EUKARYOTIC CELLS

- Eukaryotic cells are a type of cells that have a well-organized nucleus enclosed in a protective covering called a nuclear envelope. These cells have some key features like a supporting structure called cytoskeleton, special compartments with membranes (organelles), and genetic material neatly arranged into structures called chromosomes. You can find eukaryotic cells in a variety of living things such as protists, fungi, plants, and animals.
- Just like eukaryotic cells, which are more complex, have a protective layer called a cell envelope. The makeup of this envelope, however, differs among different types of eukaryotic cells. For instance, in animal cells, the cell envelope is formed only by the plasma membrane. Meanwhile, in plant cells, fungal cells, and certain protists, the cell envelope consists of both the plasma membrane and a sturdy cell wall. It's important to note that not all eukaryotic cells are the same—they have many differences that make each type unique.

Plasma Membrane or Cell Membrane

- The plasma membrane, also known as the cell membrane, is an indispensable component for all living organisms. Its significance lies in its role as the interface between a cell and the external world. The detailed exploration of the membrane's structure became possible with the advent of the electron microscope in the 1950s. Even before this, chemical investigations on the cell membrane, particularly focusing on human red blood cells (RBCs), provided valuable insights into its potential structure.
- These studies revealed that the cell membrane is predominantly composed of lipids arranged in a bilayer. The lipid molecules align with their polar heads facing outward and hydrophobic tails oriented inward. The hydrophilic (water-attracting) heads interact with the aqueous environment, while the hydrophobic tails are shielded from it. Additionally, further biochemical analyses unveiled the presence of proteins and carbohydrates in the membrane. The proportion of proteins to lipids can vary significantly across different cell types.

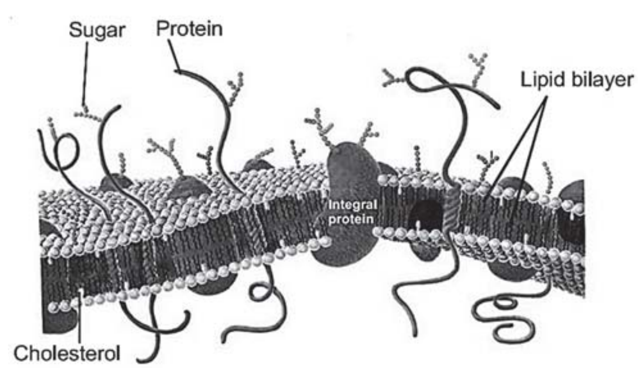

Fig. : Fluid mosaic model of plasma membrane

- Membrane proteins are categorized as integral or peripheral based on their ease of extraction. Peripheral proteins reside on the membrane's surface, while integral proteins are either partially or entirely embedded within the membrane. Those integral proteins that traverse the entire lipid bilayer are termed transmembrane or tunnel proteins. These proteins, often compared to icebergs floating in a sea of phospholipids, are not easily removable and require harsh treatment methods like detergents. The widely accepted Fluid Mosaic Model, proposed by Singer and Nicolson in 1972, describes the dynamic nature of the membrane, allowing lateral movement of proteins within the lipid bilayer.

Functions of the Plasma Membrane:

- **Fluidity for Cellular Processes:** The quasi-fluid nature of the membrane is crucial for various cellular functions, including cell growth, the formation of intercellular junctions, secretion, endocytosis, and cell division.
- **Selective Transport:** The membrane acts as a selective barrier, permitting the transport of specific molecules across it. This transport occurs through passive or active mechanisms.

  Passive Transport: Many molecules can move across the membrane without the input of energy. Simple diffusion allows neutral solutes to move along the concentration gradient, from higher to lower concentration. Osmosis, the movement of water through the membrane, is another form of passive transport. Polar molecules, unable to traverse the non-polar lipid bilayer, rely on carrier proteins for facilitated transport.

  Active Transport: This process involves the uphill movement of materials against their concentration gradient, requiring energy derived from ATP. An example is the Na^+/K^+ pump in animal cells.

Cell Wall

In the realm of bacteria, fungi, algae, and plants, cells boast an additional structural element known as the cell wall, which imparts rigidity to the cell and encases the plasma membrane. The composition of the cell wall exhibits diversity across various groups:

- **Fungal Cell Wall:** Fungi showcase a cell wall primarily composed of chitin—a polymer formed by repeating units of N-acetyl glucosamine (NAG).
- **Algal Cell Wall:** Algae present a cell wall comprising cellulose, galactans, mannans, and minerals like calcium carbonate.
- **Plant Cell Wall:** The plant cell wall is predominantly constituted of the insoluble polysaccharide cellulose. Alongside cellulose, the cell wall may contain other compounds such as hemicellulose, pectin, and proteins.

  The plant cell wall consists of two distinct regions: the primary wall and the secondary wall.
- **Primary Wall:** Formed by a young plant cell, the primary cell wall is a single layer that is thin, elastic, and capable of expansion during cell growth. Cells in meristematic and parenchymatous tissues typically possess only a primary cell wall.
- **Secondary Wall:** As a cell matures, additional layers of wall material are deposited internal to the primary wall, giving rise to the secondary cell wall. This process contributes to the thickening of the cell wall, particularly in cells forming the rigid woody portions of plants, such as lignified and suberised cell walls.
- **Middle Lamella:** The connection between adjacent cells within a plant tissue is facilitated by the middle lamella—a thin, adhesive layer composed mainly of calcium and magnesium pectate. In ripening fruits, pectate compounds in the middle lamella undergo solubilization, imparting a jelly-like consistency to the fruits. Plasmodesmata, tiny channels traversing the cell wall and middle lamella, establish cytoplasmic connections between neighboring plant cells.

