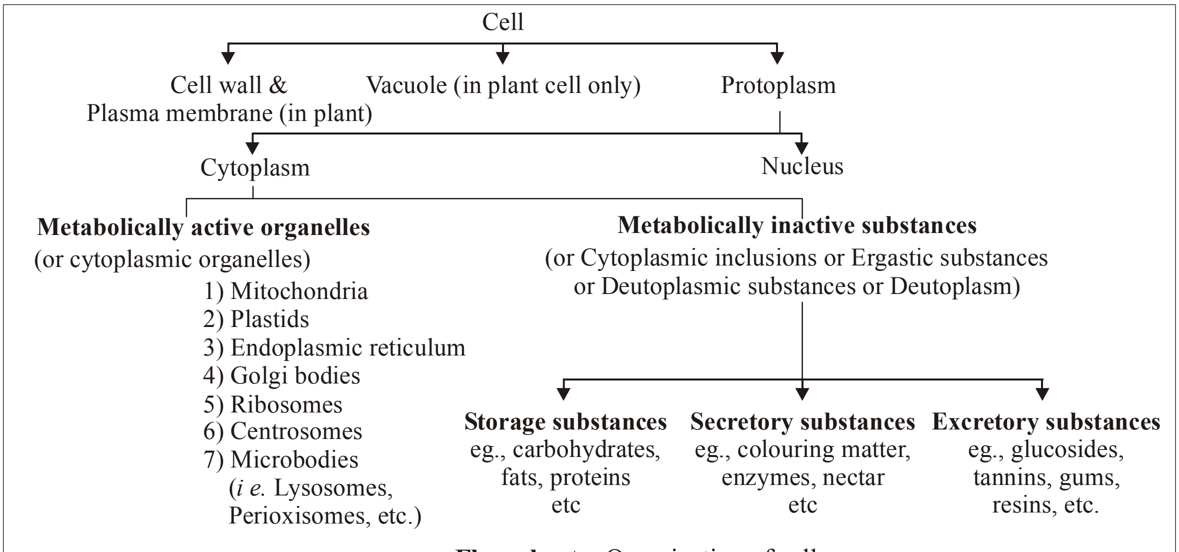
Chapter 19

Structural Organization of Cell

- Cell are the **smallest structural and functional units** of life (and of diseases processes) in all tissues, organs and organ system.
- A cell has a variety of molecules, often called biomolecules, in it.
- A biomolecules may occur in solution, or in colloidal state in the cell, or may be assembled into subcellular components of the cell.
- The subcellular components are often called as cell organelles, that is small organs.
- **Organelles** are membrane bound, enzyme containing subcellular compartments (eg mitochondria). Each type of organelles has a distincting structure and performs unique functions.
- Cell include plasma membrane, endoplasmic reticulum, ribosomes, Golgi apparatus, lysosomes, microbodies, mitochondria, plastids, microtubules, microfilaments, intermediate fibres, centrioles, basal bodies, cilia, flagella, vacuoles and nucleus.
- The **entire protoplasm of a cell** is known as **protoplast**.
- Protoplast has **four components – plasmalemma** (or plasma membrane), **cytoplasm, nucleus** & **vacuole**.



Flow chart – Organization of cell

PLASMA MEMBRANE

- The cell membranes separate a cell from its environment and form distinct functional compartments (nucleus, organelles) in the cell. The outer cell membrane is called the **plasma membrane** or **plasmalemma**.

(*For more details on plasma membrane refer chapter Biomembrane*)

- In the cells of bacteria, cyanobacteria, protists, fungi and plants, a thick, rigid, protective but porous coat, the **cell wall**, outside the plasma membrane **is found**.
- The composition of cell wall varies in different groups.

- **Composition of cell wall**
  - In **plants**, cell wall is made up of **cellulose** (β-D-glucose units), **hemicellulose** (arabinose, mannose, xylose, galactose, etc.) and **pectin** (galactose, galacturonic acid and arabinose)
  - In **bacteria**, cell wall is composed of protein-lipid-polysaccharides having two important chemical components: **N-acetyl glucosamine (NAG) and N-acetyl muramic acid (NAM)**.
  - In **fungi**, cell wall is made up of **chitin** (polymer of N-acetyl glucosamine).
  - **Algal cell** wall contains cellulose and a variety of glycoproteins.
- One of the **most important differences between plant and animal cells** is the **presence of a cell wall** (non-living protective layer) in **plant cells**.
- Cell wall was first discovered in the cell by **Robert Hooke in 1665**.
- Cell wall is **absent in animal** because cell wall is incompatible with the way in which an animal moves and grows.
- In an animal cell and many protists, cell membrane are covered by filamentous layer (also called **cell coat**) of an oligosaccharide sialic acid (called **glycocalyx**), which protects the underlying membrane and **helps in recognition of the cells** (by **Wilson**, 1907).
- Recognition ability is mainly **due to Ca^{2+} and Mg^{2+} absorbed over glycocalyx**.
- The cell coat of glycocalyx may be supported and strengthened by deposition of calcium salts, silicon or other substance.
- A typical cell wall is **made up of 4 layers** – **middle lamella**, **primary**, **secondary** and **tertiary wall**.
- **Middle lamella** is the **cementing layer** between the cells. It is made up of Ca & Mg pectates.

The **ripened fruits becomes softened** due to dissolution of middle lamella. It can be done artificially by spraying strong acids.

- **Primary cell wall**
  - It is **formed in a growing cell**.
  - It is laid down on both sides of middle lamella.
  - It is **present in all plant cells**.
  - It is **elastic** and **capable of expansion** in a growing cell.
  - It **grows in thickness by intussusception**.
  - It consists of a single layer of wall material.
  - It is **1–3 mm thick**.
  - Its cellulose macrofibrils are short, wavy and loosely arranged.
  - It **lacks pits and additional materials**.
  - Its water content is about 60%.
  - It **has relatively low cellulose content**.
  - It **has high hemicellulose, protein and lipid contents**.
- **Secondary cell wall**
  - It is **formed in a mature cell**.
  - It is laid down on the inner side of primary wall after the growth of cell stops (at maturity).
  - It is **present in certain plant cells only,** for eg. gymnosperms.
  - It is **rigid** and **non-elastic** and **incapable of expansion**.
  - It **grows in thickness by accretion**.
  - It consists of 3 or more layers of wall material.
  - It is **5–10 mm thick**.
  - Its cellulose macrofibrils are long, straight, compactly arranged.
  - Its water content is about 30–40%.
  - It has **relatively high cellulose content**.
  - It has **relatively low hemicellulose**, **protein**, **and lipid contents**.
- Sometimes **tertiary wall** is laid down on secondary wall, *e.g.*, **tracheids of gymnosperms**. It is **purely cellulosic in nature**.
- The cell wall is not uniform in thickness throughout; at certain places secondary wall or both primary and secondary walls are not laid down. Such places are called **pits**.
- Pits are of **two types** – **simple pit** in which pit chamber is uniform in diameter, and **bordered pit** in which pit chamber is flask-shaped in tracheids of gymnosperms and vessels of angiosperms.
- A number of **plasmodesmata or cytoplasmic strands** are present in pit through which the cytoplasm of one cell is in contact with another.
- Endoplasmic reticulum **plays a role in origin of plasmodesmata**.
- **Origin of cell wall** takes place from cell plate during cytokinesis. Many cell wall vesicles provided by Golgi bodies and endoplasmic reticulum combine to form a cell plate. After some chemical and physical changes, the cell plate grows on both sides to form a middle lamella. Primary and secondary walls are laid down on middle lamella to form cell wall. Beside these, different materials are deposited as – lignin, suberin, cutin, silica and mucilage.

