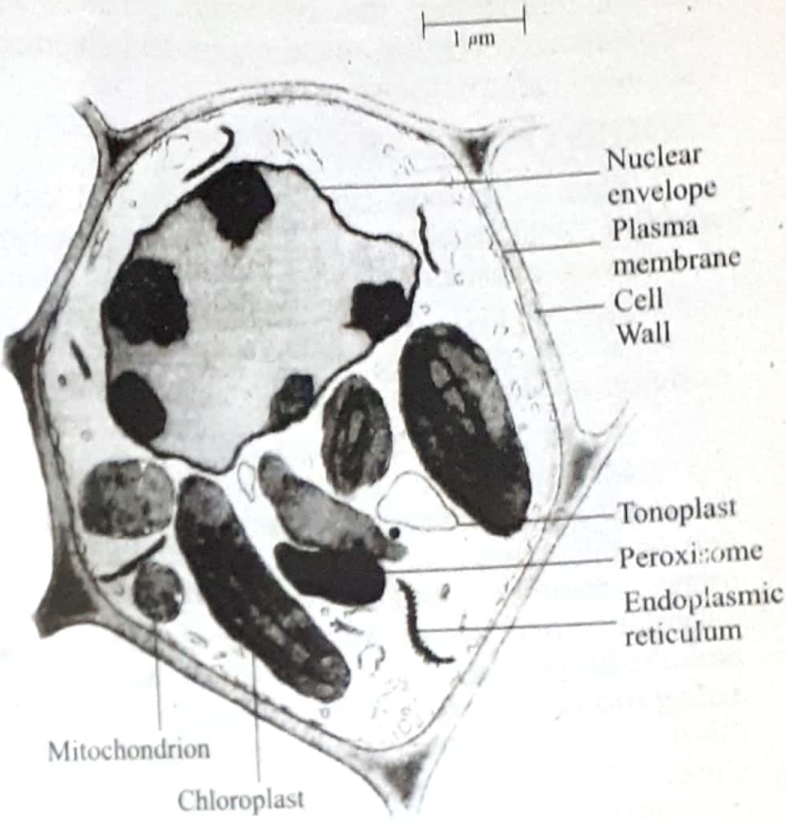
ULTRASTRUCRURE OF PLANT CELL

The cells are fundamental units of life, both in structure and function. The plant cell typically consists of a more or less rigid **cell wall** and a **protoplast** (the term refers to contents of the cell). A protoplast consists of **protoplasm** and a **nucleus**. The cytoplasm is bounded externally by the **plasma membrane** (also called **plasmalemma** or **cell surface membrane**) and includes organelles, systems of membranes, and non-membranous structures such as **ribosomes**. The rest of the cytoplasm is called **cytosol**. Nucleus, various bodies and membrane systems are suspended in the cytosol. Plant cells develop one or more liquid filled cavities called **vacuoles** within the cytosol. A single membrane called the **tonoplast** bound the vacuole. The vacuoles usually make bulk of the plant cell. The cytoplasm and its component structures are the sites of chemical reactions of life.



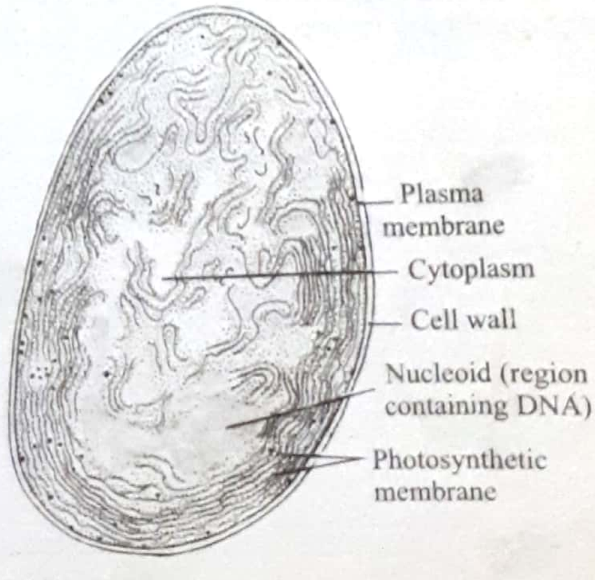
A typical plant cell

Nucleus is surrounded by a pair of membrane, the **nuclear membranes** that form nuclear envelope, and contains one or more compact spherical **nucleoli** (singular: **nucleolus** – the sites for synthesis of ribosome subunits) suspended in **nucleoplasm**. Thin threads and grains of **chromatin** (DNA combined with large amounts of histone proteins) are present in the nucleoplasm. The nucleus controls and directs the activities of the cell. The cell wall is composed of cellulose, pectins, hemicelluloses and some proteins. Adjacent plant cell walls are cemented together by the **middle lamella** between them. There are cytoplasmic connections between cells, called **plasmodesmata**.

BASIC CELL TYPES

Electron microscope has led to the discovery of two types of cellular organization: **prokaryotes** (Gr. *Pro*=before, *karyon*=nucleus) and **eukaryotes** (Gr. *Eu*=good, *karyon*=nucleus).

In **prokaryotes** (bacteria and cyanobacteria) the cell is without true nucleus (membrane bound); there is a single circular chromosome in the form of ring of deoxyribonucleic acid in the cytoplasm; the cell lacks mitochondria, chloroplasts (membrane bound organelle); and the cells are extremely small.



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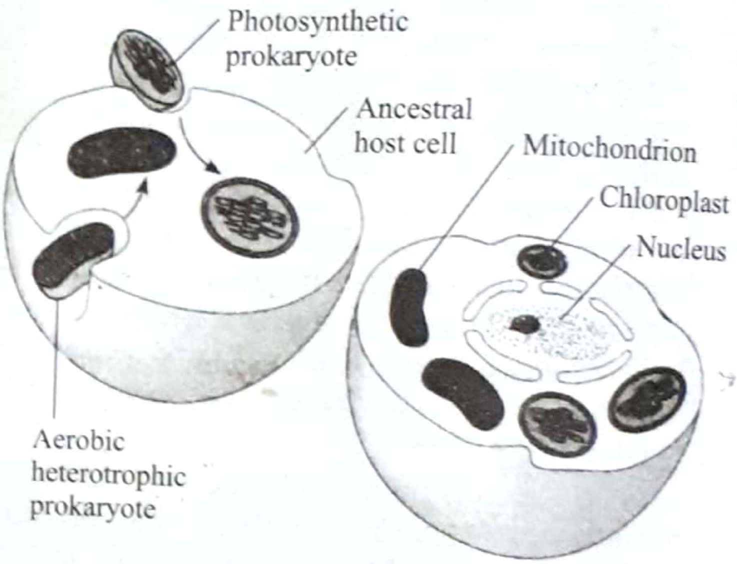
In **eukaryotes** (plants, animals, fungi), the cell has a nucleus is surrounded by nuclear membrane, the cytoplasm contains membrane bound organelle such as endoplasmic reticulum, mitochondria and chloroplasts; and the cell wall (when present) usually includes cellulose or chitin.

ORIGIN OF EUKARYOTES

One of the most significant events that took place in the evolution of life on earth was the transformation of relatively simple prokaryotic cells into complex eukaryotic cells. It involves evolution of **endomembrane system** (nuclear membrane, mitochondria, chloroplasts, etc). **K. C. Mereshkowsky** (1905) speculated that plastids and mitochondria might be prokaryotes living inside eukaryotic cells. This was called **endosymbiotic theory**.

