G.N. Ramachandran
(1922 – 2001)

G.N. RAMACHANDRAN, an outstanding figure in the field of protein structure, was the founder of the 'Madras school' of conformational analysis of biopolymers. His discovery of the triple helical structure of collagen published in *Nature* in 1954 and his analysis of the allowed conformations of proteins through the use of the 'Ramachandran plot' rank among the most outstanding contributions in structural biology. He was born on October 8, 1922, in a small town, not far from Cochin on the southwestern coast of India. His father was a professor of mathematics at a local college and thus had considerable influence in shaping Ramachandran's interest in mathematics. After completing his school years, Ramachandran graduated in 1942 as the topranking student in the B.Sc. (Honors) Physics course of the University of Madras. He received a Ph.D. from Cambridge University in 1949. While at Cambridge, Ramachandran met Linus Pauling and was deeply influenced by his publications on models of the α-helix and β-sheet structures that directed his attention to solving the structure of collagen. He passed away at the age of 78, on April 7, 2001.

CELL – THE BASIC UNIT OF LIFE

Introduction

- The presence of basic unit of life i.e. cell makes a living organism different from non-living organisms.
- The organisms, which are composed of a single cell, are called as unicellular organisms while the organisms, which are made up of multiple cells, are called as multicellular organisms.
- Unicellular organisms are capable of

  (a) Independent existance

  (b) Performing the essential functions of life.
- The structure, which is less than a cell, does not ensure independent existance.
- Cell is a basic unit of life and it is considered as structural and functional unit of an organism. **Robert Hooke (1665)** discovered cell. He first observed the cell in a piece of dead cork cells. He described cell in his book **"Micrographia".**
- **Leeuwenhoek (1674)** first observed animal (living) cell and used the term **"Animalcule"** for it.

  The study of cell stucture is called **cytology.** The study of cell sturcture, function and reproduction is called **Cell biology.**
- **Robert Hooke is known as 'Father of cytology'.**
- **Knoll and Ruska invented electron microscop and by this invention all stuructural details of this cell could be revealed.**

Cell Theory

- In 1838, **Matthias Schleiden,** a **German botanist**, examined a large number of plants.
- He concluded that all plants are made up of different cells which make tissue.
- **Theodore Schwann (1839),** a **British Zoologist,** studied different types of animal cells and plant tissue.
- He concluded that animal cells have thin outer layer, which is today known as plasma membrane.
- Based on his studies of plants, he concluded that presence of cell wall is a unique character of plant cell.
- Schwann proposed the hypothesis that the bodies of animals and plants are composed of cells and products of cells.

Matthias Schleiden and Theodore Schwann jointly proposed cell theory in 1839. Its main features are as follows

(i) **All living organisms consist of cells and their products.**

(ii) All cells are structurally and metabolically similar.

(iii) Cells perform vital activities of an organism.

(iv) Each cell is unit of heredity.

Objections

(1) Bacteria and cyanobacteria do not bear nucleus and membrane bound cell organelles.

(2) Viruses are acellular and do not contain cellular machinery.

(3) RBCs and sieve tube cells live without nucleus.

(4) Protozoans and many thallophytes have a uninucleate differentiated body that cannot be divided into cells. They are acellular.

(5) **This theory did not explain as to how new cells were formed.**

Modern cell theory

It is also known as **cell doctrine** or **cell principle**.

(1) All living organisms are made up of cells having cytosol, nucleus, organelles and a covering membranes.

(2) Functions of living organisms are the sum total of the activities of their cells.

(3) Cell can survive independantly but organelles cannot do so.

(4) Any cell arises from pre-existing cell.

(5) It is unit of structure, function and heredity.

(6) Life exist in cells.

(7) Growth of an organism is due to increase in size and number of cells.

(8) **New cell arises from pre existing cells "Omnis cellula-e cellula".** It is called **cell lineage theory. This concept was given by Rudolf Virchow (1855). The final shape to cell theory was given by Rudolf Virchow.**

Types of cells

(1) **Undifferentiated cells** – Also called **stem cells**. They are unspecialized and usually possess power of division. e.g.- Root and shoot apices, skin cells, germinal epithelium, bone marrow, zygote etc.

(2) **Differentiated cells** – They are specialized to perform special function and cell division is absent.

(3) **Dedifferentiated cells** – Actually they are specialized cells but lose their specialization and induce division. It helps in healing of wounds, regeneration in animals or vegetative propagation in plants, cell culture experiments e.g. cork cambium.

Cell - An open system:

- An open system is one which is separated from its surroundings by a boundary that allows transfer of material in and out of the cells.
- Cell is an open system because it receives a number of materials and energy from outside and liberates energy as heat.
- Cells vary greatly in their shape. They may be disc-like, polygonal, columnar, cuboid, thread like, or even irregular. The shape of the cell may vary with the function they perform.