- **Lignin** is special type of polysaccharide which deposits mainly in xylem cells and makes them hard and lignified. Due to its deposition xylem tracheids take up different forms, *e.g.*, annular thickening, spiral thickening, scalariform thickening.
- **Suberin** is a complicated mixture of fatty acids deposited on cork cells. Suberin is impermeable to water.
- **Cutin** is a wax-like fatty substance. It is deposited on the epidermal cells in the form of cuticle which reduces loss of water. Cuticle is very thick in xerophytes, thin in mesophytes and absent in hydrophytes.
- **Silica** In some cases sand or silica particles are deposited which give a rough touch, *e.g.*, *Equisetum* and *Saccharum munja*.

  In family Moraceae, Urticaceae, Cucurbitaceae and Acanthaceae, Ca oxalate and Ca carbonate crystals are deposited.
- **Mucilage:** Some cells are slippery to touch due to secretion of mucilage, e.g., blue-green algae. The cells can withstand extremes of temperature, *i.e.*, very low or very high.
- After maceration it has been found that cell wall consists of fibrils and gel like matrix.
- The macrofibrils consists of bundle of microfibrils which in turn consists of bundle of micelles.
- The matrix consists largely of polysaccharides. It also contains polygalacturonic acid and xylans.
- **Functions of cell wall** are –
  - It maintains shape of the cells.
  - It protects the cell from mechanical injury.
  - It wards off the attack of pathogens (viruses, bacteria, fungi, protozoans).
  - It provides mechanical support against gravity.
  - The cell wall prevents undue expansion of the cell when water enters by osmosis to compensate for the lack of contractile vacuole. This prevents bursting of cells.
  - It allows the materials to pass in and out of the cell.
  - Though permeable, the cell wall plays some regulatory role on the passage of materials into and out of the cell.
  - Growth of the cell wall enables the cells to enlarge in size.
  - The wall in some cases has a role in defence and offense by means of spines.

CYTOPLASM

- The **cytoplasm** surrounds the nucleus and is enclosed by the plasma membrane.
- Cytoplasm, a jelly like substance (**called cytosol** or **hyaloplasm or cytoplasmic matrix**) and composed of mainly water is **found between the cell membrane and nucleus**.
- Cytoplasm contains the structures and substances needed to decode the instruction of DNA and carry on the activities of the cell.
- Autonomic movement of matrix in the cytoplasm in a cell is called **cytoplasmic streaming** or **cyclosis**.
- Cytoplasm exists in two states – **sol** (plasmasol) and **gel** (**plasmagel**).
- **Sol** or **hydrol** is a liquid colloidal solution where the colloidal particles are well dispersed in water.
- **Gel** is a thick semi – solid colloidal system in which the colloidal particles come in contact and form a sort of network with water dispersed in the meshes.
- **Only the sol part of the cytoplasm** shows cyclosis.
- Cytoplasmic structures comprises 3 groups – **cell-organelles**, **cytoplasmic inclusions**, and **cytoskeleton**.

Cell organelles

- These are regarded as **living structure of a cell**.
- They are **capable of growth**, some may divide also and form metabolic machinery of a cell.
- These are **formed in the cell itself**.
- Eukaryotic cells are far more complex than prokaryotic cells.
- Both animal and plant cells share the same features but plant cells usually have the following feature in addition – cell wall (*described earlier*), vacuole and chloroplast.
- While centrioles, basal bodies and flagella are present in animal cells and are lacking in plant cells.
- The **type of organelles** are – ER, golgi complex, lysosome, mitochondria, ribosomes, microbodies, cytoskeletal structures, flagella and cilia etc.

Endoplasmic reticulum (ER)

- The ER was **first noted by Porter**, **Claude and Fullman** in 1945 as a network. It was **named ER by Porter** in 1953.
- It is **absent in prokaryotes** but **present in all the eukaryotes** except germinal cells and mature mammalian erythrocytes.

Structures formed by ER

- **Sphaerosomes.** Sphaerosomes (= spherosomes) are small cell organelles bounded by single membrane which take part in storage and synthesis of fats. They were discovered by **Perner** in 1953. Sphaerosomes are small spherical and refractile vesicles which are 0.5-1.0 mm in diameter. 98% of a sphaerosome is fat. Proteins constitute the remaining 2%. Some proteins are probably enzymatic and take part in the synthesis of fats. Because of the presence of fat, sphaerosomes can be seen under light microscope after staining the cells with Sudan dyes and osmium tetraoxide. Sphaerosomes **occur abundantly in the endosperm cells of oil seeds**. Sphaerosomes of some tissues (e.g., tobacco endosperm, maize root tip) contain hydrolytic enzymes. Therefore, they are considered to have lysosomic activity.
- **Ergastoplasm.** The term ergastoplasm used for the specialised ER with ribosomes. Furthermore they show special staining and cytochemical properties and may be connected with the ER.
- **Myeloid bodies.** Another kind of specialized endoplasmic reticulum (SER) which are found in the pigmented epithelial cells of retina. Ribosomes are not found attached to them. It consists of vesicles and tubules near the basement membrane of the cell so they acts as photoreceptors of the cells.
- **Microsomes.** Microsomes are the fragments of RER. It may **also derived from the plasma membrane**. They are formed as a result of fragmentation of cells. Microsomes derived from RER have ribosomes attached to outside. It should be noted that they are not found in the intact cell, *i.e.* they are not the natural cell structures.

- **Development of ER depends upon the metabolic state** and **stage of differentiation of the cells**, *e.g.*, **absent** from embryonic cells, **less developed** in spermatocytes (only a few vesicles) and **well-developed** in fully differentiated and metabolically active cells (*e.g.*, pancreas, liver, etc.) and **simple** in storage cells (in the form of tubules in adipose cells).
- The striated muscle fibres have a special type of ER called **sarcoplasmic reticulum (SR)**.
- ER is a **well-developed electron microscopic network of interconnected cisternae, tubules** and **vesicles** present throughout the cytoplasm, especially in the endoplasm.
- **Cisternae** are **flattened**, **unbranched**, **sac-like elements**. The sacs in the stack are interconnected with one another. They **bear ribosomes on the surface** that makes the cisternae appears rough.
- The cisternae **contain glycoproteins** named **ribophorin-I** and **ribophorin-II** that bind the ribosomes.
- **Tubules** are **tube-like extensions** which may be connected with cisternae or vesicles to **form a reticular system**. The tubules can be irregular or regular, branched or unbranched with a diameter of 50-100 nm **often free of ribosomes**.
- **Vesicles** are **oval or rounded**, **vacuole-like elements** 25-500 nm in diameter. They often occur isolated in the cytoplasmic matrix. They are also **free of ribosomes**. They are often called **microsomes**.
- The endoplasmic reticulum (ER) is a complex organelle, **involved in the synthesis, packaging and processing of various cell substances**.
- The ER membranes **actually attach to the cell membrane** and **the nuclear membrane as well as golgi bodies in the cytoplasm**.
- In mature cells, **ER occurs** in **2 forms** – **rough (RER)** and **smooth (SER)**.
- The fine **structure of RER** (membranes and individual ribosomes) is **visible only with the electron microscope.**
- RER (**consists mainly of cisternae**) is mainly **concerned with the synthesis of proteins** for sequestration from the rest of the cytoplasm, *i.e.*, secretory proteins such as collagen, proteins for incorporation into cell membrane, and lysosomal enzymes (separated from the rest of the cytoplasm to prevent autolysis).
- The **smooth endoplasmic reticulum** (SER) **lacks ribosomes** and thus appears smooth in electron micrographs.
- SER cisternae are **more tubular or vesicular** than those of the RER.
- SER **has many enzymes, important in lipid metabolism**, **steroid hormone synthesis**, **glycogen breakdown** (glucose-6-phosphatase) and **detoxification**. The last occurs *via* enzymatic conjugation, oxidation and methylation of potentially toxic substances.