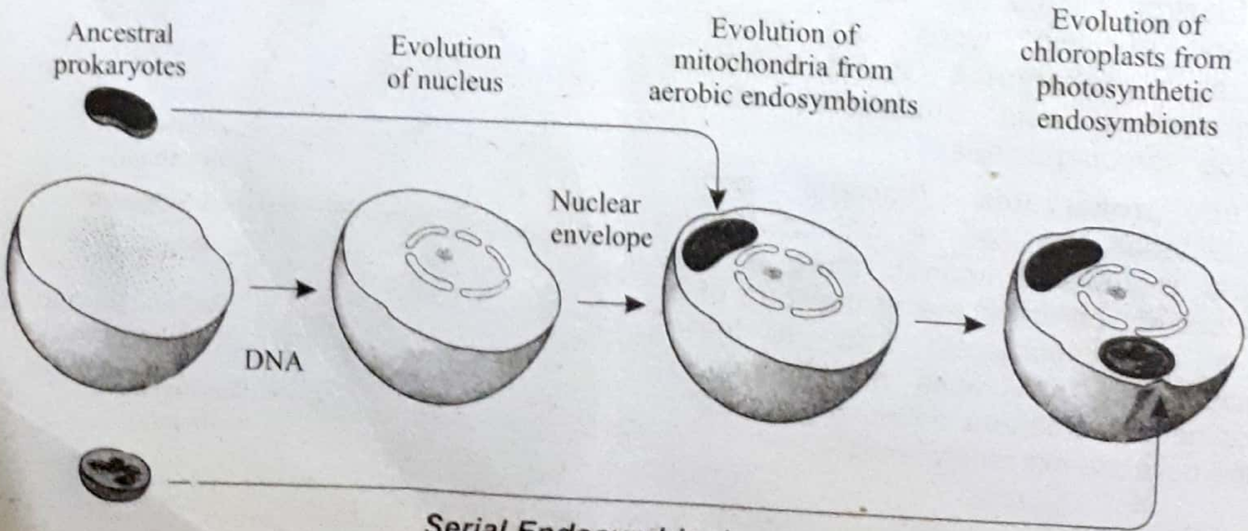
At that time there was no way to test the theory and until early 1970s, it was assumed that some intermediate had given rise to eukaryotes by gradually becoming more complex and developing an endomembrane system with mitochondria and chloroplasts. This is known as **autogenous theory**. The cyanobacteria (then known as blue-green algae) were believed to be the intermediates. However, in 1960s the endosymbiont theory was revived and **Lynn Margulis** developed it extensively. He focused attention on the origins of mitochondria and chloroplasts. The proposed ancestors of mitochondria were endosymbiotic bacteria that were aerobic heterotrophic, and chloroplasts are descendents of photosynthetic prokaryotes, probably cyanobacteria that became endosymbionts within larger cells.



(b) Endosymbiosis

Endosymbiosis

The concept that explains origin of mitochondria and chloroplasts is termed **serial endosymbiotic theory**, and the prokaryotic ancestors of mitochondria and chloroplasts are called **endosymbionts** (a cell that lives within another cell, termed **host cell**). The mitochondria are believed to evolve before chloroplasts.



Serial Endosymbiosis

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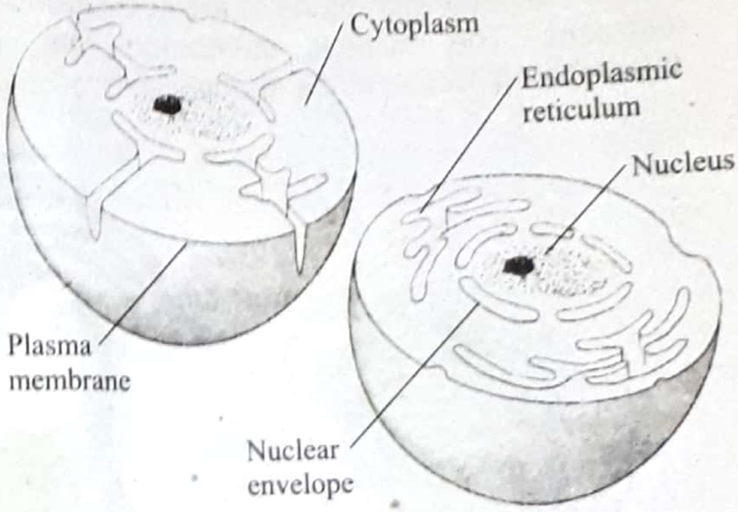
Origin of Endomembrane System

The endosymbiont theory postulates that a heterotrophic prokaryotic phagocyte (eating cell, that was living and engulfing and digesting other cells, mostly bacteria) had evolved to the point of having some eukaryotic features such as 80 S ribosomes and a nuclear envelope. It is likely that the host cell lost its cell wall and this free-living, naked cell now had the ability to increase in size, change shape and engulf extracellular objects by infolding of plasma membrane (endocytosis). The plasma membrane formed infolding that gradually divided the host cell into compartments forming nuclear membrane, mitochondria, chloroplasts, etc of the eukaryotic cell.



Invagination of plasma membrane

The DNA becomes attached to one such infolding resulting in a precursor of the nucleus. Later this infolding enclosed the DNA within the intracellular sac forming the primordial **nucleus**. A cytoskeleton developed to provide inner support to the host cell and to play a role in movement of both the cell itself and its internal components. This theory is called **membrane invagination hypothesis**.

Origin of Mitochondria and Chloroplasts

The mitochondria of the eukaryotic cell had their origin as bacterial endosymbionts, which ultimately transferred most of their DNA to the host nucleus. The host cell engulfed bacterium and instead of digesting it established a symbiotic relationship. The endosymbiont lost its cell wall and other unneeded structures, its DNA was gradually transferred to host nucleus and the endosymbiont is transformed into a **mitochondrion**. The **chloroplasts** could arise in the same way as a mitochondrion if the engulfed partner (endosymbiont) is a cyanobacterium.

The *Vorticella* is an example of a modern protist that establishes endosymbiosis with certain species of green algae *Chlorella*. The algal cells remain intact within the host cells, and provide nutrition to the heterotrophic host. In turn, the algal cell receives mineral nutrients from the host. There are many examples of prokaryotic (bacterial) and eukaryotic endosymbionts in other protests, as well as in the cells of some 150 genera of freshwater and marine invertebrates.

NUCLEUS

The nucleus is large, complex and often the most prominent organelle that occupy a major portion of the cell volume within the protoplast of eukaryotic cells. It serves as permanent storage place for the organism's genetic information, and control the cell activities by determining which protein molecules are produced by the cell and when they are produced.