Functions of Cell Wall:

The cell wall serves several pivotal functions:

- **Maintenance of Cell Shape:** It provides structural support, maintaining the shape of the cells.
- **Protection against Mechanical Injury:** The cell wall acts as a protective barrier, shielding cells from mechanical damage.
- **Defense against Pathogens:** It defends cells against pathogenic attacks by viruses, bacteria, fungi, etc.
- **Regulation of Material Exchange:** The cell wall facilitates the passage of materials into and out of the cell.

- **Cell-to-Cell Interaction:** It enables communication and interaction between adjacent cells, establishing a barrier against undesirable macromolecules.
- **Pits:** The cell wall does not exhibit uniform thickness throughout; certain areas lack a secondary wall, forming unthicken regions known as pits. Pits can be classified into simple pits, characterized by a uniform cavity diameter, and bordered pits, where the cavity takes on a flask-shaped structure, as observed in tracheids.
- **Plasmodesmata:** Serving as the living components within the cell wall, plasmodesmata are numerous channels or cytoplasmic strands found in pits. These structures allow cytoplasmic continuity between cells and are lined by plasma membrane, featuring a fine tubule known as the desmotubule. The endoplasmic reticulum plays a role in the origin of plasmodesmata, forming the symplastic system connecting two cells.

Endomembrane System

- Within the intricacies of a eukaryotic cell, numerous membrane-bound organelles each play distinct roles. Yet, some of these organelles collaborate in their functions, forming what is known as the endomembrane system. This system comprises the endoplasmic reticulum (ER), Golgi complex, lysosomes, and vacuoles. Notably, mitochondria, chloroplasts, and peroxisomes operate independently and are not part of the endomembrane system.

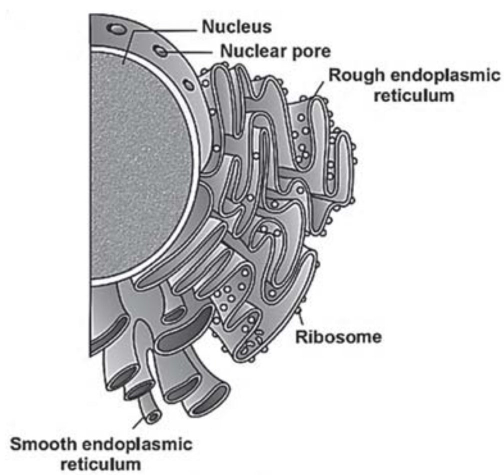

Fig. : Endoplasmic reticulum

Endoplasmic Reticulum (ER):

- Electron microscopy has unveiled a network of tubular structures in the cytoplasm, collectively termed the endoplasmic reticulum (ER).

Ultrastructure of ER:

- **Cisternae:** Elongated, flat, interconnected sac-like structures known as cisternae are present in cells actively engaged in protein synthesis. They are often associated with large ribosomal subunits (60 S), prevalent in cells with synthetic roles, such as those in the pancreas and brain.
- **Tubules:** These structures, either branched or unbranched, form a reticular system alongside cisternae and vesicles. Tubules lack ribosomes and are commonly found in cells involved in lipid and sterol synthesis.
- **Vesicles:** Oval, membrane-bound vacuolar structures without ribosomes are abundant in pancreatic cells and are the sole ER structures in spermatocytes.

Compartmentalization of ER: ER divides the intracellular space into two compartments:

- **Luminal Compartment:** The internal space enclosed by the ER membrane.
- **Extra Luminal Compartment:** The space outside the ER in the cytoplasm.

Types of ER:

- **Smooth Endoplasmic Reticulum (SER):** Devoid of ribosomes, SER appears as smooth tubular structures. It is involved in lipid and steroid synthesis, drug detoxification, and plays a role in muscle contraction by regulating Ca^{2+} ions. Muscle cells contain a type of SER known as sarcoplasmic reticulum.
- **Rough Endoplasmic Reticulum (RER):** RER, characterized by ribosomes on its surface, imparts a rough granular appearance under electron microscopy. It is extensively connected to the outer membrane of the nucleus.

Functions of ER:

- **Protein Synthesis:** RER serves as the site of protein synthesis, found in cells actively engaged in protein synthesis and secretion.
- **Precursors for Lysosomes:** RER provides precursors for enzymes, contributing to the formation of lysosomes in the Golgi complex.
- **SER Derivation:** RER gives rise to SER.
  The endomembrane system exemplifies the coordination of cellular activities, ensuring the seamless synthesis, modification, and transport of cellular components.

Golgi apparatus:

- The Golgi apparatus, first identified by Camillo Golgi in 1898, stands as a vital cellular structure involved in processing, packaging, and transporting materials. Initially described as densely stained reticular structures near the nucleus, they were aptly named Golgi bodies in honor of their discoverer. Present in eukaryotic cells, with the exception of certain specialized cells like mature sieve tubes in plants and mature red blood cells (RBCs) in mammals, as well as absent in prokaryotic cells, the Golgi apparatus is referred to as dictyosomes in plants due to its composition of unconnected units.

Structure of Golgi complex: The Golgi complex comprises four essential components: cisternae, tubules, vesicles, and Golgian vacuoles.