- SER is also **abundant in liver cells (hepatocytes)**, where it is **involved in glycogen metabolism and drug detoxification**.
- **Functions of ER** are –
  - Facilitates transport of materials from one part of the cell to another, thus forming the cell's circulatory system.
  - Detoxification of drugs
  - associated with muscle contraction by release and uptake of Ca^{2+} ions
  - Help in formation of primary lysosome with hydrolytic enzymes.
  - Helps in the synthesis of nuclear envelope during telophase of cell division.
  - Provides space for temporary storage of synthetic products such as glycogen.

Golgi complex

- Golgi complex **(Golgi apparatus or dictyosome)** participates in many activities, particularly those associated with secretion.
- In **animal cells** Golgi complex or apparatus is either single or consists of a single connected complex. The two conditions are respectively called **localized** (most vertebrate cells) and **diffused** (most invertebrate cells, liver and nerve cells of vertebrates). The localized organelle is compact. It generally occurs at one end between the nucleus and the periphery. The diffused organelle is found to form a network, e.g., around the nucleus in nerve cells.
- In **plant cells** Golgi apparatus is formed of a number of unconnected units called **dictyosomes**. Their number is highly variable—from one in certain simple algae to 25000 in rhizoidal cell of *Chara*.
- A liver cell may possess upto 50 units of Golgi apparatus called **Golgisomes**.
- This membranous organelle comprises **3 major compartments** : (1) a stack of 3-10 discrete, slightly curved, flattened **cisternae**; (2) numerous small **vesicles** peripheral to the stack; and (3) a few large condensing **vacuoles** at the concave surface of the stack.
- Products synthesized by the ER are packaged in vesicles by the Golgi complex. These secretory vesicles, or secretory granules, are transported to the plasma membrane for **exocytosis**.
- Golgi complexes are **best developed in neurons and glandular cells**, which are specialized for secretion.
- Golgi apparatus is named from **Camillo Golgi** who discovered it in 1898 in the nerve cells of barn owl and cat by means of metallic impregnation method (*i.e* osmium chloride + silver salts).
- The golgi apparatus is the **processing, packaging** and **secreting organelle of the cell**.
- **Functions of Golgi apparatus** are –
  - A variety of enzymes are localized in the Golgi complex to help in the cell's biochemical reaction.
  - Absorbs materials from the environment.
  - Lipids and proteins coming from the ER are complexed into lipoproteins in the Golgi apparatus. This process is **liposylation**.
  - Golgi apparatus links carbohydrates with protein coming from ER to form glycoproteins. This process is **glycosylation**.
  - Formation of nematocytes (in *Hydra*) and trichocysts (in *Paramecium*).
  - Formation of acrosome, an important constituents of the tip of animal sperms.

Table : Functions of golgi complex in different types of cells

	Cell type	**Golgi functions**
1.	Exocrine cells of pancreas	Secretion of zymogen (digestive enzymes – protease, lipase carbohydrates and nucleases).
2.	Goblet cells of intestinal mucosa	Secretion of mucus and zymogens.
3.	Paneth cells of intestine	Secretion of proteins.
4.	Brunner's gland cell or duodenum and ileum	Secretion of mucopolysaccharides.
5.	Hepatic cells of liver	Transformation and secretion of lipids.
6.	Follicle cells of thyroid gland	Prothyroglobulins (hormone).
7.	Plasma cells of blood	Immunoglobulins (hormone).
8.	Cells of alveolar epithelium of mammary glands	Secretion of milk proteins.
9.	Plant cells	Secretion of protein and cellulose.

– In plant cells, synthesizes pectin and some other carbohydrates, necessary for the formation of cell walls etc.

Lysosomes

- The lysosomes are **noticeable with electron microscope only**.
- The lysosomes were **first reported** by a Belgian cytologist and biochemist **Christian de Duve** in 1955.
- In 1956, **Novikoff** observed lysosomes in the cell with electron microscope and coined the term lysosome.
- Lysosomes are **common** in the cell of animals, fungi and protista, but **rare in plant cells**.
- In **animals**, lysosomes are **abundant in leucocytes, macrophages**, **Kupffer's cells** and similar cells with phagocytic activity, **prokaryotes lack lysosomes**.
- Lysosomes are spheric, single membrane-limited vesicles (produced by golgi apparatus) that may contain more than 50 enzymes each and function as the cellular digestive system.
- Lysosome is also known as **suicidal sac/bag** as they contain hydrolytic enzymes.
- At **pH 4.8** the **interior of the lysosomes is more acidic than the cytosol pH 7**.
- The **important enzymes** are – acid phosphatases, sulphatases, proteases, nucleases, lipases and glycosidases. They are also called **acid hydrolases** because these digestive enzymes (usually occur as glycoproteins) usually function in acidic medium or pH less than 7.
- The covering membrane of lysosomes keeps the hydrolytic enzymes out of contact from the cellular contents. The covering membrane becomes fragile in the absence of the oxygen, or the presence of excess of vitamins A and E, male and female hormones, bile salts, X-rays and ultra-violet rays. These are called **membrane labilizers**.
- These labilizer **cause instability of the lysosomal membrane**, **leading to release of enzymes from the lysosomes**.
- The membrane is **protected from these agencies by cortisone**, **cortisol**, **chloroquine** and **a type of cholesterol**. These substances are called **membrane stabilizers**.
- Lysosomes are of **two types** – **primary** and **secondary**.
- **Primary lysosomes** are small (5-8 nm in diameter), with electron-dense contents.
- Primary lysosomes are the **storage form of lysosomes** and **their enzymes are mostly inactive**.
- The primary lysosomes disperse through the cytoplasm. They are found in most cells but are **most abundant in phagocytic cells**, eg. macrophages, neutrophils.
- **Secondary lysosomes** are larger and less electron dense.
- They are **formed by the fusion of one or more primary lysosomes with a phagosome**.
- Their **primary function** is **digesting products of heterophagy** and **autophagy**.
- Secondary lysosomes **occur throughout the cytoplasm** in many cells, in numbers that reflect the cell's lysosomal and phagocytic activity.
- **Residual bodies** (or **tertiary lysosomes**) are membrane limited inclusions of various sizes and electron densities associated with the terminal phases of lysosome function.
- They **contain undigestible materials** such as pigments, crystals and certain lipids. Some cells (eg, macrophages) expel residual bodies as waste, but **long-lived cells** (eg, nerve, muscle) **tend to accumulate them**.
- **Autodigestion** occurs when lysosome digests parts of the cells.
- **Missing or inactive lysosomal enzymes** causes serious childhood diseases (like Tay sach's disease or Pompe's disease).
- **Functions of lysosomes** are – digestion of useful unwanted and harmful materials; renewal of cells and organelles; by releasing nucleases, it may cause mutations and breakage of chromosomes which may lead to blood cancer.

Ribosomes

- Ribosome are **small dense cytoplasmic particles** which are found individually in the cytoplasm and also line the membranes of the rough endoplasmic reticulum.
- Ribosomes were **discovered by Robinson and Brown (1953) in plant cell** and **Palade (1955) in animal cell**.
- Palade **also coined the term ribosome**.
- The ribosomes are especially **numerous in actively synthesizing cells**, such as liver cells, pancreatic cells, endocrine cells, lymphocytes, yeast cells, and meristematic cells.
- They are **fewer in less active and starved cells**. As expected the cancer cells have numerous ribosomes.

They are **absent in mammalian RBC**.