The nucleus is always surrounded by a **nuclear envelope** which is actually an **outer membrane** and an **inner membrane**. The envelope contains a large number of circular pores, the **nuclear pores**. At each pore, the inner and outer membranes are joined, forming the pore's lining. The nuclear pores have a complex structure and are

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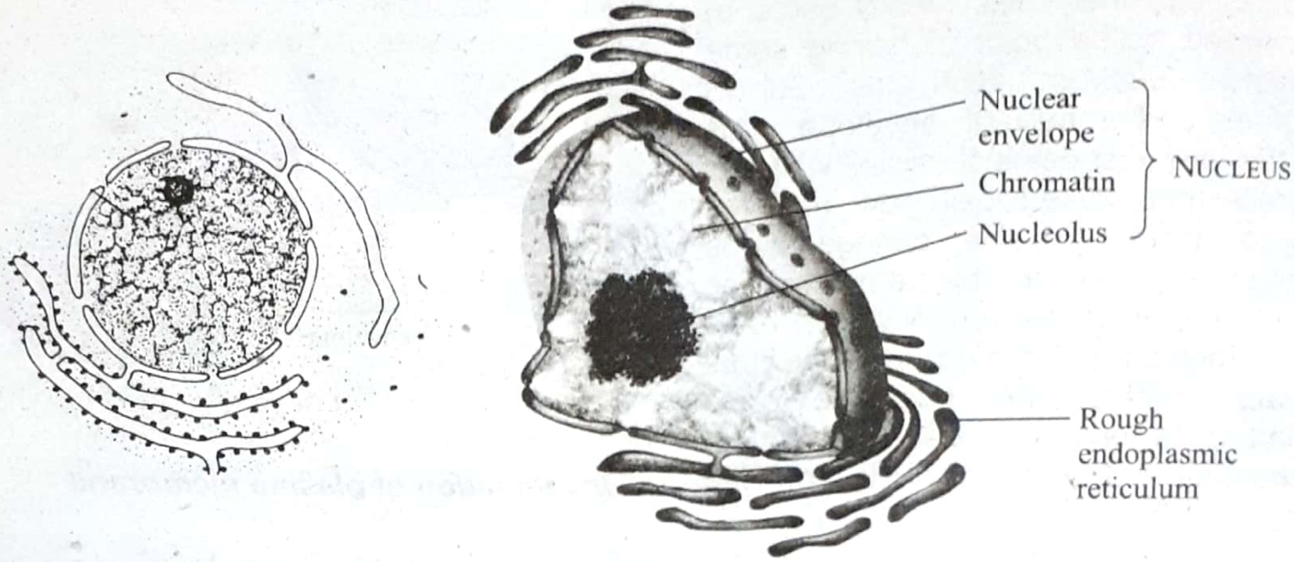
involved in exchange of materials between the nucleus and the cytoplasm. In various places the outer membrane of the nuclear envelope may be continuous with endoplasmic reticulum. The nuclear membrane may be considered as specialized, locally differentiated portion of the endoplasmic reticulum.



A substance, the **nuceloplasm** is present within nucleus. It is a complex association of DNA, enzymes, histone proteins, several types of RNA, and water. Nuclear DNA is always associated with histones, and this complex of the two is known as **chromatin**. In non-dividing nuclei the chromatin is dispersed and attached at one or more sites to the inner surface of the nuclear envelope. During nuclear division the chromatin becomes progressively more condensed as individual **chromosome**. The molecules of DNA contained within the chromosome carry hereditary information. Inside every nucleus is, one, two or rarely several bodies called **nucleoli** (sing: nucleolus). In most diploid organisms, the nucleolus contains two nucleoli, one for each haploid set of chromosomes. Each nucleolus contains large amounts of RNA and protein, along with large loops of DNA, known as **nucleolar organizing regions**, the sites where components of ribosomes are synthesized and partially assembled. Each ribosome contains a large amount of ribosomal RNA copied from ribosomal genes in the chromatin.

ENDOPLASMIC RETICULUM

The endoplasmic reticulum (ER) is a complex, three-dimensional membrane system. In sectional view, the ER appears as two parallel membranes with a narrow space or lumen between them. Each of the parallel ER membranes is a unit membrane. The endoplasmic reticulum may be: rough endoplasmic reticulum (RER) or smooth endoplasmic reticulum (SER). Both rough and smooth forms of ER occur in the same cell and have numerous connections between them. Some electron micrographs show that rough ER to be continuous with the outer membrane of the nuclear envelope. The ER functions as a communications system within the cell and as a system for transporting materials, such as proteins and lipids, to different parts of the cell.

Rough endoplasmic reticulum, which consists of flattened sacs or **cisternae** (sing: cisternum) with numerous ribosomes on their outer surface. This type of ER is abundant in cells that store proteins. As an attached ribosome synthesizes a protein, it passes through the membrane and collects the protein in the lumen. If the protein is a storage protein, it remains in ER; and if a secretory protein such as mucilage, nectar, etc

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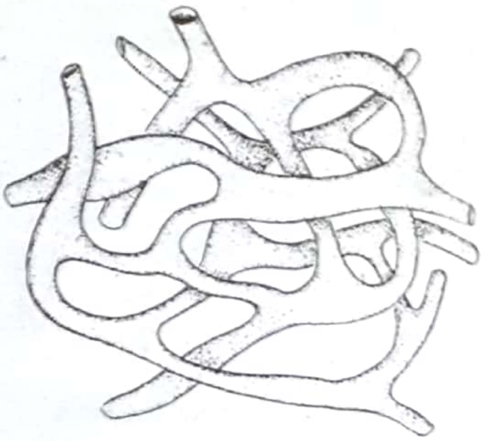
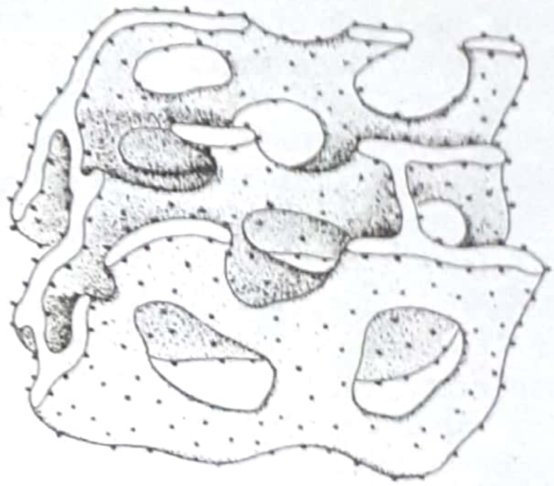
is synthesized, the ER forms a vesicle that detaches and move to the plasma membrane. In many cells proteins may be modified before export (glycoproteins).

Smooth endoplasmic reticulum (SER) lacks ribosomes and is largely in tubular form. Smooth ER is involved in lipid synthesis (therefore take part in membrane formation), and forms extensive system in cells that produce large amount of fatty acids (cutin and wax on epidermal cells), oils (palm oil and coconut oil), and fragrance of many flowers.



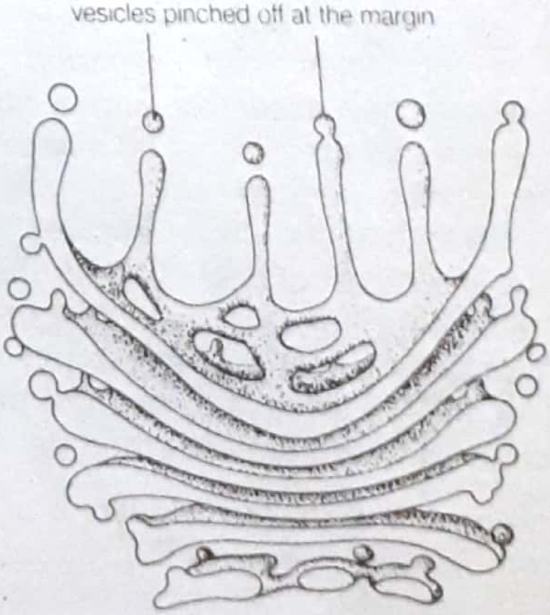
Tubular form of ER



Sheet form of ER

DICTYOSOMES or GOLGI BODIES

Dictyosomes are flat or curved stacks of flattened vesicles. Much of the material secreted by a cell must first be modified by a dictyosome. ER vesicles accumulate on one side of the dictyosome, then fuse together and form a wide, thin vesicle called a **cisterna** (pl: **cisternae**) that become attached to dictyosome. Soon more ER vesicles gather next to this one and form new cisterna. The first cisterna becomes embedded more deeply in the dictyosome as more vesicles accumulate on that side. This side is called **forming face**. After the contents of the vesicles are processed, vesicles are released from the other end known as **maturing face**. After separation the vesicles can move to the plasma membrane and release their contents. The outer edges of dictyosomes form an interconnected network of curving tubes, and these may absorb the contents from the centre of the dictyosome cisterna, then detach and move away.



