Radial spokes from each subfibre A extend to the central sheath. Adjacent doublets are joined by interdoublet links extending from each A subfiber are two arms an 'outer' arm and an 'inner' arm which contain a protein dynein that can break down ATP.

Microtubules and Microfilaments

Tubules are the most prominent structural filaments. They are long, hollow cylinders which are polymers of protein tubulin. They help to maintain the cell shape and are important for intracellular movement. Microtubules form dynamic structures such as asters and spindles (related to cell division) and complex organelles such as centrioles, basal bodies, cilia and flagella. During cell division, the microtubules radiate out from the cell centre which is microtubule organising centre and is located near the nucleus. These microtubules are the aster and spindles which play an important part in equal distribution of the chromosomes to the new cells.

Microfilaments are found in close proximity of microtubules and form a network close to the cell membrane. They are made-up of actin and are in continuity with the network of the cytosol. They are the smallest of the cytoplasmic filamentous structure. They perform some cytoskeletal and contractile function and help in cellular motion.

In addition to microtubules and microfilaments, a number of cells contain a cytoskeletal component consisting of filaments of an intermediate size which help in anchorage and

3.7 SUMMARY

In this unit you have studied that:

- The cells have various dynamic cytoplasmic structures which have specific functions to perform. These cytoplasmic organelles have single or double membranous structure. Mitochondria, nucleus and plastids are double membranous while Golgi bodies, and lysosomes have a single surrounding membrane.
- The endoplasmic reticulum is double membranous cell organelle. There are two types of ER: RER and SER. RER is well developed in cells which are actively engaged in protein synthesis whereas SER is well developed in those cells which are actively involved in lipid synthesis.
- The Golgi complex (dictyosome in plants) is located between ER and plasma membrane. Each dictyosome has two faces having a proximal face near the nuclear membrane and a distal face which yields secretory vesicles.
- Lysosomes have a digestive function both in plant and animal cells. They contain hydrolases which bring about digestion of the biological substances. Lysosomes exhibit polymorphism which means occurrence of lysosomes in different forms: primary lysosomes, secondary lysosomes, autophagic vacuoles and residual bodies.
- Endocytosis is the process of taking in solid and liquid food by phagocytosis and pinocytosis respectively. Exocytosis is the opposite process through which inside content of cell is removed outside cell.
- Mitochondria, the power house of the cell are cylindrical structures having outer and inner membranes. Inner membrane is folded into a number of cristae which expose F_1 particles upon hydrolysis of membrane. Mitochondrial matrix contains DNA, ribosomes and all the enzymes which take part in Tri Carboxylic Acid cycle (TCA).
- Plastids are of various types: chloroplasts, amyloplasts, and leucoplasts. Chloroplasts are most abundant and are present in all green plants. Chloroplasts contain a matrix substance called **stroma** in which number of **lamellae** or thylakoids are suspended. The stacked **thylakoids** constitute grana.
- Nucleus is a double membranous structure. Outer membrane or envelope remains in continuation with ER whereas inner membrane encloses nucleoplasm. In nucleoplasm, the chromatin network is embedded. The nucleus contains DNA, RNA and proteins which are both acidic and basic.
- Centriole, cilia, flagella, microtubules and microfilaments constitute the cytoskeletal system. Centriole is present mostly in animal cells. The cross-section of centriole reveals nine triplets of microtubules. Each triplet having 2 complete (A and B) and 1 incomplete (C) rings. In the centre there is no microtubule, thus exhibiting 9+0 pattern. Centrioles take part in cell division. Cilia and flagella have similar structure but they differ in having centrioles with 9+2 pattern, 9 microtubules are in the form of doublets (A and B) and the central 2 microtubules. The A and B rings have dynein arm. Cilia are more in number and smaller in size than flagella. Both help in locomotion.

3.8 TERMINAL QUESTIONS

1) How do peroxisomes play a role in detoxification? Write your answer in 3-4 lines.

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2) Why are mitochondria and chloroplasts considered as semiautonomous organelles? Write your answer in about 35-40 words.

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3) Write two important differences between structural organisation of centriole and cilia or flagella.

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3.9 ANSWERS

Self-assessment Questions

1) i) Protein synthesis
   ii) Lipid metabolism

2) This is due to location of Golgi complex between the ER and plasma membrane.

3) Golgi complex, as it plays an important role in secretion.

4) Autophagic vacuole, because during pathological conditions, autodigestion of cellular organelles, mostly mitochondria takes place to generate energy.

5) a) Mitochondria, because these generate energy (ATP) in the cell.
   b) The pores help in the exchange of material between nucleoplasm and cytoplasm.

Terminal Questions

1) The enzyme catalase present in peroxisomes breaks down H_2O_2, a toxic substance into a non-toxic substance and thereby plays an important role in detoxification.
2) DNA, the hereditary material, and ribosomes, the machinery for protein synthesis are present in mitochondria and chloroplasts, hence they are considered as semiautonomous organelles.
3) i) In centriole the microtubules have '9+0' organisation whereas in cilia/flagella, the microtubules have '9+2' organisation.
   ii) In centriole, 9 microtubules are in the form of triplets whereas in cilia/flagella, 9 microtubules are in the form of doublets.