- Ribosome is an organelle **composed of RNA** and **ribosomal proteins.**
- Ribosomes are the **site of protein synthesis** (production or construction) **in a cell** hence called **protein factory**.
- There are **2 basic types of ribosome** – **mitochondrial** (like prokaryotic, eg PPLO, bacteria, blue green algae) **ribosomes** which are smaller (20 nm) than the **cytoplasmic ribosomes** of eukaryotes (25 nm).
- **Mitochondrial ribosomes** (**70S overall**) have a 50S and a 30S subunit; **cytoplasmic ribosomes** (**80S overall**) have 60S and a 40S subunit Or the ribosomes are also of two types: **80S** and **70S**.
- 80S ribosomes or cytoplasmic ribosome are **synthesized inside the nucleolus**.
- The **two subunits of 80S** ribosome are – **60S** (large subunit) and **40S** (small subunit). 5S RNA is synthesised separately while others are formed by the nucleolus. 80S ribosomes **do not become functional inside the nucleolus**. Their subunits come out of the nucleus and become operational in cytoplasm.
- Cytoplasmic ribosomes occur in 2 forms– **free** (found in cytosol) or **bounded** (membrane bound, found exterior of the ER constituting rough ER).
- **70S** ribosome have **50S** and **30S subunits**. **Magnesium** ions **play an important role in holding the two subunits together** and also in **maintaining the structure of the two subunits**.
- **Svedberg unit** (S) is a measure of rate of sedimentation of a particle in a centrifuge, where the sedimentation rate is associated with the size of the particle.
- **Polyribosomes or polysomes** are groups of ribosomes distributed along a single strand of messenger RNA (*m*RNA) in an arrangement that permits synthesis of multiple copies of a protein from the same message.
- Polysomes **occur free in the cytoplasm** (free polysomes) and are attached to membranes of the rough endoplasmic reticulum.
- **Ribosomes read (translate) the *m*RNA code** and thus play a critical role in assembling amino acids into specific proteins.
- **Functions of ribosomes** are –
  - Furnish enzymes and factors needed for the formation of polypeptides.
  - Provide sites for the attachment of tRNAs and mRNA which participate in protein synthesis.
  - Newly formed polypeptide is protected from degradation by cytoplasmic enzymes in a tunnel of the large ribosomal subunit before releasing it into RER lumen.
  - Groove between the two subunits furnishes the site for the synthesis of polypeptide.

Microbodies

- The microbodies were **first seen by Rhodin in 1954** in the electron micrographs of mouse kidney tubule cells.
- The microbodies occur in nearly all eukaryotic cells. They **usually lie near the endoplasmic reticulum**, sometimes near the mitochondria or plastids or both.
- The **microbodies** are minute, simple, roughly spherical sacs bounded by a single unit membrane.
- They contain a densely granular matrix which has a regular **core** or **nucleoid** of crystalline material. The latter represents a variety of enzymes. These **enzymes catalyse oxidation reactions not involved in respiration**.
- The microbodies bud off from the rough endoplasmic reticulum after receiving the enzymes synthesized on the latter.
- The **microbodies** are of **three main types: peroxisomes** (**animal** and **plant peroxisomes**) and **glyoxysomes**.
- The **peroxisomes were so called** because of their potential peroxidase activity. Peroxisomes in contrast to lysosome are **produced only on the smooth ER**. The rare total genetic disease Zellweger's syndrome is the result of malformed peroxisomes. All types share peroxisomes catalase activity.
- **Animal peroxisomes** are **abundant in the liver and kidney cells of vertebrates**. They are also found in other organs, such as brain, small intestine, testis, and adrenal cortex. They also occur in the invertebrates and protozoans, such as *Paramecium*.
- The peroxisomes **contain one or more peroxide producing enzymes** like urate oxidase, D-amino acid oxidase, α-hydroxy acid oxidase and β-hydroxy acid oxidase. Molecular oxygen is required for producing hydrogen peroxide (H_2O_2).
- Peroxisomes also contain another enzyme, **catalase**, for metabolising hydrogen peroxide.
- Peroxisomes **help in detoxifying the alcohol in the liver cells**. In animal cells, peroxisomes **take**

part in oxidation of a number of biochemicals including extra amino acids, alcohol and toxins. *For example*, about 50% of the alcohol consumed by a person is detoxified by peroxisomes inside liver cells. The microbodies may also take part in **lipid metabolism.**

- **Plant peroxisomes** are **found in the leaf cells** capable of photosynthesis.
- They **contain enzymes present in both animal peroxisomes and glyoxysomes**. In addition, they have enzyme **glycolic acid oxidase** that oxidises glycolic acid (glycolate), a product of photosynthesis, to glyoxylic acid, a process called **photorespiration.**
- Photorespiration is **so called** because light induces the synthesis of glycolic acid in chloroplast. The entire process involves intervention of two basic organelles – chloroplast and peroxisomes.
- The **plant peroxisomes have enzymes for all these reactions** also. Thus, **they are the most complex microbodies**.
- **Glyoxysomes** are microbodies which **contain enzymes for β-oxidation of fatty acids** and **glyoxylate pathway**.
- These microbodies have been recorded only in plant cells. They are quite common in germinating oil seeds such as castor, watermelon, cucumber, peanut and others.
- Like other microbodies, glyoxysomes have a single covering membrane and an enzyme rich matrix with a crystalloid core. β-oxidation of fatty acids produces acetyl CoA. The latter is metabolised in glyoxylate cycle to produce carbohydrates. Glyoxylate cycle converts two acetyl CoA units into C_4 acids for gluconeogenesis.

Plastids

- Plastids are organelles enclosed by a **double membrane found in all plants** and **some unicellular organisms** (*Euglena*) of uncertain affinity.
- Plastids are of **different types** varying in shapes, size, colour and function.
- **E. Haeckel** (1865) gave the term plastid.
- Plastid are the **largest cell organelle**, and **involved in the formation** and **storage of soluble and insoluble carbohydrates**.
- Plastids are **broadly classified into two groups** – **leucoplast** *i.e* colourless plastids incapable of performing photosynthesis and **chromoplast** *ie* coloured plastids which are photosynthetically active.
- These organelles are bound by two membranes. As these organelles contain their own genetic material, and protein synthesizing machinery *i.e* DNA, RNA and ribosomes, they are **capable of multiplication by a fission like process**.
- **Leucoplasts** are **colourless plastids**. Oval, spherical rod like or filamentous leucoplasts **occur in large number in cells of fruits**, **seeds**, **tubes** and rhizomes. Leucoplasts **act as storage organelles**.
- Leucoplasts are **classified into three types** on the basis of the material stored -
  - **Amyloplast** (of potato) stores starch.
  - **Elaioplast** stores droplets of oil or fats.
  - **Proteinoplast** store protein grains (**aleuroplast**)
- **Chromoplasts** are **coloured plastids** with yellow, orange and red carotenoids and other pigments.
- Chromoplasts are **responsible for colours** in flowers, ripening fruits, autumn leaves and some root like carrot.
- Chromoplast arises from proplastid or chloroplast.
- **Proplastids** are found in embryonic tissue, composed only of an inner membrane, outer membrane, a small amount of stromal space with **DNA**.
- The term **chloroplast** was **coined** by **A.J.W. Schimper** in 1883.
- Besides leucoplast (aleuroplast), starch grains can develop in **chloroplast**.
- Chloroplast are the **photosynthetic organelles** (able to capture light energy using H_2O and CO_2) **of green plants and contain the pigment chlorophyll**.
- Chloroplast is the organelle which **acts as factory for the synthesis of sugars in autotrophic eukaryotes.**
- Each chloroplast is covered with a **double membrane** containing a proteinaceous matrix (or ground substance) called **stroma**.
- Stroma contains a small circular **double-helical DNA**, **ribosomes** and **several enzymes**.
- **Ribosomes of chloroplasts** are **70S type containing 23S and 16S RNA**.
- Many sheet-like lamellae (called **thylakoids**) occur in stroma.
- The term thylakoid was given by **Menke (1961).** About **20-50 thylakoids** are placed one above the other like a stack of coins to form a **granum**.
- Many membranous tubules called **stroma lamellae** interconnect thylakoids of different grana.

Table : Plastids, their occurrence and functions.