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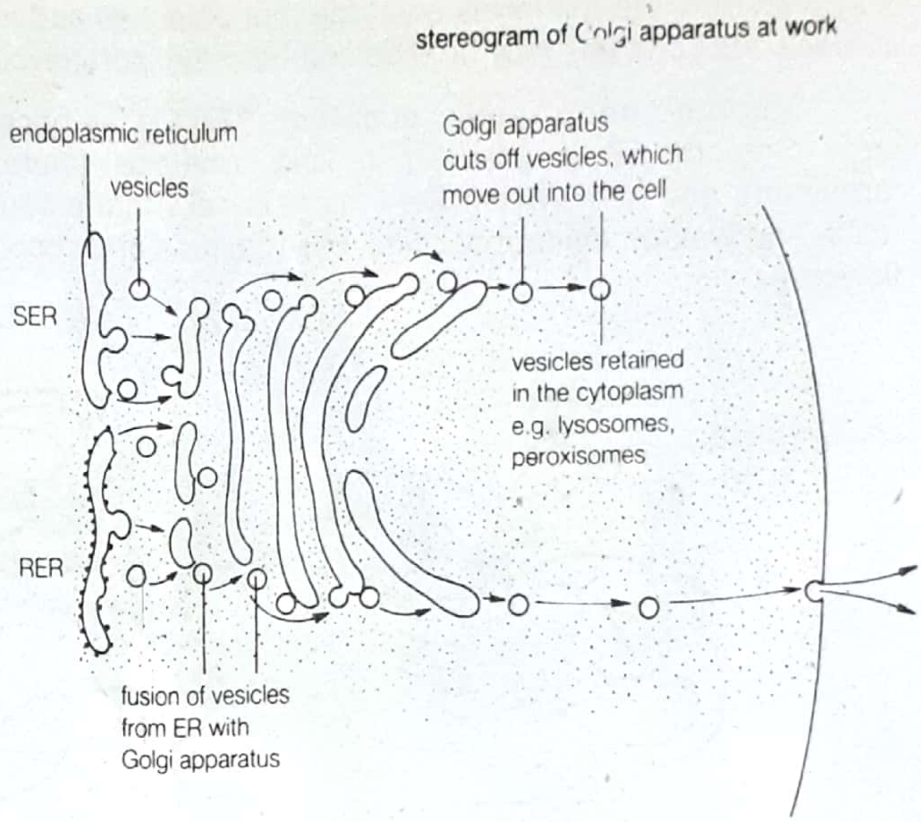
Dictyosomes can form large, complex associations. In animal cells that secrete very large amount of proteins, hundreds of dictyosomes lie side by side and form a cup-shaped structure called **Golgi body** or **Golgi apparatus**. In the Golgi body, the dictyosome's maturing faces are on the inner side of the cup, while the forming faces and associated ER are on the outside. Dictyosomes only rarely aggregate into Golgi bodies in plants, one example being the root hair where growth and cell wall formation occur.



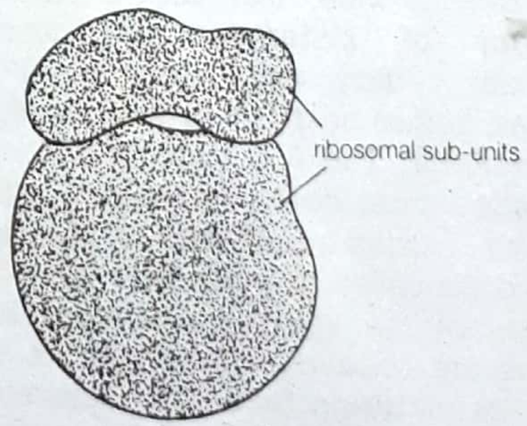
the role of the Golgi apparatus

Different types of processing may occur within a dictyosome. The modification of vesicle's contents involves addition of sugars onto proteins, forming glycoproteins. Sugar- containing proteins occur in plasma membrane, the cell wall, and storage products in seeds. There is strong evidence that dictyosomes polymerise sugars to polysaccharides used in cell wall construction.

RIBOSOMES

Ribosomes are small cytoplasmic particles only about 17 to 23 nanometers in diameter that read the genetic message in mRNA and construct proteins guided by that information.

Each ribosomes is composed of two subunits, one larger and the other smaller produced in nucleolus and exported to the cytoplasm where they assemble into a ribosome. Each subunit is made up of about 80 different types of **proteins** (exact number still unknown) and **ribosomal RNA** (rRNA). The smaller subunit contains one molecule of rRNA and the large subunit contains one molecule each of three types of rRNA. When ribosome subunits fit together there is a groove for mRNA to pass through, a **channel** through which the growing protein emerges.



Ribosomes found in the cytoplasm of eukaryotes are designated as **80S** (**S** is a **Svedberg unit**, used to measure the rate at which a particle sediments in a centrifuge). Ribosomes of plastids, mitochondria and prokaryotes are smaller, lighter **70S ribosomes**.

Ribosomes actively involved in protein synthesis occur in clusters or aggregates called **polysomes** or **polyribosomes**. Each molecule of messenger RNA is long enough for six to ten ribosomes to attach to it and read it simultaneously. The ribosomes are thus

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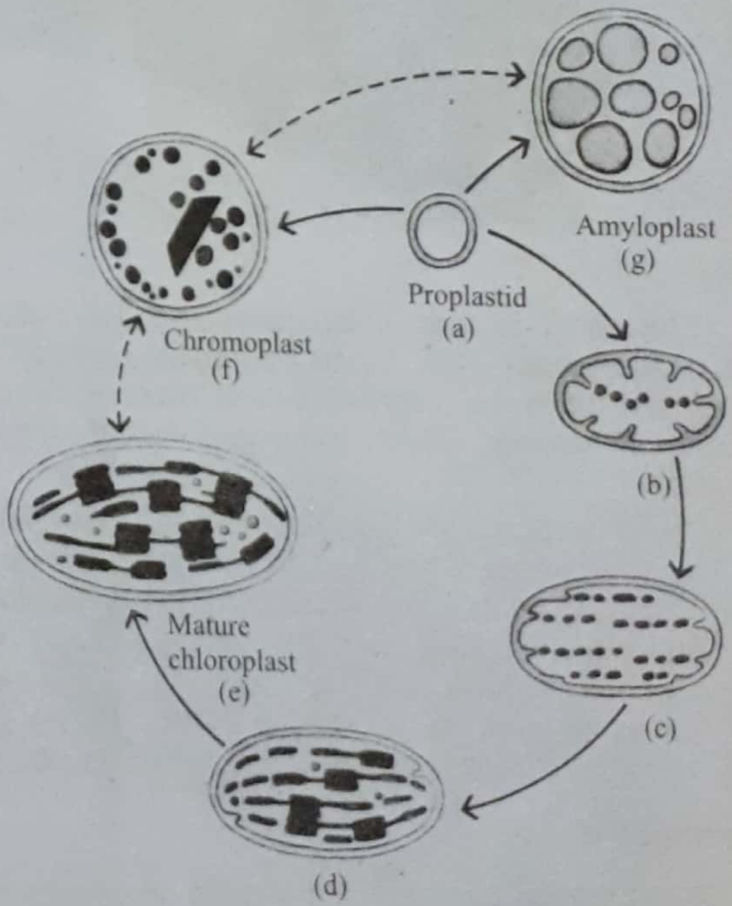
bound together by the messenger RNA forming a cluster. A single ribosome can make an average-sized polypeptide in less than a minute. However, a single mRNA is used to make many copies of a polypeptide simultaneously, because several ribosomes work on translating the message at the same time. Once a ribosome moves past the initiation codon, a second ribosome can attach to the mRNA, and thus several ribosomes may trail along the same mRNA.