- **Cisternae:**
  Flattened Sac-like Structures: Cisternae are flattened, sac-like structures stacked in layers, usually numbering 4-8 in a stack. Resembling smooth endoplasmic reticulum, they form an extensive network arranged in a concentric pattern near the nucleus.
  Network Organization: An extensive network of cisternae displays variations in size, shape, and number across different cells while maintaining a consistent organization within a specific cell type. The diameter of these structures ranges from 0.5 μm to 1.0 μm.
  Distinct Convex and Concave Faces: Golgi cisternae exhibit a concentric arrangement near the nucleus, featuring distinct convex (cis or forming face) and concave (Trans or maturing face) regions. The cis and Tran's faces are interconnected yet structurally distinct.
- **Tubules:** These are small, flat, interconnecting structures emerging from the periphery of cisternae through fenestrations.
- **Vesicles:** Large rounded sacs clustered at the edges of cisternae, vesicles are pinched off from tubules.
- **Golgian Vacuoles:** Large, spherical vacuoles produced at the maturing face of the Golgi apparatus, filled with granular or amorphous substances. Some function as lysosomes.

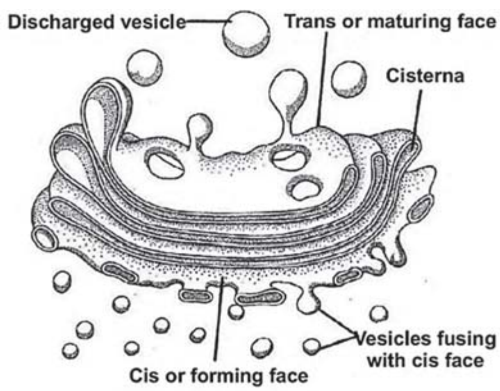

Fig.: Golgi apparatus

Functions of Golgi apparatus

- **Processing, Packaging, and Transport:** Golgi apparatus plays a pivotal role in processing, packaging, and transporting materials for secretion. Materials in transit from the endoplasmic reticulum (ER) to the Golgi apparatus take the form of transitional vesicles. These vesicles fuse with the cis face, progressing toward the maturing face before being delivered either intracellularly or extracellularly. The close association of Golgi apparatus with ER extends to both structural and functional aspects.
- **Protein Modification:** Proteins synthesized by ribosomes on the ER undergo modification in the cisternae of the Golgi apparatus before release from the Trans face.
- **Glycoprotein and Glycolipid Formation:** Golgi apparatus serves as a key site for the formation of glycoproteins (glycosylation of proteins) and glycolipids (glycosidation of lipids).
- **Root Cap Secretion:** Golgi bodies in root cap cells secrete mucilage, facilitating lubrication of the root tip.
- **Acrosome Modification:** The acrosome of sperm represents a modified Golgi apparatus.
- **Plasma Membrane Formation:** Golgi apparatus contributes to the formation of the plasma membrane during cytokinesis.

Lysosomes

- Lysosomes, essential components within the cellular landscape, are compact, spherical sac-like structures uniformly dispersed in the cytoplasm. These dynamic entities emerge from the intricate packaging process within the Golgi apparatus and are enveloped by a singular membrane. What sets lysosomes apart is their rich content of hydrolytic enzymes, including lipases, proteases, and carbohydrases.
- **Optimal Activity in Acidity:** Functioning optimally under acidic conditions, lysosomal enzymes demonstrate proficiency in digesting a spectrum of cellular components such as carbohydrates, proteins, lipids, and nucleic acids. This acidic environment is meticulously maintained within lysosomes through the active transport of $H+$ ions into these organelles.
- **Polymorphic Nature:** Lysosomes exhibit polymorphism, manifesting in diverse forms based on their morphology, contents, and functions:

  Primary Lysosomes: Emerging as small, vesicle-like structures freshly crafted at the Trans face of the Golgi apparatus, primary lysosomes house inactive enzymes awaiting activation.

  Secondary Lysosomes: Also known as heterophagosomes or digestive vacuoles, secondary lysosomes come into existence through the fusion of phagosomes with pre-existing primary lysosomes. Laden with enzymes specifically tailored for the targeted material, these lysosomes undertake the digestion process.

Residual Bodies: Representing secondary lysosomes that encapsulate undigested substances, residual bodies embark on an outward journey. Upon encountering the cell membrane (plasmalemma), they expel their contents to the extracellular environment through processes like ephagy or exocytosis.

Autophagic Vacuoles: The formation of Autophagic vacuoles involves the amalgamation of numerous primary lysosomes around aging or defunct organelles. Enclosed by a vacuolar membrane, these lysosomes engage in autolysis or auto digestion, earning them the moniker "suicidal bags." Autolysis plays a crucial role in biological processes such as the disappearance of larval organs during metamorphosis, exemplified by the tail resorption in frogs.

Vacuoles

- **Introduction to Vacuoles:** Vacuoles, integral membrane-bound spaces nestled within the cytoplasm, serve as dynamic repositories containing water, sap, excretory byproducts, and other materials deemed nonessential for the cell. Often referred to as sap vacuoles, these structures contribute significantly to cellular functions.
- **Plant Cell Dominance:** In the realm of plant cells, vacuoles assume a prominent role, capable of occupying up to an astounding 90 percent of the cell's volume. Enclosed by a singular semipermeable membrane known as the tonoplasts, these vacuoles wield influence over cellular dynamics. The tonoplast's semi permeability enables the transport of ions and various materials into the vacuole, challenging concentration gradients and establishing an environment where concentrations surpass those in the cytoplasm.