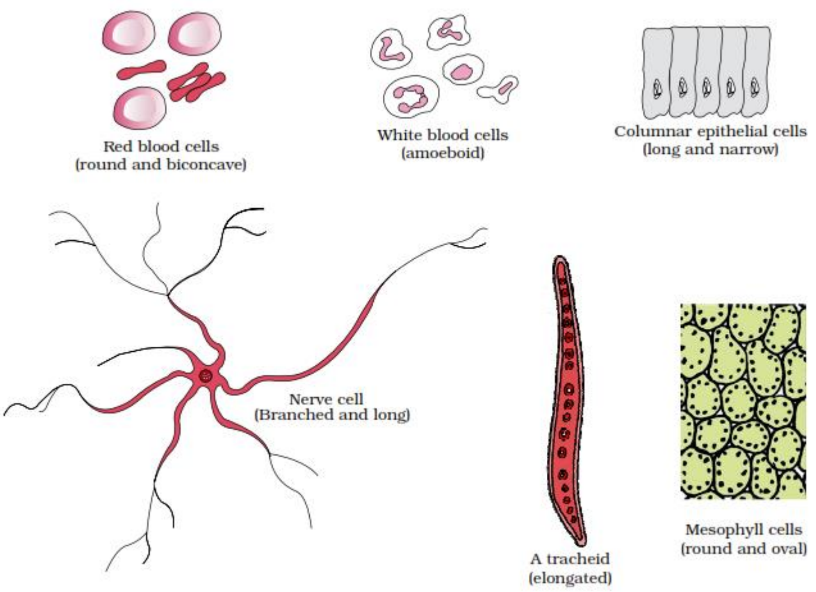


Figure: Diagram showing different shapes of the cells

- Cells differ greatly in size, and activities. For example -
  (a) The smallest cell - Mycoplasma 0.3μm.
  (b) Bacteria - (3 - 5) μm.
  (c) Largest isolated single cell - egg of an Ostrich.
  (d) Human RBCs - 7.0 μm in diameter.
  (e) Nerve cells are some of the largest cells.

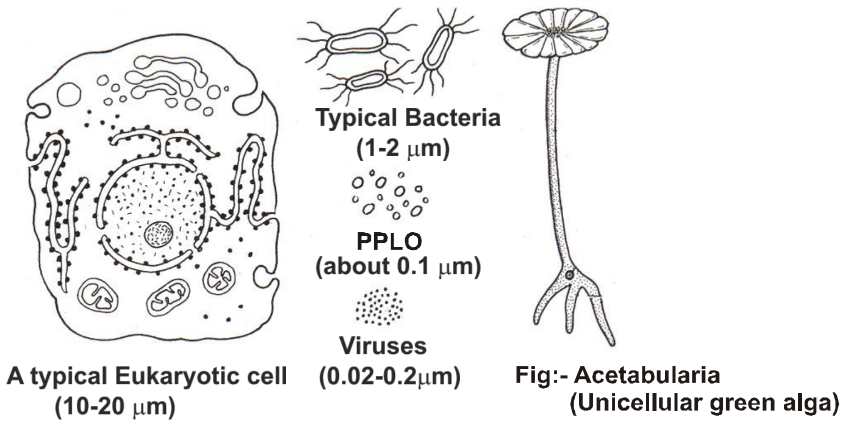


Fig:- Acetabularia (Unicellular green alga)

Fig:- Comparison of unicellular organisms with typical eukaryotic cell

Cell Organisation: On the basis of nucleus, two types of cells are present –

Differences between Prokaryotic and Eukaryotic Cell			
S.No	**Prokaryotic Cell**	**S.No**	**Eukaryotic Cell**
1	The Cell size is small (0.1–5.0 μm.) They multiply rapidly.	**1**	The cell size is comparatively larger (5–100 μm). They multiply slowely than Prokaryotic cell.
2	A prokaryotic cell has one envelope organisation.	**2**	A eukaryotic cell has two envelope organisation.
3	An organized nucleus is absent. Instead a nucleoid is found.	**3**	An organized nucleus is found. It is differentiated into nuclear envelope, chromatin, one or more nucleoli and nucleoplasm.
4	Cell wall, if present, contains muramic acid.	**4**	Cell wall, if present, muramic acid is absent
5	DNA is naked, it means histones absent	**5**	DNA is found with histones.
6	DNA lies freely in the cytoplasm.	**6**	Most of the cell DNA is found in the nucleus. A small quantity is also found in the plastids and mitochondria.
7	DNA is circular or organised into a single chromosome.	**7**	Nuclear DNA is linear whereas Extra nuclear DNA is circular. Genetic material is organised into chromosomes.
8	Transcription and translation take place in the cytoplasm.	**8**	Transcription occurs in the nucleus while tanslation takes place in the cytoplasm.

9	Cytoplasm does not show cyclosis.	**9**	Cytoplasm usually shows cyclosis.
10.	No extensive compartmentalisation of cytoplasm.	**10.**	Extensive compartmentalisation of cytoplasm through the presence of membrane bound organelles.
10	Membrane bound organelles like Mitochondria, Golgi apparatus, ER, lysosomes and other microbodies are absent.	**10**	Mitochondria, ER, Golgi apparatus and microbodies including lysosomes present in cell of organisms.
11	Microtubules and microfilaments are commonly absent.	**11**	Mircrotubules and microfilaments present.
12	Gametes are not formed, since sexual reproduction and meiosis are absent.	**12**	Gametes are formed either directly or through meiosis, as sexual reproduction is found in the life cycle.
13	A spindle apparatus is not formed during division.	**13**	A spindle apparatus is produced during nuclear division.
14	70S types of Ribosomes are found.	**14**	Ribosomes are of 80S types. 70S ribosomes are found in mitochondria and plastids.
15	Centriole is also absent	**15**	Centriole is present in animals and lower plants
16	e.g.Bacteria, Cyanobacteria, Mycoplasma and PPLO (Pleuro Pneumonia like organisms)	**16**	e.g.Protists, Fungi, Plants and Animals.