PLASTIDS

Plastids are characteristics structures of plant cells that are concerned with processes such as photosynthesis and storage. The principal types of plastids are **chloroplasts**, **chromoplasts** and leucoplasts. An envelope consisting of two membranes bound each plastid. Internally, the plastid is differentiated into a system of membranes or **thylakoids**, and a more or less homogeneous matrix, the **stroma**. The degree of development of thylakoid system varies among plastid types. Plastids are semi-autonomous organelles that contain one or more **nucleoids**, the grana-free regions containing DNA; and ribosomes about two-thirds the size of ribosome found in cytoplasm. The plastids reproduce by fission (the process of dividing into equal halves).

Proplastids

All the three types of plastids arise from small, colourless, pale green, undifferentiated plastids called **proplastids** present in meristematic (dividing cells) of roots and shoots. They are the precursors of more highly differentiated plastids such as chloroplasts, chromoplasts or amyloplasts (leucoplasts that store starch grains). Initially the proplastid contains few or no internal membranes. As the proplastid differentiates into a chloroplast, flattened vesicles develop from the inner membrane of the plastid envelope and eventually align themselves into grana and stroma thylakoids. The thylakoid system of mature chloroplast appears discontinuous with the envelope. Proplastids may also develop into chromoplasts and leucoplasts. The chromoplasts may also be formed from chloroplasts or amyloplasts.



Chloroplasts

Chloroplasts are green, disc-shaped plastids that contain chlorophylls and carotenoid pigments. The green colour of the chloroplasts is because of chlorophyll. The chlorophyll pigments are receptors for light energy necessary for photosynthesis, therefore chloroplasts act as sites of photosynthesis. Two membranes, **outer membrane** and an **inner membrane** surround the chloroplast. Both these membranes are separated

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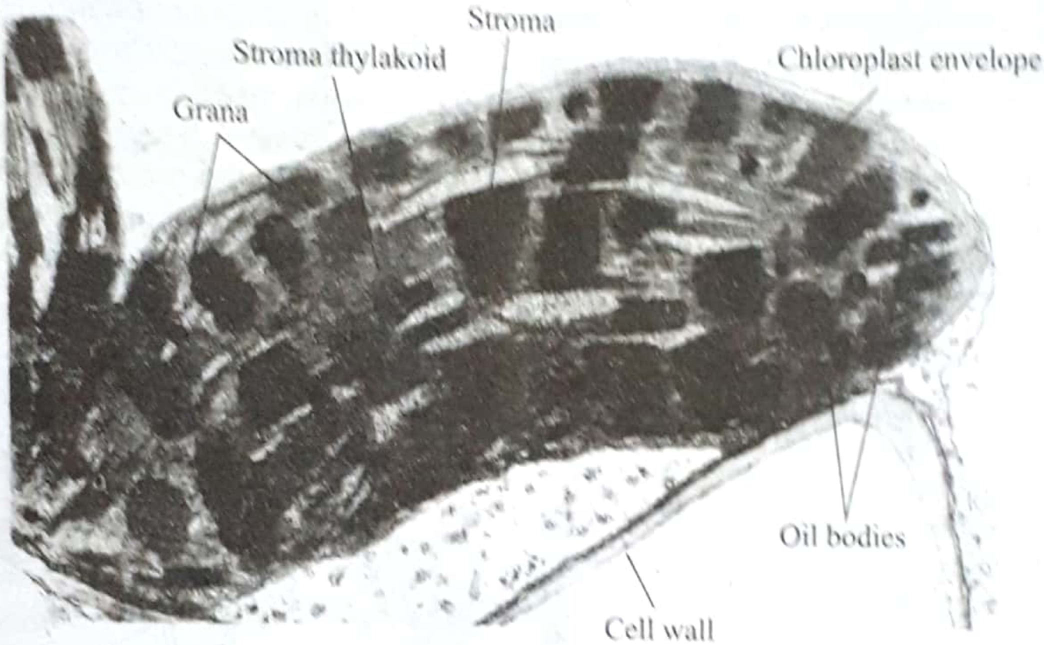
by a very narrow intermembrane space. The inner membrane encloses a fluid known as **stroma**. The inner membrane becomes extensively folded to form membranous sheets called **thylakoids** that project into the matrix. In certain regions the thylakoids form small bag-like vesicles (grana thylakoids) that become stacked together. The stack of vesicles is called a **granum** (pl.: grana). Thus, the inner membrane divides the interior of chloroplast into two compartments, the thylakoid space and the stroma. Chlorophylls and carotenoid pigments are embedded in the thylakoid membranes. These pigments are responsible for capturing light that drives photosynthesis. The DNA of the chloroplast exists in circular form and is not associated with histones



The ability to form chloroplasts and the pigments involves the contribution of nuclear and plastid DNA. Some chloroplast proteins are encoded by plastid DNA and synthesized within the chloroplast itself. Most of the chloroplast proteins, however, are encoded by nuclear DNA, synthesized in the cytosol, and then imported into the chloroplast.

The chloroplasts are the ultimate source of virtually all of our food supplies and our fuel. The chloroplasts of green algae and plants often contain starch grains and small oil bodies (lipid pigments, carotenoids) called **plastoglobuli** (sing: plastoglobulus). The starch grains are temporary storage products and accumulate only when the alga or plant is actively photosynthesizing. They may be lacking in the chloroplasts of plants that have been kept in the dark for as little as 24 hours. The starch has been broken down to supply sugar to the plant, which is unable to photosynthesize in the dark.

Chromoplasts

Chromoplasts are pigmented plastids of variable shape. These lack chlorophyll but synthesize carotenoid pigments and are often responsible for the yellow, orange or red colour of many flowers, old leaves, some fruits and some roots such as carrots. Chromoplasts contain an extensive membrane system but grana are absent. The pigments may be present either as part of the membrane or discrete droplets, **plastoglobuli** (sing: plastoglobulus). As fruits ripen, chloroplasts often synthesize large amounts of lipid pigments, alter their thylakoids and convert to chromoplasts.