Diverse Varieties of Vacuoles:

- **Contractile Vacuole:** Embodied in organisms like Amoeba, the contractile vacuole plays a pivotal role in excretion. This specialized vacuole partakes in regulating the cellular environment by expelling excess water and waste products, contributing to the organism's homeostasis.
- **Food Vacuoles:** Encountered in a myriad of cells, particularly within protists, food vacuoles come into existence through the engulfing of food particles. These vacuoles serve as designated spaces for the digestion and processing of ingested nutrients, playing a vital role in the cell's nutritional activities.
- **Gas Vacuoles (Pseudo vacuoles):** Present in the realm of prokaryotes, gas vacuoles, also known as pseudo vacuoles, defy the conventional membrane-bound structure. These vacuoles, devoid of a membrane, contribute to buoyancy in prokaryotic organisms. By modulating their internal gas content, these vacuoles aid in maintaining an optimal position in aquatic environments, showcasing their adaptive significance.

Mitochondria

- Mitochondria, singularly referred to as a mitochondrion, represent cylindrical or sausage-shaped organelles enveloped by double membranes and distributed within the cytoplasm of cells. These microscopic entities pose visibility challenges, requiring staining with the vital dye Janus green for enhanced observation. Mitochondria exhibit a remarkable diversity in their shape, size, and quantity.
- **Size:** A prototypical mitochondrion assumes a sausage-shaped or cylindrical configuration, featuring a diameter within the range of 0.2-1.0 μm (with an average of 0.5 μm) and a length spanning 1.0-4.1 μm, showcasing considerable variability in shape and size.
- **Number:** The quantity of mitochondria varies across distinct cell types, contingent upon the specific workload and energy demands of the cell.

Structure:

- Mitochondria are encapsulated by two membranes, identified as the outer and inner membranes. The outer membrane, constituting 40% lipid and 60% proteins, forms a smooth, continuous boundary. In contrast, the inner membrane, rich in cardiolipins, undergoes infoldings termed cristae. The chemical composition of the inner membrane includes 80% protein and 20% lipids. The presence of these two membranes partitions the organelle into two chambers filled with aqueous fluid:

- **Outer Compartment or Intermembrane Space:** Positioned between the two mitochondrial membranes, this area is also known as the peri-mitochondrial space.
- **Inner Compartment or Matrix:** Located inside the inner membrane, the cristae, infoldings directed towards the matrix, increase the surface area for enzyme action.
- **Matrix:** The matrix contains a single circular dsDNA molecule (with high G=C content), a few RNA molecules, 70S ribosomes, and components essential for protein synthesis. Additionally, enzymes for the Tricarboxylic Acid (TCA) cycle are present in the matrix.
- The two membranes harbor specific enzymes associated with mitochondrial function. Mitochondria undergo division through fission, and the enzymes and electron carriers crucial for Adenosine Triphosphate (ATP) formation are exclusively located in the inner membrane.

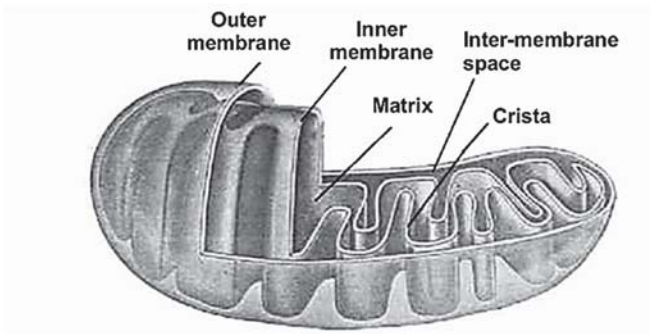

Fig. : Structure of mitochondrion (Longitudinal section)

The cristae and the inner face of the inner membrane are adorned with numerous spherical or knob-like protuberances, referred to as elementary particles, Particles of Fernandez and Moran, F particles, or oxysomes. Each oxysome is differentiated into a base, stalk, and headpiece, with the headpiece containing the enzyme ATP synthetase, facilitating oxidative phosphorylation coupled with ATP release.

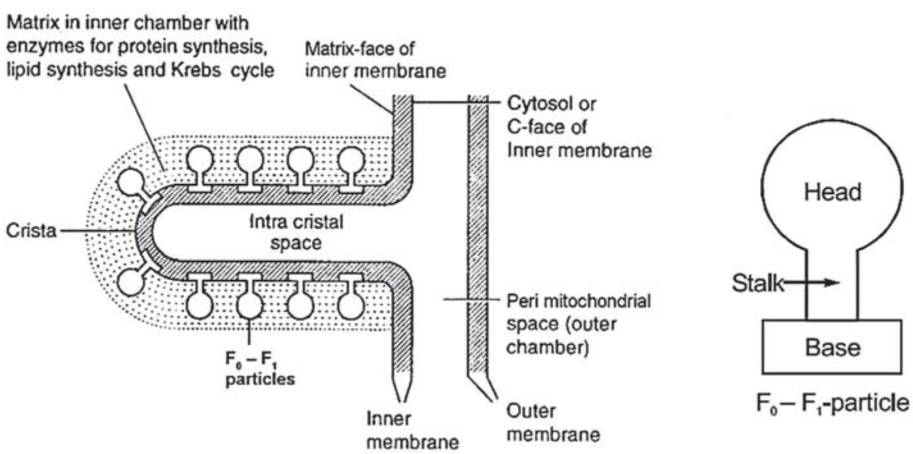

Fig. : Detailed Structure of Cristae and Oxysome

Functions:

- **Mitochondria as Sites of Aerobic Respiration:** Function as miniature biochemical factories where respiratory substrates undergo complete oxidation to produce carbon dioxide and water. The liberated energy is stored in the form of ATP, facilitating the oxidation of carbohydrates, proteins, and β-oxidation of fats.
- **ATP Production for Energy-Requiring Cellular Processes:** The energy (ATP) generated in mitochondria supports various cellular activities such as muscle contraction and nerve impulse conduction. Due to their pivotal role in ATP formation, mitochondria are often referred to as the powerhouse of the cell.