	Kind of plastids	Occurrence	Functions	Pigment
		Chromoplasts		
A.	**Photosynthetically active chromoplasts**			
1.	Chloroplast	Higher plants and green algae	Photosynthesis	Chlorophyll-*a* and chlorophyll-*b*
2.	Pheoplasts	Brown algae, diatoms dinoflagellates	Light absorption	Fucoxanthin along with chl *a* and chl *c*
3.	Rhodoplasts	Red algae (rhodophyceae)	Light absorption	Chl *a* along with phycoerythnin and phycocyanin
4.	Blue-green chromoplasts	Blue-green algae	Photosynthesis	phycocyanin, phycoerythrin, chlorophyll-*a*, and carotenoids
5.	Chromoplasts of photosynthetic bacteria	Purple and nonpurple sulphur bacteria	Absorption of infra-red portion of light	Bacteriochlorophyll
B.	**Chromoplasts devoid of photosynthetic activity**			
6.	Carotenoids	Tomato, redpepper, flower parts, fungi, bacteria and fruits	—	Lycopene and capsanthin
		Leucoplasts		
7.	Amyloplasts	Storage tubers, cotyled-ons and endosperm	Starch storage	None
8.	Elaioplasts	Epidermal cells of Orchidaceae and Liliaceae	Oil storage	None
9.	Aleuroplasts	Epidermal cells of Helleborus and seeds of *Ricinus* and Brazil nut	Protein storage	None

- **Quantasomes** are **photosynthetic units** present on the surface of grana.
- Each quantasome contains **230 chlorophyll molecules**.
- Chlorophyll molecule has a complex **porphyrin ring** with a long **phytol chain**.
- The metal **magnesium** is located at the **centre of chlorophyll molecule**.
- The blood pigment **haem** is almost identical to chlorophyll but it contains **iron** instead of magnesium.
- Chlorophyll has **four pyrrole rings**, so called a **tetrapyrrole**.
- **Pigments of chlorophyll** are – chl *a*, *b*, *c*, *d*, *e*, and carotenoids.
- **Anthocyanin** does not occur in chloroplast.
- **Absence of chlorophyll** in plants is known as **albinism**.

Mitochondria

- Mitochondria is the **third largest organelle in plant cell** and **second largest organelle in animal cells**.
- Mitochondria are the **site of chemical reactions** that transfer energy from organic compounds to ATP.
- ATP is called the **energy currency of the cell**.
- ATP production is called **cellular respiration**.

- The mitochondria were **first seen in 1880 by Kolliker**, who isolated them from insect muscle cells. They were **named mitochondria by Benda** in 1898.
- Mitochondria can be **stained differentially with Janus Green** and are **easily distinguishable under light microscope** though ultrastructure can be studied only under electron microscope.
- The mitochondria are often **concentrated in the more active regions of cells**, like – in the muscle cells, in the sperm, in the gland cells, in the intestinal epithelial cells near the absorptive surface, in dividing cells, and in cilia bearing cells, because these location of mitochondria quickly deliver ATP for cell activities.
- Each mitochondrion is bounded by **2 unit membranes**.
- The **outer mitochondrial membrane** has a smooth contour and **forms a continuous but relatively porous covering**. It is **freely permeable to various small molecules**.
- The **inner mitochondrial membrane** is less porous and thus is semipermeable. It **has many infoldings or cristae** that project into the mitochondrion's interior.
- The cristae **greatly increases the surface area of the inner membrane** by providing more space for the chemical reaction to occur.
- The **intermembrane space** is located between the inner and outer membranes and is continuous with the intracristal space which extends into the cristae.
- The wide space between the cristae is called the **inner chamber**. It is **filled with a dense fluid termed the mitochondrial matrix.**
- The matrix **contains proteins and enzymes, lipids, some ribosomes, RNA, one or two DNA molecules and certain ions, fibres, crystals and granules**. The ribosomes are 70S in size like those of the prokaryotic cells. They are called **mitoribosomes** in contrast to the 80S **cytoribosomes** that occur in the cytoplasm. The DNA molecules are circular, short and without proteins as in the prokaryotic cells. All the three types of RNAs (rRNA, tRNA and mRNA) are present in the mitochondrial matrix. The ions include Ca^{++} and Mg^{++}. These are necessary for the functioning of mitochondrial enzymes.
- The numerous soluble enzymes, present in matrix, involved in **specialized mitochondrial functions** such as the Krebs cycle (tricarboxylic acid cycle), β-oxidation of lipids and mitochondrial DNA synthesis.
- The inner surface is covered by inner membrane subunits, also called **F_1 subunits/mitochondrial particles/oxysomes etc**.
- These particles were **first seen by fernandez Moran in 1961**.
- In recent works only **the stalked particles of the inner membrane are involved in various oxidation reaction and are supposed to supply electrons to the interior of the organ**. Therefore they are **termed as electron transport particle or functional unit of mitochondria**. These particles are spaced about 100 Å interval.
- An oxysome **consists of 3 parts** – a rounded **head piece**, or **F_1 subunit**, joined by a short **stalk** to a **base piece**, or **F_0 subunit**, located in the inner membrane. There may be 100,000 to 1,000,000 oxysomes in a single mitochondrion.
- The oxysome, also called **F_0-F_1 complex**, represents **adenosine triphosphatase,** or **ATPase**, or **ATP synthetase,** enzyme and is thus **concerned with ATP formation**.
- The rest of the inner mitochondrial membrane contains the electron carrier molecules (coenzymes) of the electron transport chain (flavoprotein, FeS, CoQ, cyt. b, cyt c_1, cyt. c, cyt. a, cyt. a_3), succinate dehydrogenase and enzymes of fatty acid synthesis.
- Mitochondria **provide energy for chemical and mechanical work** by storing energy, generated from cellular metabolites, in the high energy bonds of ATP.
- Mitochondria **grow and reproduce by fission or budding** and can undergo rapid movement and shape changes.
- Mitochondria are also called **semi-autonomous organelle** as they synthesize their own DNA and some proteins.
- **Cardiac muscle cells are notable for their abundant mitochondria**. Epithelial cells lining the kidney tubules have abundant mitochondria interdigitated between basal plasma membrane infoldings where active transport of ions and water occurs.
- Mitochondria are also **called the powerhouse of the cells** because their primary purpose is to manufacture adenosine triphosphate (ATP), which is used as a source of energy.

Enzymes of Mitochondria	
Outer membrane • Monoamine oxidase • Rotenone-insensitive NADH-cytochrome c reductase • Kynurenine hydroxylase • Fatty acid CoA ligase	
Space between outer and inner membranes • Adenylate kinase • Nucleoside diphosphokinase	
Inner membrane • Respiratory chain enzymes • ATP synthetase • Succinate dehydrogenase • β-hydroxybutyrate dehydrogenase • Carnitine fatty acid acyl transferase **Matrix** (contain enzymes of Krebs cycle) • Malate and isocitrate dehydrogenases • Fumarase and aconitase • Citrate synthetase • α-keto acid dehydrogenases • β-oxidation enzymes	**Constitute respiratory unit**