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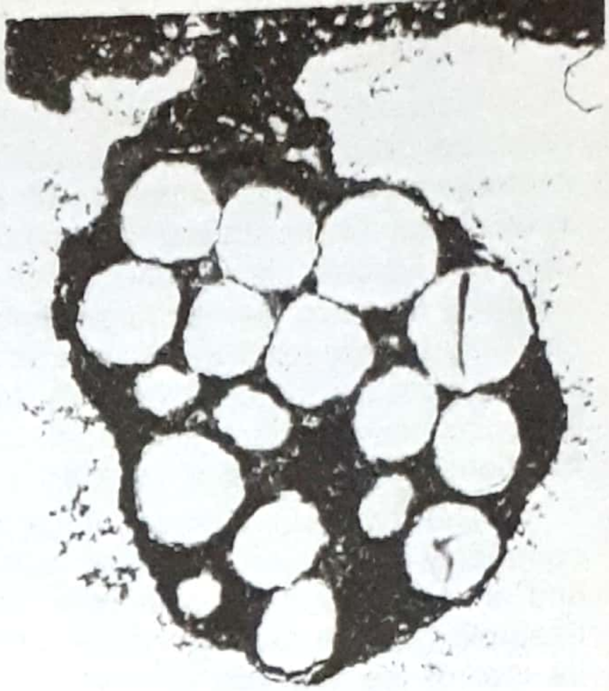
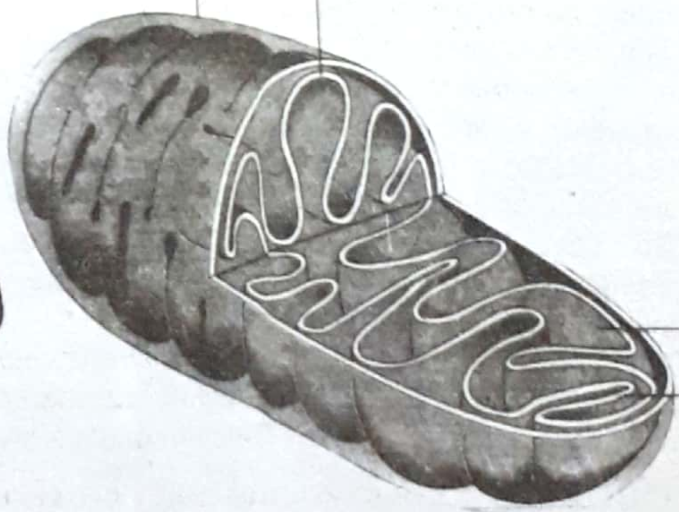
Leucoplasts



Leucoplasts are unpigmented plastids that have neither chlorophyll nor lipid pigments (carotenoids). These are least differentiated structurally and lack an elaborate membrane system. The leucoplasts are involved in synthesis of many types of fats and lipids which are transported to other organelles and inserted into their membranes, and proteins. Some leucoplasts known as amyloplasts synthesize starch. In plants **iron** is stored attached to a large protein called **phytoferritin** in leucoplasts.

MITOCHONDRIA

Mitochondria are the organelles that carry out cellular respiration. Each mitochondrion is enclosed in an envelope of two membranes. The outer membrane is smooth, but the inner membrane is folded forming large sheets or tubes called **cristae** (sing: crista). Many respiratory enzymes are embedded in the cristae. The cristae provide large surface area to make it possible to contain many copies of each enzyme, therefore more reactions can occur simultaneously. The outer and inner membranes enclose intermembrane space. The outer membrane is freely permeable, but the inner membrane is selectively permeable and has numerous pumps and channels. The inner membrane encloses a compartment, the **mitochondrial matrix** that also contains enzymes for some steps of cellular respiration.



Mitochondria are semiautonous organelles that measure about half a micrometer in diameter and exhibit great variation in length and shape. They divide by fission. The inner membrane of mitochondrial matrix contains RNA, DNA and small ribosomes similar to those of bacteria. The DNA occurs as circular molecules in one or more clear areas called **nucleoids**. Mitochondria are in constant motion, turning and twisting and moving from one part of the cell to another. Mitochondria tend to aggregate where energy is required. In some species mitochondria fuse together to form a giant mitochondrion.

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VACUOLE

Vacuoles are membrane-bound regions within the cell that are filled with a liquid called **cell sap**. The single membrane surrounding the vacuole is known as **tonoplast** or **vacuole membrane**. Together with plastids and a cell wall, the vacuole is one of the three characteristic structures that distinguish plant cells from animal cells. The immature plant cell typically contains numerous small vacuoles but as the cell grows and enlarges, vacuoles fuse into a single large **central vacuole**. About 90% of the volume of a mature cell may be occupied by vacuole and the cytoplasm consists of a thin peripheral layer closely pressed against the cell wall. The vacuole may originate directly from the endoplasmic reticulum and Golgi complex. Different kinds of vacuoles with distinct functions may be found in a single mature cell.

The principal component of the cell sap is water. In addition the vacuoles commonly contain inorganic ions such as Ca^{2+}, K^+, Na^+ and H_2PO_4; sugars; organic acids and amino acids. If a substance is present in higher concentration, it forms crystals, for example Calcium oxalate crystals. Cell sap is usually slightly acidic. Some cell sap, such as that of the vacuoles in citrus fruits, is very acidic. In most cases vacuoles do not synthesize the molecules they accumulate but instead receive them from other parts of the cytoplasm.

Vacuoles perform a variety of functions. These include:

i. Vacuoles are important storage compartments for both nutrients, such as sugars and organic acids; and reserves, for example proteins stored in seeds that are used when seed germinate.

ii. Vacuole help in cell growth. Most of the increase in the size of the cell results from enlargement of vacuoles. This also results in development of internal pressure and maintenance of tissue rigidity.

iii. A system to excrete wastes never evolved in plants; instead metabolic waste products are pumped across the tonoplast and stored permanently in the central vacuole. The tonoplast is impermeable to these wastes, therefore these do not leak back into the cytoplasm. Most of these compounds are bitter and noxious therefore keep the grazing animals away.

iv. The central vacuole is a digestive organelle as well. As organelles age and become non-functional they fuse with the tonoplast and are transported into the central vacuole, where digestive enzymes break them down. Therefore, vacuoles are comparable in function with the lysosomes in animal cells. The liberated monomers are transported back to the rest of the cell where they are used again.

v. The vacuole is often a site of water soluble pigment deposition, especially anthocyanins that provide blue, violet, purple, dark red and scarlet colours of plant cells, vegetable, fruits and flowers.

vi. Calcium regulates the activity of many enzymes, and plant cells keep protoplasmic concentrations at the proper level by moving calcium into vacuoles, where it reacts with oxalic acid to form inert Calcium oxalate crystals.

MICROBODIES – Glyoxysomes and Peroxisomes

Microbodies are electron microscopic structures about the size of 0.5 to 1.5 micrometers in diameter. There are two classes of microbodies: **peroxisomes** and **glyoxysomes**. Reactions that either produce or use dangerous compounds such as hydrogen peroxide (H2O2) occur within these bodies. If peroxide were to escape through the microbody membrane, it would damage almost anything it comes in contact with. Both these bodies contain catalase, which detoxifies peroxide by converting it into water and oxygen.