Plastids

- Plastids, present in all plant cells and certain organisms like euglenoids, are readily observable under a microscope due to their substantial size. They can be classified into three main types based on their color and contained pigments: leucoplasts, chromoplasts, and chloroplasts.

Leucoplasts:

- **Characteristics:** Colorless plastids commonly found near the nucleus in non-green cells, displaying variable size, form, and stored nutrients. They lack granum.
- **Types:**
  Amyloplast: Starch-containing leucoplasts, found in organs such as potato tubers and rice.
  Elaioplasts: Responsible for storing fats and oils, as seen in castor plants.
  Aleuroplast: Leucoplasts storing proteins, observed in aleurone cells of maize.

Chromoplasts:

- **Characteristics:** Plastids exhibiting yellow, orange, or reddish colors due to carotenoid pigments. They can originate from either leucoplasts or chloroplasts. For example, the transformation of chloroplasts to chromoplasts during the ripening of tomatoes and chillies results in a change from green to reddish color. The orange hue in carrot roots is due to chromoplasts.

Chloroplasts:

- **Characteristics:** Greenish plastids containing photosynthetic pigments like chlorophylls and carotenoids, actively participating in food synthesis. Predominantly found in the mesophyll cells of plant leaves, they exhibit variability in size, shape, and number.
- **Size:** Variable thickness ranging from 2-4 µm and length from 5-10 µm.
- **Shape:** Varies from spherical, lens-shaped, oval, and discoid to ribbon-shaped in certain plants.
- **Number:** Varies from 1 per cell in green algae like Chlamydomonas to 20-40 per cell in mesophyll cells of certain plants.

Structure of Chloroplast:

- **Membranes:** Like mitochondria, chloroplasts are double membrane-bound organelles with an outer and inner membrane. The inner membrane is less permeable and contains more proteins, including carrier proteins. The space enclosed by the inner membrane is termed the stroma.
- **Thylakoids and Grana:** Stroma comprises organized, flattened membranous sacs known as thylakoids, arranged in stacks called grana. These grana are interconnected by flat membranous tubules called stroma lamellae.
- **Lumen:** The membrane of thylakoids encloses a space known as the lumen.
- **Stroma:** Contains enzymes required for carbohydrate and protein synthesis, along with small, double-stranded circular DNA molecules and ribosomes (70S).

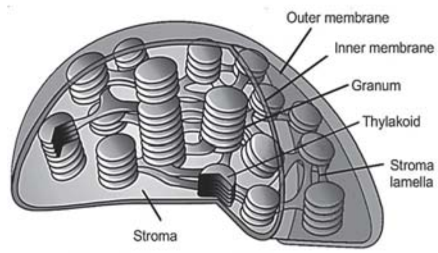

Fig.: Sectional view of Chloroplast

Functions of Chloroplasts:

- **Photosynthesis:** Involves light reactions (occurring in thylakoids) and dark reactions (in stroma).
- Storage of starch.

Ribosomes

- Ribosomes, discovered by George Palade in 1953 within animal cells, were initially observed as dense particles in the cytoplasm under an electron microscope. Comprising ribonucleic acid (rRNA) and proteins, ribosomes lack a surrounding membrane.
- **Structure of Ribosomes:** Ribosomes are composed of two subunits. The larger subunit possesses a dome-like shape, while the smaller subunit is positioned above it, forming a cap-like structure. Specific concentrations of $Mg2+$ ions maintain the unity between these subunits. Decreasing $Mg2+$ ion concentrations lead to their separation, but elevating the ion concentration in the matrix causes the subunits to associate, forming a dimer. During protein synthesis, numerous ribosomes align on a common messenger RNA, creating polyribosomes, polysomes, or ergasomes.

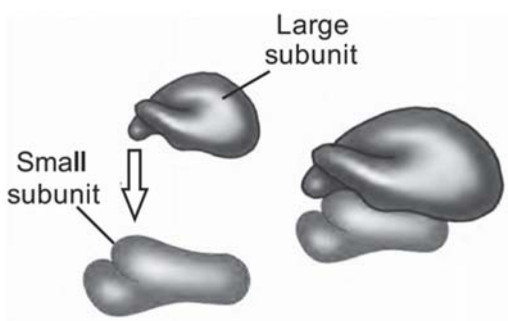

Fig : Ribosome

Types of Ribosomes:

- Ribosomes come in two types - 70S and 80S, with 'S' representing the sedimentation coefficient that indirectly measures ribosome density and size. Prokaryotic ribosomes are 70S, while eukaryotic ribosomes are 80S. Mitochondria and chloroplasts contain 70S ribosomes.

70S Ribosomes:

- Comprising ribonucleoproteins in a 60:40 ratio (RNA: Protein).
- 30S smaller subunit consists of 21 protein molecules and 16S rRNA.
- 50S larger subunit includes 34 protein molecules and 23S and 5S rRNA.