Cilia & Flagella

- **Cilia** are **short, more numerous** hair like structures made of **bundle of microtubules** to help cells move.
- Cilia **occur in group ciliata of protista, flame cells of worms**, **larval bodies of many invertebrates, epithelium of respiratory tract**, **renal tubules**, **oviducal funnel**, etc.
- A **flagellum** is like a cilium, but it is **longer** and there is usually only one or 2 flagella on a cell.
- There are **three main varieties of flagellum** – the **bacterial flagellum** (a helical filament that rotates like a screw), **archaeal flagellum** (similar but nonhomologous to the bacterial flagellum), and the **eukaryotic flagellum** (a whip-like structure that lashes back and forth).
- Flagella of bacteria **do not show 9 + 2 arrangement**.
- The **principal protein** of cilia and flagella is **tubulin**.
- Both cilia and flagella have following parts – **basal body**, **rootlets**, **basal plate** and **shaft**.
- **Basal body or kinetosome** is also called **basal granule** or **blepharoplast**.
- The basal bodies of cilia are found embedded in the refractile, gelatinous ectoplasm immediately beneath the cell surface and are uniformly spaced in straight parallel rows. The **basal bodies are said to be homologous to the centriole**.
- **Rootlets** are striated fibrillar outgrowths which develop from the outer lower part of the basal body and are **meant for providing support to the basal body**.
- The rootlets are **made of bundles of microfilaments**. They are **commonly present** in the ciliated epithelium of lower animals but are **absent** in the ciliated epithelium of mammals and in the ciliated protozoa.
- **Basal plate** is an area of high density which **lies above the basal body** at the level of plasma membrane. In the region of basal plate, one sub-fibre of each peripheral fibril disappears. The central fibrils develop in this area.
- **Shaft** is the **hair-like projecting part** of flagellum or cilium.
- The shaft is covered on the outside by a sheath which is the extension of plasma membrane. Internally, it contains a semifluid matrix having an **axoneme** (an essential motile element) of 9 peripheral doublet fibrils and 2 central singlet fibrils. This arrangement is called **9 + 2 or 11-stranded in comparison to 9 + 0 arrangement of the centriole or basal body**.
- Each axoneme is organized by and anchored in a **basal body**.
- The function of cilia and flagella includes **locomotion** for one celled organism and **to move substances over cell surface** in multicelled organism.
- The movements of cilia and flagella are brought about by sliding of doublets past each other rather than by their contraction.
- The cilia may beat in **metachronous** or **synchronous (isochronous) rhythm.** In metachronous rhythm, the cilia of a row beat one after the other, whereas in synchronous rhythm all the cilia of a row beat simultaneously.
- Movements of cilia and flagella are of **four types** – **pendulus movement**, **undulant movement**, **unciform movement**, and **infundibuliform movement.**

Table : Major protein structures of the axoneme of the cilia and flagella.

	Axoneme component	Functions
1.	Tubulin (8 nm)	Principal component of microtubule.
2.	Dynein (24 nm)	Project from microtubule doublets and interacts with adjacent doublets to produce bending.
3.	Nexin link (86 nm)	Hold adjacent microtubule doublets together.
4.	Radial spokes (29 nm)	Extend from each of the nine outer doublets inward to the central pair.
5.	Sheath projection (14 nm)	Projects as a series of side arms from the central pair of microtubules; together with radial spokes these regulates the form of ciliary beat.

- **Functions of cilia and flagella** are –
  - They help in locomotion in flagellate and ciliated organisms.
  - They create current for obtaining food from aquatic medium. It is also called food current.
  - In some protists and animals, the organelles take part in capturing food.
  - The canal system of porifers operates with the help of flagella present in their collar cells or choanocytes.
  - In coelenterates, they circulate food in the gastrovascular cavity. In tunicates and lancelets, the cilia help in movement of food and its egestion.
  - In land animals the cilia of the respiratory tract help in eliminating dust particles in the incoming air.
  - Internal transport of several organs is performed by cilia, e.g., passage of eggs in oviduct, passage of excretory substances in the kidneys, etc.
  - Ciliated larvae take part in dispersal of the species.

Centriole (Centrosomes)

- Centrioles are **submicroscopic**, **microtubular**, **subcylindrical structures** which **usually occur in the form of two granules** oriented at right angles to each other. These are also called **diplosomes** (= pair of centrioles).
- Two centrioles are always found inside a specialized distinctly staining cytoplasm that lacks other cell organelles and is called **centrosphere** or **cytocentrum**.
- The **complex formed of centriole and centrosphere** was termed **centrosome**.
- The term '**centrosome**' was given by **Theodar Boveri** 1888.
- A centriole is 150 nm in overall diameter and 350-500 nm long, **containing 9 microtubule triplets in a pinwheel array**. Fibrils are **absent in the centre**. The arrangement is therefore called **9 + 0**.
- Each microtubule in a triplet, shares a portion of the wall of the neighbouring microtubule.
- Centrioles are the **structural organizers of the cell**.
- **Centriole duplication is a pre-requisite** for cell division and during mitosis the centrioles organize the microtubules of the mitotic spindle.
- The centriole and associated golgi complexes constitute the cell **cytocentre**, which appears as a clear zone near the nucleus.
- During the S phase of interphase, each centriole duplicates by giving rise to a **procentriole** that grows at right angles to the original. During mitosis, the new **centriole pairs migrate to opposite cell poles** to organize the spindle.
- **Centriole and basal bodies have common structure** and **power of duplication**.
- Basal bodies are structurally similar to centrioles with 9 microtubule triplets.
- Basal bodies occur in the **cytoplasm**, one at the base of each cilium or flagellum, and serve as the **anchoring points** and **microtubule organizers** for these structures.
- Some spindle microtubules (**continuous fibres**) extend from centriole to centriole. Others (**chromosomal fibres**) extend from one centriole to the centromere of a chromosome.
- The centrioles **occur in nearly all animal cells** and **in motile plant cells** such as zoospores of algae, sperm cells of ferns and motile algae. They are **absent** in amoebae, prokaryotic cells, higher gymnosperms and all angiosperms.
- **Functions of centriole** are –

– **Serves as basal bodies** for cilia and flagella.
– Concerned with **spindle formation** during cell division, therefore called microtubule organising centre (MTOCs).
– Though centriole does not contain DNA yet they are capable of forming new centrioles with the helps of **massules or pericentriolar satellites** which function as nucleating centres.

Cell inclusions

- The cell inclusions are **non-living materials** present in the cytoplasm.
- They are often called **deutoplasmic substances**.
- They may be **organic or inorganic compounds**, or both.
- The **common cells inclusions** are– **stored organic food materials**, **secretions** and **excretions** and **inorganic crystals** (*See table given below*).
- **Reserve food materials** are of **four major types**: starch grains, glycogen granules, aleurone grains, fat droplets.
- **Starch grains** are **found in plant cells only**, particularly in storage organs such as seeds, fruits, rhizomes, and tubers. They are spherical, oval, elliptical or polyhedral bodies. Each starch grain contains a shining body called **hilum** made of protein.
- **Fat droplets** are **found in adipocytes** (fat-storing cells) of animals, the **endosperm of castor** and **coconut** and **cotyledons of groundnut** and **mustard seeds**.
- **Glycogen granules** are small, spherical or large rosette-shaped particles occurring near SER in liver and muscle cells. Glycogen granules are also found in blue-green algae, slime moulds, fungi and bacteria.
- **Aleurone grains** contain stored proteins. They are present in all cereal grains such as wheat, maize and barley below seed coat.
- **Excretory and secretory products** are of several types like mucus in several animal cells; essential oils, alkaloids (eg atropine, colchicine, nicotine etc), resins, gums, tannins, latex, nectar, gum, resins in plant cells, etc.