Note: Dodge recognised mesokaryotic organisation in **dinoflagellates**.

Mesokaryotic cell: Histone protein absent but nucleus with nuclear membrane present. Chromosomes are condensed and visible even in interphase. e.g. Dinoflagellates.

Differences between Plant and Animal Cells

S.No.	Plant Cell	S.No.	Animal Cell
1	A plant cell has rigid wall on the outside.	**1**	A cell wall is absent.
2	Plastids are found in plant cells	**2**	Plastids are usually absent.
3	A mature cell has a large central vacuole.	**3**	An animal cell may have many small vacuoles.
4	Nucleus lies on one side in the peripheral cytoplasm due to central vacuole.	**4**	Nucleus usually lies in the centre.
5	Centrioles are usually absent.	**5**	Centrioles are found in animal cells.
6	Spindle apparatus formed during nuclear division is anastral.	**6**	Spindle is amphiastral.
7	Golgi apparatus consists of number of distinct and unconnected units called dictyosomes.	**7**	Golgi apparatus is either localised or diffused and consists of a well connected single complex.
8	Reserve food is generally starch and fat.	**8**	Reserve food is usually glycogen and fat.
9	Adjacent cells may be connected through plasmodesmata.	**9**	Adjacent cells are connected through a number of cell junctions.
10	Cytokinesis occurs by cell plate.	**10**	Cytokinesis takes place by cleavage.

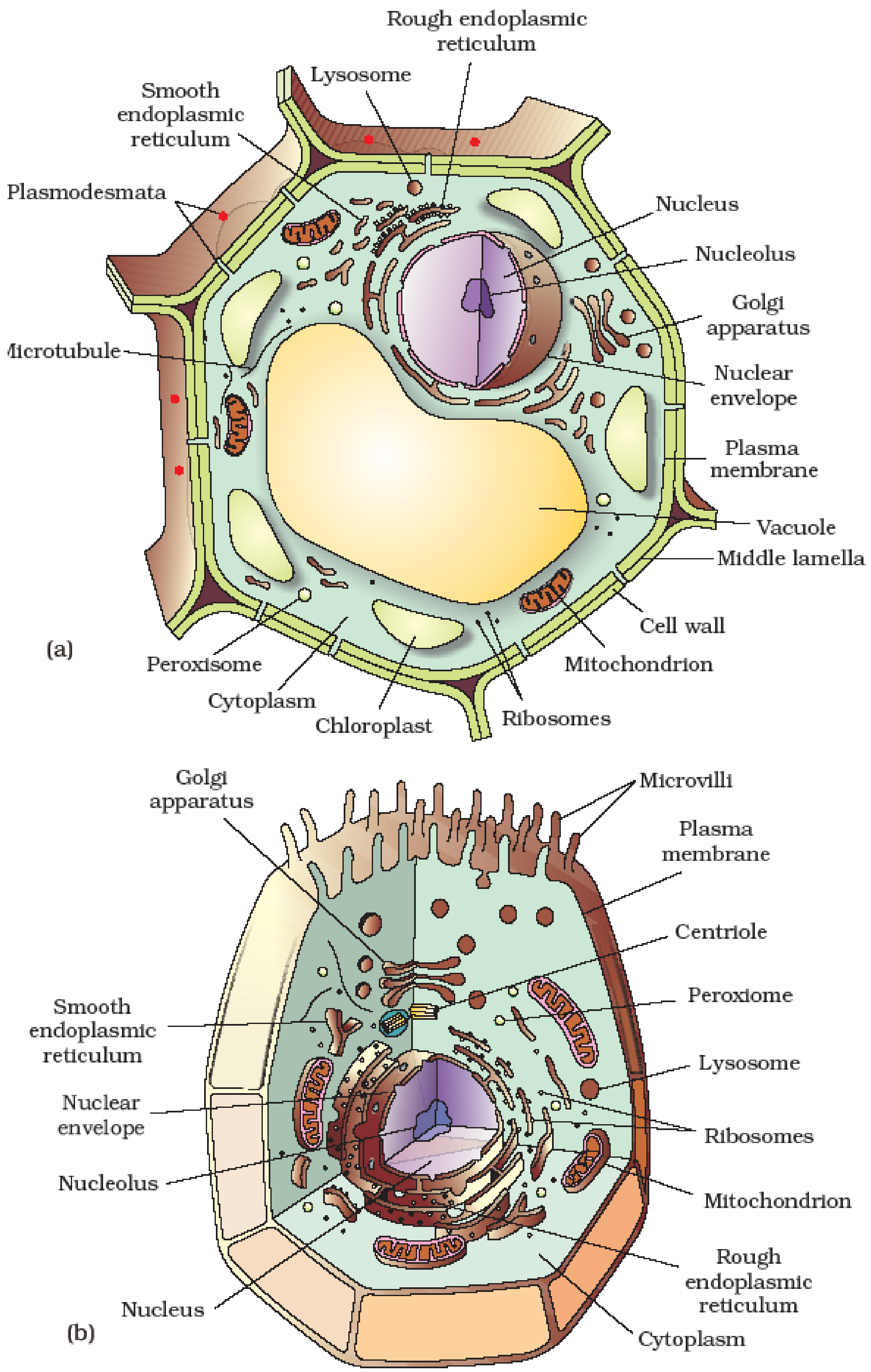


Figure: Diagram showing : (a) Plant cell (b) Animal cell

Prokaryotic cell – Cell that bears naked genetic material i.e. nucleus is without envelop is known as prokaryotic cell. This group is represented by Bacteria, Blue Green Algae (Cyanobacteria), Mycoplasma.