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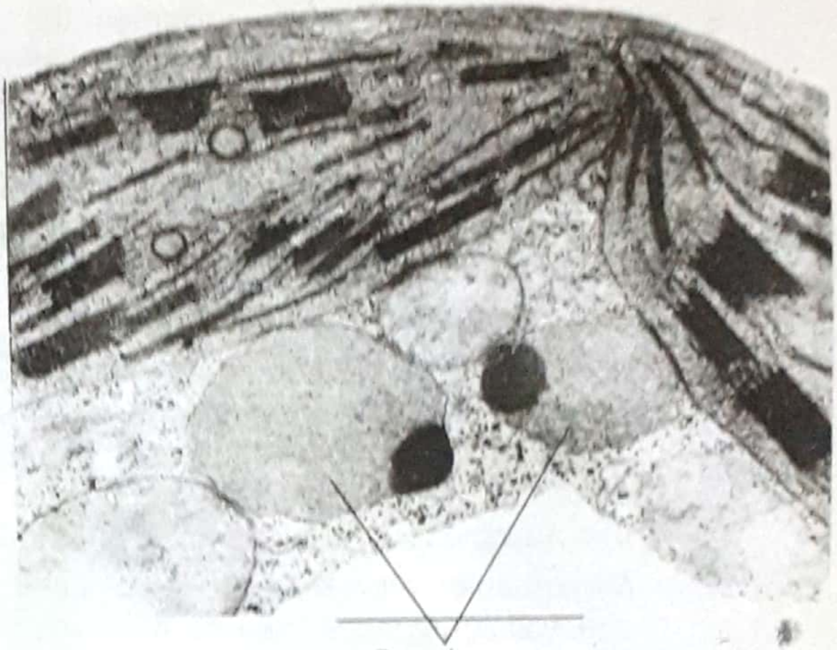
Peroxisomes

Peroxisomes are spherical organelles bounded by a single membrane found both in animal and plant cells. They have a granular interior, which may contain a body composed of protein. Typically peroxisomes are closely associated with one or two segments of endoplasmic reticulum, therefore were thought to have their origin from the endoplasmic reticulum. However, peroxisomes are now believed to be self-replicating organelles, but they import their import the materials required for their replication.



Peroxisomes

Peroxisomes are found closely associated with chloroplasts and mitochondria. These are involved in detoxifying certain by-products of photosynthesis. Some peroxisomes play an important role in photorespiration (glycolate cycle). Also peroxisomes contain catalase that helps protect cell organelle from toxic effect of hydrogen peroxide.

Glyoxysomes

Glyoxysomes are microbodies found mostly in lipid rich seeds such as soybeans. These contain enzymes for fatty acid metabolism and glucogenesis, i.e., conversion of stored lipid molecules of germinating seeds into carbohydrates.

OIL BODIES

Oil bodies or lipid droplets, are more or less spherical structures that provide granular appearance to the cytoplasm of a plant cell when viewed under light microscope.Under electron microscope, these bodies appear amorphous. Oil bodies are widely distributed throughout the cells of the plant body but are most abundant in fruits and seeds, for example about 45% of the weight of sunflower, peanut and sesame seeds is composed of oil. The oil bodies are thought to arise in endoplasmic reticulum and chloroplasts (sites of lipid synthesis) but are not bounded by a membrane.

CYTOSKELETON

Cytoskeleton is a complex network of protein filaments that extends throughout the cytosol in all eukaryotic cells. Cytoskeleton is intimately involved in many processes including cell division, growth and differentiation, and movement of organelle from one location to another within the cell. The cytoskeleton of plant cells consists of two main types of protein filament: **microtubules** and **microfilaments** or **actin filaments**. In addition plant cells may contain **intermediate filaments**.

Microtubules

Microtubules are long, thin cylindrical structures about 24 nanometers in diameters and of varying lengths. Each microtubule is built up of subunits of the proteins called **tubulin**. The subunits are arranged in a helix to form 13 rows or **protofilaments**, around

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a hollow core. Within each protofilament the subunits are oriented in the same direction, and all the protofilaments are aligned in parallel with the same polarity. Microtubules are dynamic structures that undergo regular sequences of breakdown and re-formation into new configurations at specific points in the cell cycle. Their assembly takes place at sites within the cell known as **microtubule organizing centres**. The surface of the nucleus and portions of the cytoplasm just inside the plasma membrane have been identified as microtubule organizing centres.

Microtubules have many functions:

i. In enlarging and differentiating cells, microtubules in cytoplasm inside the plasma membrane (cortical cytoplasm) are involved in orderly growth of the cell wall. These microtubules control the alignment of the cellulose microfibrils that are added to the cell wall, and the direction of cell expansion is governed, in turn, by this alignment of cellulose microfibrils in the wall.

ii. Microtubules also serve to direct secretory Golgi vesicles containing non-cellulosic cell wall substances towards the developing wall.

iii. Microtubules make up the spindle fibres that play a role in chromosome movement in cell plate formation in dividing cells.

iv. Microtubules are important components of flagella and cilia and are involved in the movement of these structures.

Microfilaments or Actin Filaments

Microfilaments, also called **actin filaments** are composed of a protein called **actin** and occur singly as long filaments of 5 to 7 nanometers in diameter or in the form of bundles. These are associated with microtubules and form new configurations at specific points in the cell cycle.

Actin filaments are involved in a variety of activities in plant cells including cytoplasmic streaming, cell wall deposition, tip growth of pollen tubes, movement of the nucleus before and following the cell division, organelle movement, vesicle-mediated secretion, and organization of the ER.

CELL WALL

The cell wall is the basis of many of the characteristics of plants as organisms. It distinguishes a plant cell from an animal cell. The cell wall is rigid and therefore limits the size of the protoplast, preventing rupture of the plasma membrane when the protoplast enlarges following the uptake of water by the cell. The cell largely determines the size and shape of the cell, the texture of the tissue, and the final form of the plant organ. Cell types are often identified by the structure of their walls, reflecting the close relationship between cell wall structure and cell function.

Once regarded as merely an outer, inactive structure produced by the protoplast, the cell wall is now recognized as having specific and essential functions and to be an integral part of the plant cell. Cell walls contain a variety of enzymes and play important roles in the absorption, transport, and secretion of substances in plants. They may also serve as sites of digestive activity.

In addition, the cell wall may play an active role in defense against bacterial and fungal pathogens by receiving and processing information from the surface of the pathogen and transmitting this information to the plasma membrane of the plant cell. Through gene-activated processes, the plant cell may then become resistant to attack through the production of **phytolexins,** antibiotics that are toxic to pathogens; or through the synthesis and deposition of substances like lignin, which acts as a barrier to invasion.