Cytoskeleton

- The cytoskeleton is a cellular scaffolding or skeleton contained within the cytoplasm.
- Cytoskeleton consists of a network of **long protein tubes and strands** in the cytoplasm to give **cells shape** and **helps move organelles**.
- The cytoskeleton is a mesh of filamentous elements called **microtubules**, **microfilaments** and **intermediate filaments** and provide structural stability for the maintainence of cell shape.
- It is important in cell movement and in the rearrangement of cytoplasmic components.
- **Microtubules** are larger, **hollow** tubules of the protein called **tubulin** that maintain **cell shape,** serve a **tracks for organelle movement** & help cells divide by **forming spindle fibres that separate chromosome pairs.**
- Microtubules are thickest cytoskeleton components with diameters of 24 nm. They are fine tubular structures of variable length, with dense wall (5 nm thick) and a clear internal space (14 nm across).
- The walls are composed of subunits called **tubulin heterodimers**, each of which consists of one α-tubulin and one β-tubulin protein molecule.
- The tubulin heterodimers are arranged in thread like polymers called **protofilaments.**
- Microtubules increase in length by adding new heterodimers to one end, called the **nucleation site**. This polymerization can be controlled experimentally by regulating calcium ion concentration or by treating cells with antimitotic alkaloids.
- **Colchicine** blocks the process by binding to the nucleation site. Vinblastine disrupts microtubules by binding to free tubulin.
- Microtubules **have roles** in the maintenance of cell

Table : Types of inorganic crystals

(a) *Cystolith*	It consists of calcium carbonate crystals deposited around a cellulose framework, as in epidermal cells of *Momordica*, hypodermal leaf cells of *Ficus benghalensis*.
(b) *Crystal sand*	It is a powdery mass of calcium oxalate as in *Atropa*.
(c) *Raphides*	These are needle-like crystals of calcium oxalate in *Lemna*, *Eichhornia*.
(d) *Sphaeraphides*	These are star-shaped groups of calcium oxalate crystals in *Colocasia, Chenopodium* and *Begonia*.
(e) *Prismatic crystals*	Crystals of calcium oxalate occur in the dry scales of *Allium cepa*.

shape, axoplasmic transport in neurons, melanin dispersion in pigment cells, chromosome movements during mitosis, organization of the Golgi complex, and the shuttling of vesicles within the cell.

- Unlike microfilaments, microtubules are unable to contract. Shortening occurs *via* **depolymerization.**
- Microtubules are found throughout the cytoplasm of most cells and in highly groupings in centrioles, cilia, flagella, basal bodies and the mitotic spindle apparatus.
- **Microfilaments** are **rope like** structures made of 2 twisted strands of the **protein actin** capable of contracting to cause cellular movement (muscle cells have many microfilaments).
- Microfilaments, the thinnest cytoskeletal components (5-7 nm wide) are usually composed of one of several types of actin protein.
- Microfilaments are contractile, but to contract they usually must interact with myosin.
- Microfilaments **occur in eukaryotic plant and animal cells**.
- Microfilaments often associate to form **hexagonal bundles**. They may also occur in parallel bundles or loose network. Microfilaments generally lie at sol-gel interphase as well as below plasma membrane. Microfilaments are also connected with spindle fibres, endoplasmic reticulum, chloroplast, etc.
- During mitosis of animal cells, they have been found associated with cleavage furrows.
- Microfilaments **form the contractile machinery of the cell**, like formation and retraction of pseudopodia, plasma membrane undulations, microvilli, endocytosis, cytoplasmic streaming and movement of other cell organelles.
- The **microfilaments serve a number of functions** – support, intracellular movement, streaming movement, cleavage, locomotion, change in form, contraction, movement of villi, movement of plasma membrane, membrane undulations, and formation of spindle.
- **Intermediate filaments** are intermediate in thickness (10-12 nm) between microtubules and microfilaments. They are **supportive elements in the cytoplasm of the eukaryotic cells** except the plant cells.
- They occur in the cell junctions and in the form of basket around nucleus of animal cells.
- **Examples of intermediate filaments** are – **cytokeratins** in epithelial cells, **vimentin** in mesenchymally derived cells (eg, fibroblasts. chondrocytes), **desmin** in muscle cells, **glial fibrillary acidic protein** in glial cells, **neurofilaments** (intermediate filament bundles) in neurons.
- The **IFs serve a variety of functions** –
  - They form a part of cytoskeleton that supports the fluid cytosol and maintains the shape of the cell.
  - They stabilize the epithelia by binding to the spot desmosomes.
  - They form major structural proteins of skin and hair.
  - They integrate the muscle cell components into a functional unit.
  - They provide strength to the axons.
  - They keep nucleus and other organelles in place.
  - Cardiac muscle cells are interconnected by spot desmosomes. Desmin filaments interconnect these desmosomes, allowing the stress and strain of the contractile force of one muscle to be transmitted to the other.

NUCLEUS

- The nucleus is often the **most prominent structure** within an eukaryotic cells and it controls **all functional activities of the cell**.
- The nucleus is the **control centre of the cell for cell metabolism and reproduction**.
- The nucleus is a specialised **double membrane bound organelle** which **contains genetic information (DNA) on special strands called chromosomes**.
- A nucleus **in the non-dividing or metabolic phase** is called **interphase nucleus** as it controls metabolic activites of the cell.
- The nucleus is also known as **karyon** and its study is known as **karyology**.
- The cell nucleus was **discovered** by an English botanist **Robert Brown** in 1831.
- The nucleus is the **primary carrier of hereditary material in the cell**.
- The nucleus contains a **linear code (DNA) for the synthesis of cell components and products** conferring upon the cell a range of adaptability to changing environmental conditions and to extrinsic signals such as hormones.

- The **nucleus serves many functions** –
  – Cell maintenance and growth
  – Cell metabolism
  – Genetic information
  – Cell replication
  – Ribosome formation
  – Variation
  – Cell differentiation.
- The nucleus can be divided into **five parts**: **nuclear membrane**, **nucleoplasm**, **nuclear matrix**, **chromatin** and **nucleolus** (or **nucleoli**).
- Nuclear envelope is **double membrane** that separate nucleoplasm from cytoplasm.
- The nuclear contents are set apart from the cytoplasm by a **double membrane** called the **nuclear envelope** (**karyotheca**) and a narrow (40-70 nm) intermembrane space called the **perinuclear cisternae**, or perinuclear space.
- The **outer membrane** is connected with endoplasmic reticulum and its outer surface may contain ribosomes while **inner surface is smooth**.
- In most cells, the **barr body** is attached to the **inner surface** of the nuclear envelope. In a neutrophilic leucocyte, it may appear as a drumstick shaped appendage of the lobulated nucleus.
- The nuclear envelope is **perforated by many nuclear pores**, each of which has a diameter of about 70 nm and is bounded by 8 globular subunits called **annular proteins** which presents an octagonal appearance in some preparations.
- The **pores and annuli together** are called **pore complex**.
- Nucleus communicates with cytoplasm through **nuclear pores**.
- Structure of nuclear envelope facilitates **nucleocytoplasmic exchange of materials**.
- The pores **provide a channel for the movement of important molecules between the nucleus and cytoplasm** including nucleic acids synthesized in the nucleus and used in cytoplasm (mRNA, rRNA, tRNA) and proteins synthesized in the cytoplasm and used in the nucleus (histones, polymerases).
- The nuclear envelope is **formed during telophase** by coming together and fusion of small vesicles into which the nuclear envelope breaks up during prophase.
- Nuclear envelope **serves four functions**–
  – It maintains the shape of the nucleus.
  – It keeps the nuclear contents in place and distinct from cytoplasm.
  – It regulates the flow of materials into and out of the nucleus.
  – Its pores allow the exit of ribosomal subunits and tRNAs and mRNAs.
- The nucleus contains a viscous fluid, the **nucleoplasm** (**nuclear sap** or **karyolymph**) which keeps nucleus turgid and has a different pH from cytosol.
- The **nucleoplasm** contains raw materials (nucleotides), enzymes (DNA and RNA polymerases) and metal ions (Mn^{++}, Mg^{++}) for the synthesis of DNA and RNAs. It also contains histone and nonhistone proteins for combination with DNA, and other proteins for combination with DNA, and the formation of ribosomal subunits.
- The **nucleoplasm has the following functions** –
  – It is the seat of synthesis of DNA, RNAs and ribosomal subunits.
  – It supports the chromatin material and nucleoli.
  – It provides turgidity to the nucleus.
  – Some of the proteins present in nucleoplasm are essential for spindle formation.
- The **nuclear matrix** is a network of fine, criss-crossing, acid protein-containing fibrils which are joined to the nuclear envelope by their ends. It **forms a sort of nuclear skeleton**. It remains intact after the chromatin and DNA have been removed. Terminal ends of chromatin fibres or telomeres are embedded in nuclear or fibrous lamina.