They have following characters:

(i) Like eukaryotic cells, they are different in shape and size but smaller than eukaryotes and divide rapidly.

(ii) Naked genetic material is called **genophore / Nucleoid**.

(iii) Genomic DNA is circular and naked (without histone protein) and termed as single chromosome.

(iv) Beside genomic DNA, small circular DNA is also present in many bacteria called plasmid which make them antibiotic resistant, regulates some phenotypes and also responsible for bacterial transformation.

(v) Most prokaryotic cells mainly the bacterial cell has envelope consists of three layers, which are tightly bound outer glycocalyx, middle cell wall and innermost cell membrane.

(vi) Although each layer of the envelope performs distinct function, they act together as a single protective unit.

(vii) If these envelopes are stained by Gram stain then they are called Gram positive bacteria while other those don't have are called Gram negative bacteria.

(viii) Glycocalyx, a polysaccharide envelope forms either loose sheath **slime layer** or thick and tough structure **capsule**.

(ix) Cell wall usually consists of peptidogylan, absent in mycoplasma.

(x) The cell wall determines the shape of the cell and provides a strong structural support to prevent the bacterium from bursting or collapsing.

(xi) Cell membrane consists of lipoprotein. It is common structure between prokaryotic cell and Eukaryotic cell.

(xii) The cell membrane is selectively permeable in nature and interacts with the outside world.

(xiii) Essential infoldings of Plasma membrane towards cytoplasm are called Mesosomes. They can be in form of the **Vesicles Tubules** and **Lamellae.**

(xiv) These help in:

(a) Cell wall formation (b) DNA replication and distribution to daughter cells (c) Respiration **(analogous to mitochondria)** (d) secretion of processes (to increase the surface area of the plasma membrane and enzymatic content).

(xv) In cyanobacteria, there are other membranous extensions into the cytoplasm called **chromatophores that contain pigments (analogous to chloroplast).**

(xvi) Cell wall form some filamentous extensions called **flagellum**. It consists of **filament**, **hook** and **basal body** and helps in locomotion.

(xvii) Besides flagella, Pili and Fimbriae are also surface structures of the bacteria but do not play a role in motility. The **pili** are elongated tubular structures made of a special protein pilin. The **fimbriae** are small bristle like fibres sprouting out of the cell that provides attachment to substratum or host tissue.

(xviii) In prokaryotes, ribosomes are associated with the plasma membrane of the cell. They are about 15 nm by 20 nm in size.

(xix) 70S type of ribosomes are found in prokaryotic cells. Its two subunits are 50S and 30S. Several ribosomes are joined with mRNA to form polysome or polyribosome for efficient conduction of protein synthesis.

(xx) Reserved food materials are stored in cytoplasm in the form of non-living inclusion bodies. **(NEET-2017)**

(xxi) Inclusion bodies are not bound by any membrane system and lie free in the cytoplasm.

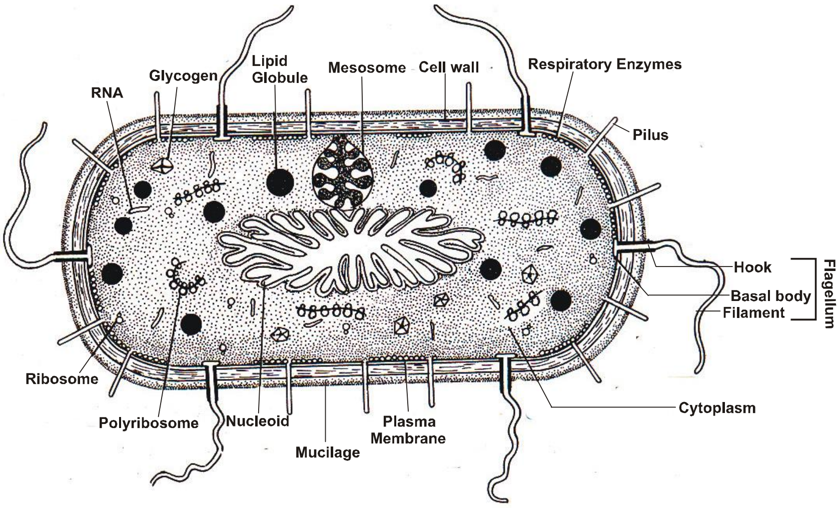


fig:- Ultrastructure of Prokaryotic cell

Cell wall

- It was first studied by **Robert Hooke in cork cells**.
- It is outer most dead covering around plant cell. That is secreted by **cytoplasm/(Protoplasm).**
- Cell wall not only gives shape to the cell and protects the cell from mechanical damage and infection, it also helps in cell-to-cell interaction and provides barrier to undesirable macromolecules. Algae have cell wall, made of cellulose, galactans, mannans and minerals like calcium carbonate.
- In **plant cell** it is usually composed of **cellulose**, hemicellulose, pectins and proteins but in **bacteria and BGA** it is composed of **peptidoglycan and DAPA.** In **fungi** it consists of **chitin.** It is **absent** in **Animals, Mycoplasma**.