80S Ribosomes:

- Consisting of ribonucleoproteins in a 40:60 ratio (RNA: Protein).
- 40S smaller subunit comprises 33 protein molecules and a single 18S rRNA.
- 60S larger subunit includes around 40 protein molecules and three types of rRNAs - 28S, 5.8S, and 5S.

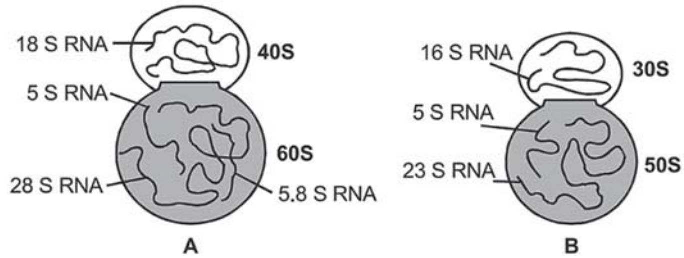

Fig. : Structure of (A) 80 S and (B) 70 S Ribosomes

Functions: Ribosomes serve as sites for protein synthesis. Free ribosomes produce non-secretory proteins, while those bound to the endoplasmic reticulum (ER) synthesize secretory proteins. Free ribosomes are responsible for generating structural and enzymatic proteins for internal cellular use. Attached ribosomes, on the other hand, synthesize proteins for transport, earning them the designation of "protein factories." Newly synthesized proteins undergo processing with the assistance of chaperone proteins.

Cytoskeleton

- The cytoskeleton, a complex network within eukaryotic cells, consists of minute, fibrous, filamentous, and tubular proteinaceous structures. This structural framework serves essential roles in mechanical support, cellular motility, and the maintenance of cell shape.
- **Microtubules:** Microtubules are present in the cytoplasmic matrix, as well as in structures such as cilia, flagella, centrioles, basal bodies, and the mitotic apparatus, but are notably absent in prokaryotic cells. These hollow, unbranched cylinders are approximately 25 nm in diameter, featuring a hollow core of about 15 nm. The microtubule boundary consists of 13 parallel protofilaments, each comprising α and β subunits of tubulin protein, a non-contractile protein. The assembly and disassembly of microtubules necessitate GTP and Ca2+.

Functions:

- Formation of spindles and astral rays during cell division.
- Constituting the cytoskeleton of cilia and flagella.
- Contributing to cell shape, rigidity, and form, as well as cell motility.
- Facilitating the anaphasic movement of chromosomes.
- Assisting in intracellular transport of nutrients and inorganic ions.
- Determining the position of the future cell plate.
- **Microfilaments:** Microfilaments are solid, unbranched, rod-like fibrils of indefinite length, primarily composed of the globular protein actin, with filamentous protein myosin also present. They form an extensive network in the cell cytoplasm and may associate with the plasma membrane.
- Providing support to the plasma membrane.
- Representing the cell's contractile system, involved in cytoplasmic streaming and amoeboid movements.
- Facilitating the formation of pseudopodia.
- Contributing to the formation of the cleavage furrow during cell division.
- **Intermediate Filaments:** Intermediate filaments are non-contractile hollow filaments composed of acidic proteins. They play a role in the formation of scaffolds for chromatin and create a basket-like structure around the nucleus. These structures contribute to the overall stability and integrity of the cell.
- The cytoskeleton, through its intricate arrangement of microtubules, microfilaments, and intermediate filaments, is indispensable for cellular architecture, support, and dynamic cellular processes.

Cilia and Flagella

- Cilia (singular: cilium) and flagella (singular: flagellum) are slender, hair-like projections originating from the cell membrane. While cilia function as smaller structures resembling oars, causing either cell or surrounding fluid movement, flagella, comparatively longer, are primarily responsible for cell propulsion. Although both structures are present in prokaryotic and eukaryotic cells, they exhibit structural distinctions.

Eukaryotic Cilia and Flagella:

- Cilia and flagella emerge as extensions of the plasma membrane, originating from basal bodies reminiscent of centrioles. These basal bodies serve to anchor and regulate the movements of cilia and flagella.
- Both structures feature a cylindrical design, with an internal core known as the axoneme. The axoneme houses a series of microtubules aligned parallel to the structure's long axis. This arrangement is characterized by the presence of nine microtubule doublets positioned radially along the periphery, along with a pair of microtubules singularly located in the center, forming what is known as the (9 + 2) organization.
- The centrally positioned pair of tubules are interconnected by a bridge and enclosed within a common sheath referred to as the central sheath.
- The central sheath connects to each peripheral doublet of microtubules through radial spokes, resulting in a total of nine radial spokes.
- The peripheral doublets are further connected to one another via linkers composed of the nexin protein, contributing to the structural integrity of the cilia and flagella.