Enzymes of the nucleus

➢ Many enzymes associated with DNA and RNA synthesis are present in the nucleus. These enzymes include nucleoside phosphorylase and ribonuclease. The synthesis of DNA takes place inside the nucleus. Bulk of the RNA is synthesized in the nucleus and nucleolus and later these RNAs move into cytoplasm. Enzymes involved in protein synthesis are also present in the nucleus.

➢ Glycolytic enzymes like aldolase, enolase, 3-phosphoglyceraldehyde dehydrogenase are present in the nucleus.

➢ Inorganic materials like salts of calcium, magnesium, zinc, iron are present in the nucleus. These are very essential for enzyme activities.

- The **nuclear matrix has the following functions** –
  – It maintains the shape of the nucleus.
  – Chromatin fibres are anchored to nuclear matrix.
  – The machinery for various nuclear activities, such as replication and transcription, is associated with the matrix.
- **Nuclear chromatin** is **intensely basophilic** and consists of DNA and associated basic histone and acidic or neutral nonhistone proteins.
- Histones are structural protein and non-histones are functional proteins.
- Chromatin is the **interphase chromosomal material**, a complex between eukaryotic DNA and protein.
- The **major proteins of chromatin** are the **histones**, small proteins containing high proportion of basic amino acids (arginine and lysine) that facilitate binding with **negatively charged DNA molecule**.
- Chromosomes, the most highly condensed form of chromatin, are **visible during mitosis**,.
- The chromatin **forms chromosomes during cell division by condensing and tight coiling of chromatin fibres**.
- The **whole chromatin is not functional**, **only a portion of euchromatin** which is associated with acid proteins, **takes part in transcription or formation of RNA's**.
- After cell division, the chromosomes change back into chromatin fibres. Most of the fibres become uncoiled, extended and scattered. They form the **euchromatin** (**true chromatin**) of the interphase nucleus. It stains lightly. Some chromatin fibres remain coiled and compacted in the interphase also. They constitute the **heterochromatin** (**the other chromatin**). It stains deeply. It lies close to the nuclear lamina.
- **Nucleolus** (or **nucleoli**) was **discovered by Fontana in 1781**, **described by Wagner in 1840** and the term 'nucleolus' was **coined by Bowman in 1840**.
- Nucleolus is **characterized by the absence of limiting membrane**, **presence of chromatin** and **granules** and **fibrils of RNA and protein**.
- There is **one nucleolus** for **each haploid set** of chromosomes.
- Nucleolus is largely **composed of RNA and it stains more darkly than the nucleus**.
- **Nucleolus** consists of **DNA + RNA + protein**.
- The nucleolus **disappears during prophase** of mitosis and reappears after mitosis is completed. Distinct nucleolar components can be seen with the **electron microscope**.
- Nucleolus disorganises itself during **late prophase** and reappears during **telophase**.
- **Nucleoli** are the **synthesis sites for most ribosomal RNA (rRNA)**. They are **largest** and **most numerous in embryonic cells**, **in cells actively synthesizing proteins and in rapidly growing malignant tumor cells**.
- Nuclei **display wide variation** in –
  – Size both absolute and relative to the amount of cytoplasm (**nucleo-cytoplasmic ratio**);
  – Number per cell, allowing classification of cells as **enucleate**, **mononucleate**, **binucleate or multinucleate**;
  – Chromatin pattern *i.e.*, the amount and distribution of **heterochromatin**; and
  – Location, e.g., basal, central, ecentric.
- Nucleoli were divided into **2 main groups**– **plasmasomes** (or true nuclei), which stain with acidic dyes and disappear during mitosis, and **karyosomes** (or false nuclei), which stains with basic dyes and are of flakes of chromatin.
- Nucleolus has **four components** – **amorphous matrix**, **granular part**, **fibrillar portion** and **chromatin**.
- **Amorphous matrix** is the homogeneous ground substance of the nucleolus. Matrix is formed of protein.
- **Granular part** consists of granules of the size of 150—200 Å which lie scattered in the amorphous matrix. The granules are formed of protein and RNA in the ratio of 2 : 1. They are **believed to be precursors of ribosomes**.
- **Fibrillar portion** (nucleolonema) is formed of a large number of small fibrils that are 50 – 80 Å long. The fibrils are made up of both protein and RNA and are believed to be precursors of granules.
- **Chromatin portion** is that part of chromatin which is associated with nucleolus. Depending upon its position nucleolar chromatin is of two types– **perinucleolar** and **intranucleolar**.
- The **perinucleolar chromatin** lies around the periphery of the nucleolus. It gives rise to in growths or trabeculae which produce the intranucleolar chromatin.
- **Functions of nucleolus** are –
  – Principal or active site for the development of

ribosomal RNAs. It produces 70–90% of cellular RNA in many cells. The chromatin in the nucleolus contains genes or ribosomal DNA (rDNA) for coding ribosomal RNA.
  - Centre for the formation of ribosomes.
  - Stores nucleoproteins. The same is synthesized in the cytoplasm (over the ribosomes) and transferred to nucleolus.
  - Essential for spindle formation during nuclear division.
- The configuration of nucleolus is maintained by **calcium**.
- The messenger RNA is formed **inside the nucleus** but **outside nucleolus**.

VACUOLE

- Vacuole may be defined as a **non-living reservoir**, bounded by a differentially or selectively permeable membrane, the **tonoplast**.
- The structure of tonoplast is similar to that of single unit membrane, *i.e.*, tripartite structure.
- In a young cell, vacuoles are extremely small in size or may be absent. As the cell enlarges, these smaller vacuoles fuse and form a large central vacuole at maturity. So in a mature cell the protoplasm is present as thin layer, pushed towards the wall of the cell. This thin layer of protoplasm is called as **primordial utricle**.
- Vacuole is not an air-filled cavity, rather it is filled with a highly concentrated solution called **vacuolar sap or cell sap**.
- This cell sap is **generally neutral but at maturity it becomes acidic**.
- Cell sap contains many dissolved solutes such as organic acids, soluble carbohydrates, soluble nitrogenous compounds as nitrates, enzymes, tannins, chlorides, phosphates, amino acids, alkaloids and anthocyanin pigments.
- Vacuoles and their contents are considered to be distinct from the cytoplasm and are classified as ergastic.
- In general, **vacuole functions** include
  - Removing unwanted structural debris
  - Isolating materials that might be harmful or a threat to the cell
  - Containing waste products
  - Maintaining internal hydrostatic pressure or turgor within the cell
  - Maintaining an acidic internal pH
  - Containing small molecules
  - Exporting unwanted substances from the cell.
  - Enabling the cell to change shape.
  - Proteins found in the tonoplast control the flow of water into and out of the vacuole through active transport, pumping potassium (K^+) ions into and out of the vacuolar interior.
- Vacuoles **also play a major role in autophagy**, **maintaining a balance between biogenesis** (production) and **degradation** (or turnover), of many substances and cell structures. They also aid in destruction of invading bacteria or of misfolded proteins that have begun to buildup within the cell.

Vacuoles

Depending upon contents vacuoles are of 4 types

Sap vacuoles
- Bubble like sac
- Contain cell sap
- Store and concentrate mineral salts
- Contain water soluble vacuoles pigments —anthocyanin and anthoxanthine
- Present in plant cell

Contractile vacuoles
Helps in osmoregulation and present in freshwater protozoans

Food vacuole
- Occur in protozoan protists, lower animals etc.
- Contain digestive enzymes

Air vacuole or Pseudovacuole
- Occur in prokaryotes
- Store gases, regulate buoyancy of cell, provide mechanical support etc.

Flow chart : Types of vacuoles.

End of the Chapter