Structure of the cell wall

- The **diameter** of cell wall varies from **0.1–10μm.**
- A cell wall contains **(a) matrix (b) fibrils (c) depositions**

Chemical Compostion of cell wall:

Matrix: Water-60%. Hemicellulose-5-15%. Pectic Substances-2-8%. Lipids–0.5–3.0%. Proteins-1-2%

Microfibrils: Cellulose / fungus cellulose–10–15%.Other depostions 0.025%. Cellulose is a main component of cell wall.

The cell wall is formed of following layers

(i) Middle Lamella **(ii) Primary wall** **(iii) Secondary Wall** **(iv) Tertiary wall**

(i) Middle Lamella:

- It is thin amorphous cementing layer for joining of two adjacent plant cells.
- It is composed of **pectin as calcium and magnesium pectate** (mainly calcium pactate).
- It is absent on the outer free surface of cell and plasmodesmata.
- Retting of fibres and softening of fruits are due to dissolution of calcium pectate in middle lamella by pectinase enzyme.
- The cell wall and middle lamellae may be traversed by plasmodesmata which connect the cytoplasm of neighbouring cells.

(ii) Primary wall:

- It is elastic, permeable and thin, single layered outer most wall layer of plant cell.
- Cellulose, hemicellulose and pectin contents are roughly in equal amount in primary wall.
- Root hairs, parenchymatous cells and meristematic cells are formed of only primary wall.
- It is capable of growth. Its growth takes place by **intussusception (Addition of materials with in the existing wall).**
- It generally diminshes as the cell matures.

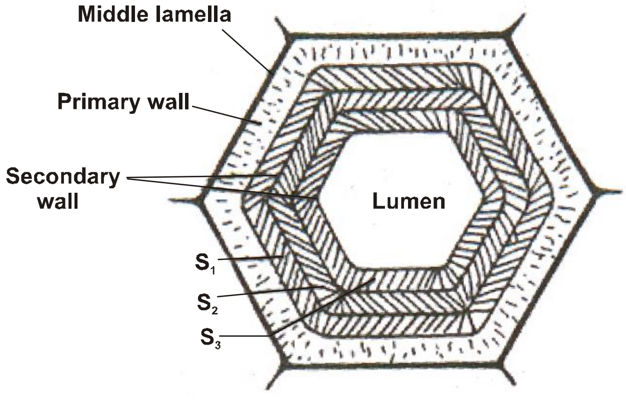


Fig:- Parts and Layers of cell wall

(iii) Secondary wall:

- It lies inside the primary wall i.e. it lies towards membrane side of the cell
- Its growth takes place by **Accretion (deposition of materials over the surface of existing structure).**
- It consists of at least **three layers–S_1, S_2, S_3,** this wall is made up of cellulose, hemicellulose and pectin.

Differences Between Primary and Secondary Walls			
S.No.	**Primary Wall**	**S.No.**	**Secondary Wall**
1	It is single layered formed in young growing cell.	1	It is three or more layered formed when the cell has stopped growing.
2	Cellulose microfibrils are shorter, wavy and loosely arranged.	2	Cellulose microfibrils are longer, closely arranged, straight and parallel.
3	Cellulose content is compartively low.	3	Cellulose content is compartively high.
4	Hemicellulose is upto 50%.	4	Hemicellulose is about 25%.
5	Pits are usually absent.	5	Pits are common.
6	It grows by intussusception.	6	It grows by accretion.
7	Lipid content is 5-10%, protein is 5%.	7	Lipid is absent, protein content is 1% or less.

Thickenings of cell wall

(a) Spiral thickenings **(b) Annular thickenings** **(c) Sclariform thickenings**
(d) Reticulate thickenings **(e) Pitted thickenings**

Pits: They represent unthickened areas in the secondary walls of plant cells that occur as depressions. A pit contains **pit chamber and a pit membrane**.

- The pit membrane composed of **primary wall and middle lamella.** Pits are two types

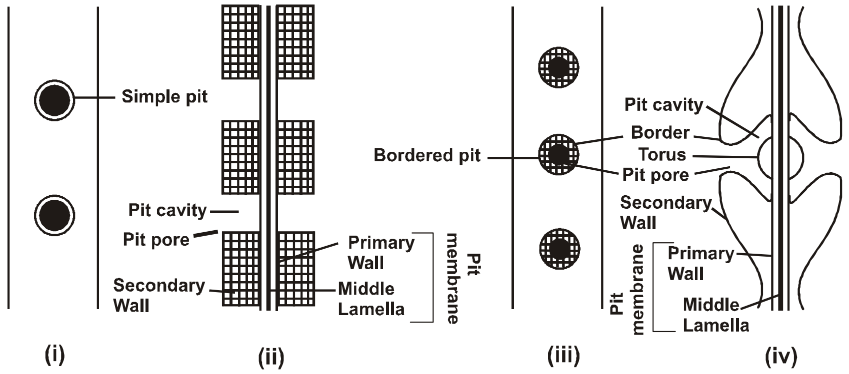


Fig:- Pits. (i) surface view of simple pits. (ii) simple pit pairs in section. (iii) Surface view of bordered pits.(iv) Bordered pit pairs in section.