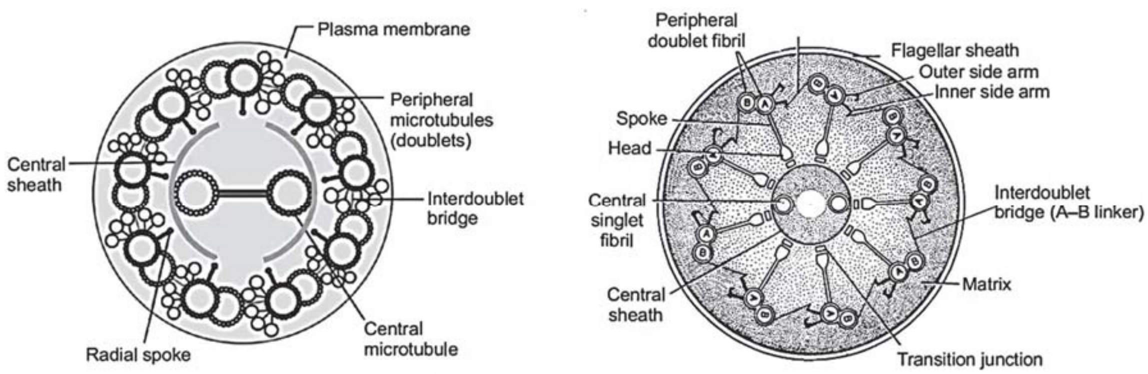

Fig. : Ultrastructure of a Flagellum in Cross-section

- Eukaryotic cilia and flagella, with their intricate (9 + 2) microtubule organization and radial spoke-linker architecture, showcase a remarkable structural complexity. These structures play vital roles in cellular movements and fluid propulsion, contributing to essential physiological functions in various cell types.

Centrosome and Centrioles

- The centrosome is an organelle typically housing two cylindrical structures known as centrioles, enveloped by a cloud of shapeless pericentriolar material referred to as centrosphere or kinoplasm. These centrioles, collectively termed the diplosome, are positioned within the centrosome at right angles to each other.
- Centrioles are present in nearly all eukaryotic cells, including animal cells, fungi, and algae, though notably absent in higher plant cells.

Structure of a Centriole:

- A centriole exhibits a whorl pattern consisting of nine evenly spaced peripheral fibrils made of tubulin, with an absence of a central fibril, resulting in a 9 + 0 arrangement.
- Each fibril is composed of three sub fibers, forming what is known as a triplet fibril comprising sub-fibres A, B, and C.
- C-A proteinaceous linkers connect adjacent triplet fibrils.
- At the center of the centriole, there is a rod-shaped proteinaceous mass called the hub. From this hub, nine proteinaceous strands extend towards the peripheral triplet fibrils, known as radial spokes.
- The presence of radial spokes and peripheral fibrils gives the centriole a distinctive cartwheel appearance.
- While a centriole lacks a membrane boundary, it is surrounded by pericentriolar satellites, also known as massule or Microtubule generator (MTG).

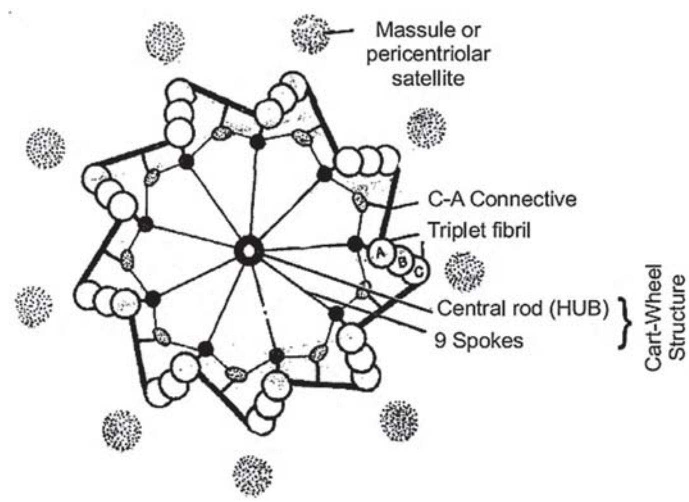

Fig. : T.S. of Centriole

Functions:

- **Formation of Basal Bodies:** Centrioles play a crucial role in the formation of basal bodies, which serve as the foundation for the generation of cilia and flagella.
- **Spindle Fibres:** During cell division, centrioles contribute to the formation of spindle fibres, which in turn give rise to the spindle apparatus, facilitating the proper segregation of chromosomes.

Centrioles, with their unique structural features and essential functions in cellular processes, are integral components of the eukaryotic cell architecture. Their involvement in the organization of cellular components highlights their significance in key cellular functions.

Nucleus

- The nucleus, a pivotal cell organelle, was initially identified by Robert Brown in 1831. Flemming (1879) coined the term "chromatin" for the material within the nucleus that stains with basic dyes. As a large and vital organelle, the nucleus governs the activities of eukaryotic cells. Some cells exhibit unique nuclear characteristics, including the absence of a nucleus (anucleate) in mature cells like mammalian red blood cells and sieve tube cells.

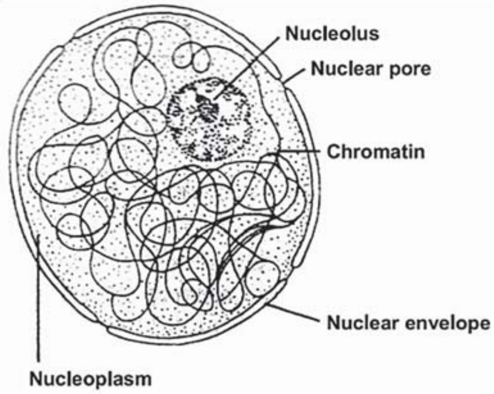

Fig. : Structure of a Nucleus

Structure of a Typical Interphase Nucleus:

- **Nuclear Envelope**
  Boundaries: The nuclear envelope encloses the nucleus, separating it from the cytoplasm, with two membranes—inner and outer.
  Membrane Features: The inner membrane is smooth, while the outer membrane may be smooth or bear ribosomes similar to the rough endoplasmic reticulum (RER).
  Pore Complex: Numerous complex pores in the nuclear envelope control the passage of substances such as RNA, ribosomes, and proteins.
- **Nucleoplasm:**
  Composition: A transparent, semi-fluid, colloidal substance filling the nucleus, housing the nucleolus and chromatin.
- **Nucleolus**
  Structure: A spherical, non-membrane-bound structure within the nucleoplasm, the site for ribosomal RNA (rRNA) synthesis.
  Role: Nucleoli are more prominent in cells actively engaged in protein synthesis.
- **Chromatin:**
  Composition: A loose, extended network of nucleoprotein fibers within the interphase nucleus.
  Components: Composed of DNA, histone proteins, RNA, and non-histone proteins, forming chromosomes during cell division.
  Chromosome Formation: Chromatin fibers condense to form chromosomes during cellular processes.