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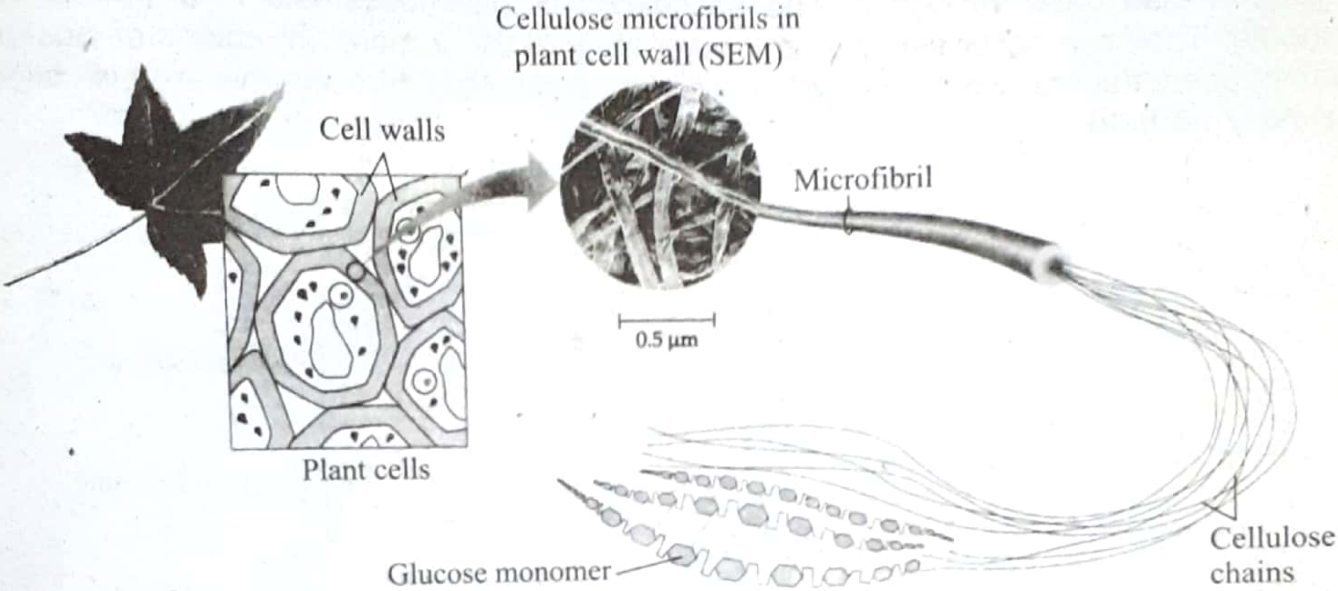
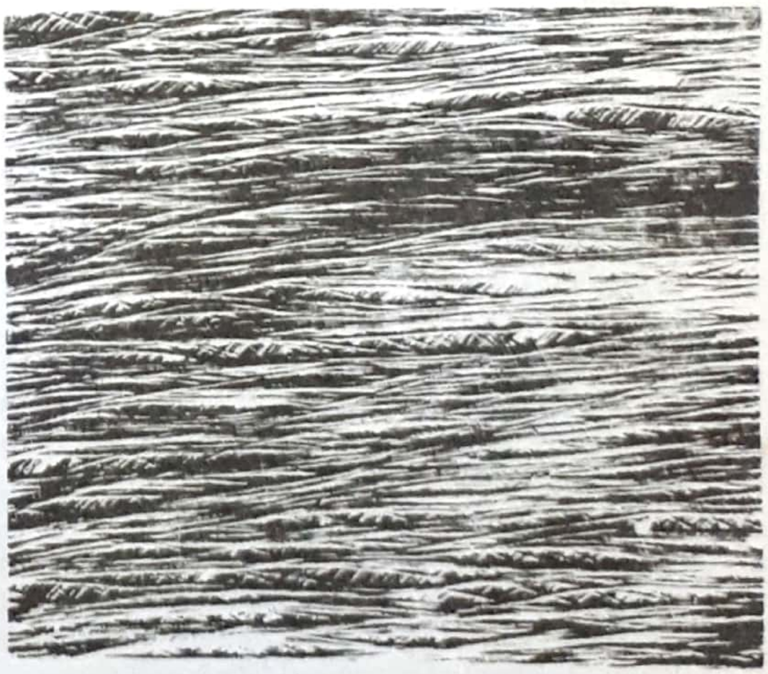
Certain cell wall polysaccharides (oligosaccharins) may function as signal molecules, regulating the plant growth and development.

The cell wall contains a considerable amount of the polysaccharide **cellulose**. Adjacent parallel cellulose molecules crystallize into an extremely strong **microfibril** 10 to 25 nm wide. Numerous microfibrils are wound around the cell completely covering the plasma membrane. Each cellulose molecule grows at one end only, where a complex of enzymes can add new sugars to the chain. New cellulose molecules can be added only on the inner side of the wall, adjacent to plasma membrane.





Cellulose microfibrils are bound together by other polysaccharides called **hemicelluloses**, which are produced in dictyosomes and brought to the wall by Golgi vesicles. Hemicelluloses are deposited between the cellulose microfibrils and bind chemically to the cellulose, producing a solid structure that resemble reinforced concrete. In multicellular plants, the wall of one cell is glued to the walls of the adjacent cells by an adhesive layer called **middle lamella**. The middle lamella is composed of another class of polysaccharides, **pectic substances**.

All plants have a thin wall called the **primary cell wall**. In certain cells the protoplast deposits a **secondary wall** between the primary wall and the plasma membrane. The secondary wall is usually much thicker than primary wall and is impregnated with **lignin**, which makes the wall stronger. Both primary and secondary cell walls are permanent, one deposited they are almost never degraded or depolymerised.

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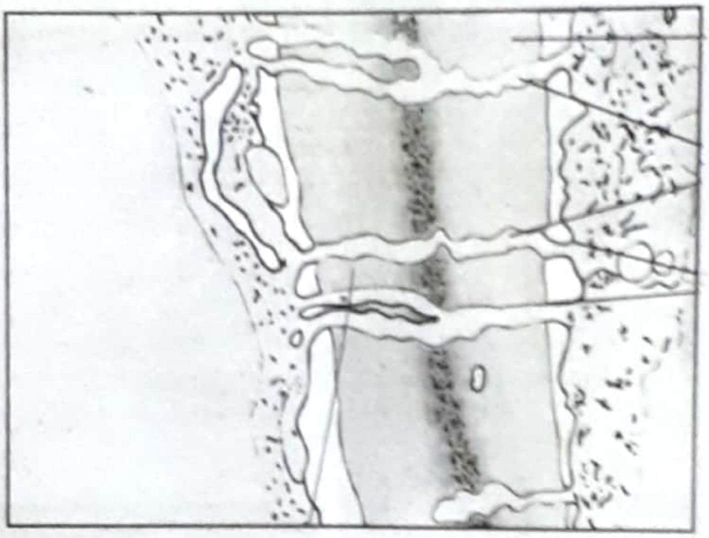
Plasmodesmata

In multicellular organisms each cell interacts with its neighbouring cells. They share the same sources of photosynthesis, oxygen, carbon dioxide, salt and water. Direct physical contact between cells cannot occur in plants because the two primary walls and middle lamella are located between any two adjacent protoplasts. However, plant cells are interconnected by fine holes in the wall called plasmodesmata. The plasma membrane of one cell passes through it and is continuous with the plasma membrane of the adjacent cell. A small channel of cytosol and short section of specialized endoplasmic reticulum also pass through it. The abundance of plasmodesmata in a wall is quite variable. They can occur singly or in groups of 10 to 20 or more. In regions of clustered plasmodesmata, the two primary walls are often particularly thin, and this area is called a **primary pit field**.



Apoplast and Symplast

Plasmodesmata act as cytoplasmic channels from one protoplast to another; therefore the protoplasm within a single plant is part of interconnected mass, the **symplast**. However, in most tissues any two adjacent cells act independently, the communication through the plasmodesmata is not enough to prevent individuality of the cells.

Walls act as a second nonliving compartment inside plants. Water moves through cells walls by capillary action. In addition many cells have **intercellular spaces** between them, at least at their corners. In some tissues, especially leaves cells are loosely connected that most of the tissue volume is intercellular space. The intercellular spaces plus the cell constitute the **apoplast**. The apoplast and symplast together make up the whole plant. The apoplast acts as a series of channels and spaces that permit the rapid diffusion of gases. Diffusion through a gas-filled space is approximately 10,000 times faster than through a liquid filled space.

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