(a) Simple pits: It bears uniform width of the pit chamber.

(b) Bordered pits:

- Its chamber is flask-shaped due to overarching of secondary wall on its mouth.
- Its pit membrane has thickening of suberin called **Torus**.
- In bordered pits the diffusion is regulated by torus and it functions as a valve.
- These pits are found abundantly in **tracheids of gymnosperms (have maximum number of bordered pits) and in vessels of angiosperms.**

(iv) Tertiary wall:

Sometimes innermost layer of the secondary wall is distinct both chemically as well as in staining properties due to the presence of xylans. It is called tertiary wall Eg. Tension wood in gymnosperms.

Important point on cell wall

(1) Plasmodesmata: The cytoplasmic bridges between adjacent plant cells are called plasmodesmata. They contain E.R. tubules called **Desmotubules**.

(2) Expansin: It is special protein that takes part in growth of cell wall by loosing cellulose microfibril and addition of new cell wall material in the space.

(3) Extensin: This protein connects pectin and hemicellulose.

(4) Cell Coat: In many animals and protistans distinct layer of glycocalyx is found in the outer surface of cells. It is fibrous and composed of oligosaccharides. It helps in cell recognition, protection etc.

Cell Membrane

- It is outermost covering of the cell that is **elastic, living, pliable, hydrophilic and selective permeable membrane**.
- It is found in both prokaryotic and eukaryotic cells.

Structure

- The detailed structure of the membrane was studied only after the advent of the electron microscope in the 1950s.
- Cell membranes can be observed in electron microscope. It appears trilaminar or tripartite layer under electron microscope.
- Meanwhile, chemical studies on the cell membrane, especially in human red blood cells (RBCs), enabled the scientists to deduce the possible structure of plasma membrane.
- Chemically a cell membrane contains proteins, Lipids, carbohydrates, water. DNA, RNA are absent.
- The ratio of protein and lipid in plasma membrane varies e.g. in human beings, the membrane of the erythrocyte has approximately 52 per cent protein and 40 per cent lipids.
- Proteins are globular in nature including structural, enzymatic, carrier, permease and receptor proteins.
- **Lipids** are usually **phospholipids (**arranged in bilayer) that are **amphiatic / amphipathic** containing **polar hydrophilic heads** (outside) and **nonpolar hydrophobic tails** (inside).
- Cholesterol provides regidity and stability to the cell membrane.
- **Carbohydrates** of cell membranes are small unbranched or branched chains of **oligosaccharides.**
- They combine with both lipids and protein molecules on outer surface of the membrane and form **glycolipids and glycoproteins respectively.**

Model of cell membrane:

(i) Lamellar or sandwitch model: Plasma membrane bears both lipids layers in between two protein layers.

(ii) Unit membrane model: It was proposed by **Robertson (1959)**. He stated that lipid bilayer is surrounded by extended β - protein. He gave unit membrane concept.

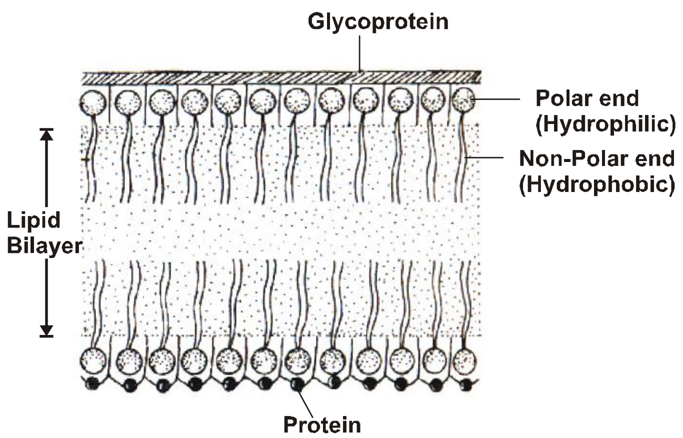


Fig:- Unit membrane model of Robertson

This model is unable to explain the selective permeability and elasticity of plasma membrane.

(ii) Fluid mosaic model:

- It was proposed by **Singer and Nicolson (1972).**
- It is most recognized model for plasma membrane.

- According to this, the quasi-fluid nature of lipid enables lateral movement of proteins within the overall bilayer.
- This ability to move within the membrane is measured as its fluidity.
- They stated that plasmamembrane contains lipid bilayer in which protein are found on both outer and inner side to form mosaic pattern.
- Thus they described it as **protein icebergs in sea of lipids.**
- The fluid nature of the membrane is also important from the point of view of functions like cell growth, formation of intercellular junctions, secretion, endocytosis, cell division etc.
- **Depending on ease of extraction, proteins of membrane are of two types.**

  (a) External or extrinsic proteins:
  - It is peripheral protein **(30% of total protein)**.
  - They lie on the surface of the membrane.
  - It can be easily removed **e.g. Spectrin in RBC.**

  (b) Integral or intrinsic proteins:
  - It is about **70% of total protein.**
  - They are buried partially or totally in plasma membrane.
  - These can not be separated easily. **e.g. Cytochrome oxidase, Porin Proteins.**
  - They may function as **carriers, permeases, enzymes, receptors**.
  - Some large globular intrinsic proteins pass as a helix into the lipid bilayer from outside to inside to form **tunnel proteins or transmembrane proteins.**
  - The transmembrane proteins act as channels for passage of water soluble materials and water.