Structure of a Chromosome:

- **Chromatids and Centromere:**
  Chromatids: Chromosomes consist of two identical halves called chromatids, held together at the centromere.
  Centromere: The centromere appears as a primary constriction, holding chromatids together.
- **Centromere Classification:**
  Metacentric Chromosome: Centromere at the center, dividing the chromosome into two equal arms during anaphase.
  Sub-metacentric Chromosome: Centromere slightly away from the center, resulting in one shorter (p arm) and one longer (q arm) arm.
  Acrocentric Chromosome: Centromere close to one end, forming one extremely short and one very long arm.
  Telocentric Chromosome: Centromere at the terminal end, creating a single-arm appearance.

- **Additional Chromosomal Features:**
  Secondary Constrictions: Nonstaining secondary constrictions or nucleolar organizers (NOR) near chromosome ends.
  Satellite Chromosomes: Chromosomes with a satellite region beyond the secondary constriction, known as SAT-chromosomes or marker chromosomes.

Certain chromosomes exhibit supplementary constrictions known as Nonstaining secondary constrictions or NOR (nucleolar organizer) in proximity to their ends. The segment of the chromosome situated beyond this secondary constriction is referred to as a satellite. Chromosomes possessing such satellite regions are labeled SAT-chromosomes, and they serve as marker chromosomes? In humans, there are five pairs of SAT chromosomes.

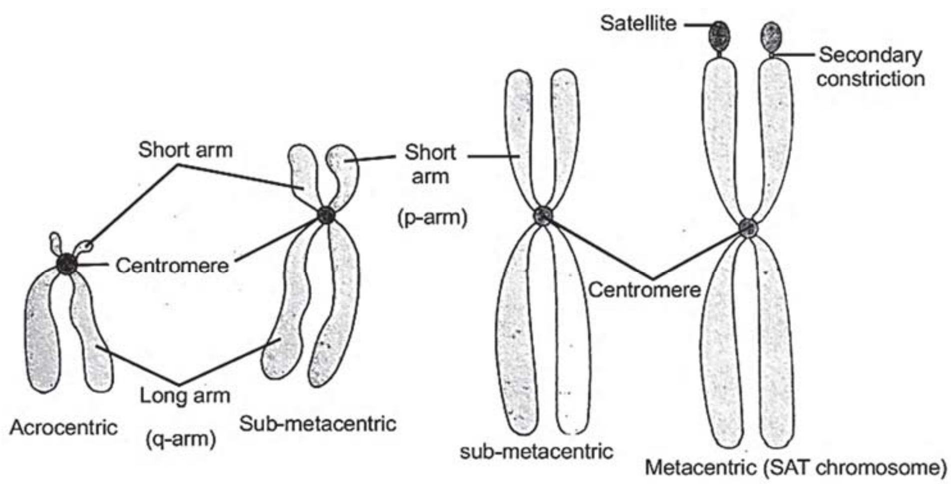

Fig. : Types of Chromosomes based on the Position of Centromere

This structural feature adds a layer of complexity to chromosomal organization, providing insight into chromosomal behavior and potential genetic implications. The presence of these secondary constrictions and satellite regions contributes to the diversity and individuality observed in chromosomal configurations among individuals. Understanding the specifics of these features is crucial for unraveling the intricacies of genetic information and its role in various cellular processes.

Microbodies

- Micro bodies, which are small vesicles enclosed by a single membrane and house a diverse array of enzymes, are a characteristic feature found in both plant and animal cells. These microbodies play a crucial role in facilitating oxidation reactions that extend beyond the scope of cellular respiration.

The various types of microbodies include:

- **Peroxisomes:** These microbodies are integral to cellular processes involving oxidation reactions. Within their membrane-bound compartments, peroxisomes harbor enzymes that contribute to the breakdown of fatty acids and the detoxification of harmful substances, such as hydrogen peroxide. Additionally, peroxisomes are involved in various metabolic pathways, showcasing their significance in cellular function.
- **Sphaerosomes:** Another category of microbodies, sphaerosomes, participates in lipid metabolism within plant cells. These vesicles, enclosed by a single membrane, are involved in storing and mobilizing lipids, particularly during phases of active growth or when energy demands require lipid breakdown. Sphaerosomes contribute to the dynamic regulation of cellular lipid composition.

- **Glyoxysomes:** Glyoxysomes are specialized microbodies found in plant cells, primarily in germinating seeds. These microbodies play a pivotal role in glyoxylate cycle-related activities. During seed germination, glyoxysomes facilitate the conversion of stored lipids into carbohydrates, providing an energy source for the developing seedling until it can photosynthesize independently. This adaptation allows plants to efficiently utilize stored lipids as an energy reserve during early growth stages.