- The plasma membrane is **asymmetric** due to **oligosaccharides** which form glycolipids and glycoprotein alongwith lipids and proteins respectively.
- Both glycolipids and glycoproteins form **glycocalyx**.
- Oligosaccharide part in glycocalyx acts as recognition centre, site for attachment and provides antigen specificity to cell membranes, blood grouping, immune response and matching of tissues in transplantation of organs.

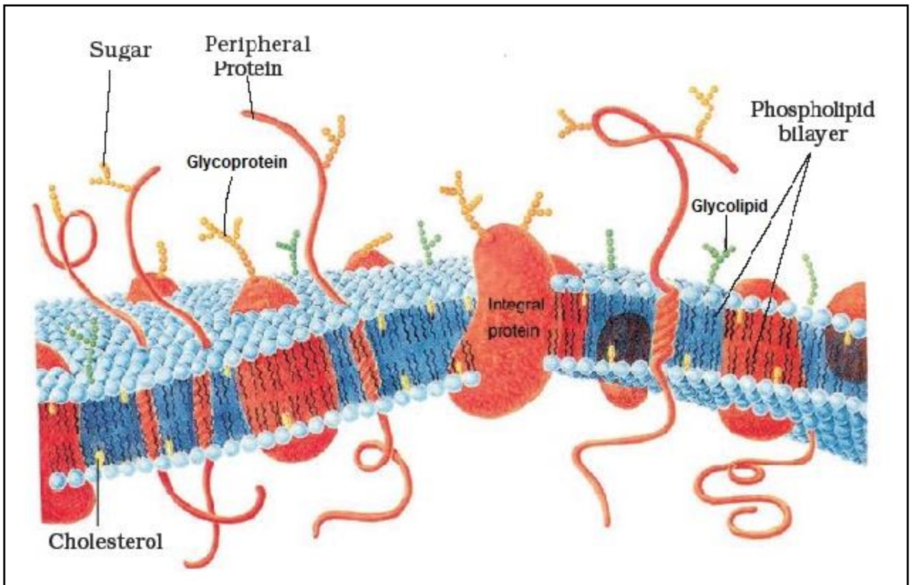


Figure: Fluid mosaic model of plasma membrane

- ## Special points of cell membrane

(i) Phospholipid also show exchange of molecule from one monolayer to the monolayer of other side it is called as **flip-flop movement.**

(ii) Flip-flop movement is absent in protein molecules.

(ii) Protein and lipid both can show rotational and lateral diffusion in membrane.

(iii) **Eukaryotic plasma membrane contains cholesterol but in prokaryotes hopanoids are present instead of it.**

(iv) Lipids provide fluidity, elasticity and stability and make growth, formation of cell junctions, cell division and endocytosis possible.

(v) Glycoproteins and glycolipids provide antigen specificity eg. RBC antigen, fertilizin- antifertilizin reaction

(iv) Cell membrane is diffrential permeable.

(v) Fat soluble substances can channelise directly across lipid layer

(vi) Neutral solutes may move across the membrane by the process of simple diffusion along the concentration gradient, i.e., from higher concentration to the lower.

(vii) Water may also move across this membrane from higher to lower concentration. Movement of water by diffusion is called osmosis.

(viii) The polar molecules cannot pass through the nonpolar lipid bilayer, they require a carrier protein of the membrane to facilitate their transport across the membrane called as facilitated diffusion.

(ix) Some ions or molecules are transported across the membrane against their concentration gradient, i.e., from lower to the higher concentration. Such a transport is an energy dependent process, in which ATP is utilised and is called active transport, e.g., Na+/K+ Pump.

- ## Modification of cell membrane

(1) Microvilli:

- They are finger like evagination found on cell surface also called as **brush border**.
- They help in absorption such as intestinal cells, hepatic cells and uriniferous tubules.
- In intestinal epithelium microvilli are very large (approx - 3000 per cell).
- They also increases the surface area having web of micro filaments, actin, myosin, spectrin etc.

(2) Endocytic vesicles: They are infolding of membranes for taking fluid and solid pieces by the formation of Pinosomes and phagosomes.

(3) Sheaths: Plasma membrane grows over cilia and flagella form sheaths.

- ## Functions of plasma membrane

Membrane transport:

- Cell membrane is considered as selective permeable membrane.
- Passage of substances across biomembranes occur by following methods.

(I) Passive transport: It involves following methods **(i) Diffusion (ii) Osmosis (iii) Facilitated diffusion**

(II) Active transport: In this method, movement of substances occur against their concentration gradient by consuming ATP. It can be done by Na^+- K^+ exchange pump.

(III) Bulk transport: It take place by two methods.

(i) Endocytosis: The inward transport of material by means of carrier vesicles is called endocytosis. It includes two types.

(a) Pinocytosis or Potocytosis (Cell drinking): Intake of fluid substances by plasmalemma in the form of vesicles **(Pinosome)** is called pinocytosis.

(b) Phagocytosis (Cell eating) : Intake of solid food substances by plasmalemma in the form of vesicles **(Phagosome)** is called phagocytosis.

(ii) Exocytosis (Cell vomitting or emiocytosis): It is reverse of endocytosis in which waste materials are removed from the cell. It involves **reverse pinocytosis.**

Cytoplasm

- It lies between the nucleus and cell membrane.

  In both prokaryotic and eukaryotic cells, a semi fluid matrix called as cytoplasm occupies the volume of the cell.

  Cytoplasm is the main arena of cellular activities in both plant cells and animal cells.

  Various chemical reactions occur in cytoplasm to keep the cell in living state.

  It includes two parts.

(1) Cytosol / Hyaloplasm / Ground plasm:

- Liquid part of cytoplasm except cell organelles
- It can exist in sol and gel state called plasmasol and plasma gel.

Cytoplasmic streaming: It is also called as protoplasmic streaming or cyclosis occur in eukaryotic cells.

Function:

(a) Help in movement of organelle such as chloroplast in relation to light intensity.

(b) Distribution of various substances and food vacuole in Amoeba.

(c) Formation of pseudopodia in Amoeba and in repair of membrane and in heat distribution.

(2) Trophoplasm: It involves cell organelles and cell inclusions.

Cell Inclusions:

They are non-living substances also known as ergastic bodies. They are of three types–

(1) Reserve food: It includes starch, glycogen, fat droplets and aleuron grains.

(i) Starch grains

(ii) Glycogen granules: Animal cells

(iii) Fat droplets: Animal and Plant cells

(iv) Aleurone grains

(2) Excretory or secretory products:

- Mucus in several animal cells, essential oils, alkaloids, resins, gums, tanins, latex etc.

(3) Mineral matter:

- Silica found in epidermal cells of grasses.
- **Calcium carbonate crystals (cystolith)** found in epidermal cells of momordica, hypodermal leaf cells of Banyan.
- **Calcium oxalate** occurs in the form of powdery mass (crystal sand) in atropa, star shaped **sphaerophide** in Colocasia, Begonia, Chenopodium prismatic crystals in dry scales of Onion, needle shaped **raphides** in lemna, Eichhornia.

CELL ORGANELLES

(1) Plastids:

- They are found in all plant cells and in Euglenoids.
- These are easily observed under the microscope as they are large.
- These are **double membrane bound**, DNA containing **largest** organelles in plant cells.
- **Origin:** All types of plastids have common origin from **proplastids** (sac like non-lamellar structures).
- They bear some specific pigments, thus imparting specific colours to the plants.

Based on type of pigments, they are of three types.

(i) Leucoplasts **(ii) Chromoplasts** **(iii) Chloroplasts**

(i) **Leucoplasts: Colourless**, largest plastids. They are classified on the basis of stored material

(a) **Amyloplasts:** They store carbohydrates in the form of starch e.g. Potato.

(b) **Aleuroplasts or Proteinoplasts:** They store proteins.

(c) **Elaioplasts:** They store oil or fats.

(ii) **Chromoplasts:** They are **coloured** plastids those have fat soluble carotenoids like carotene, Xanthophyll and others are present. e.g. carotene in carrot, **lycopene** in tomato and chillies.

(iii) This gives the part of the plant a yellow, orange or red colour.

(iii) Chloroplasts:

- Chloroplast is a double membraned, self-replicating, DNA containing, oxidative, energy transducing, semiautonomous largest organelle of cell.
- **Chloroplast** is considered as **semi autonomous cell organelle** due to **presence of DNA, RNA, 70s ribosomes and proteins synthesis systems.**
- It is also called **autoplasts or photosynthetic apparatus or Kitchen of cell.**
- Majority of the chloroplasts of the green plants are found in the mesophyll cells of the leaves.
- Their number varies from 1 per cell of the *Chlamydomonas*, a green alga to 20-40 per cell in the mesophyll.

Size: its size is 5–10 μm × 2–4 μm

Shape:

Plant	Shape of chloroplasts
Chlamydomonas	Cup shaped
Ulothrix	Girdle shaped
Spirogyra	Spiral (Ribbon like)
Zygnaema	Stellate
Oedogonium	Reticulate
Higher plants	Discodial / oval / Lens / spherical

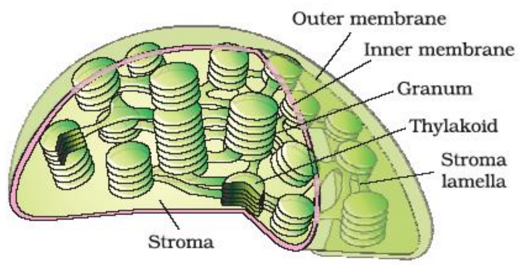


Fig.: Sectional View of Chloroplast

Structure of Chloroplast

Each chloroplast contains three parts

(i) Envelope **(ii) Stroma** **(iii) Lamellar system**

(i) Envelope

- It contains two lipoprotein unit membranes.
- The space between these two membranes is called intermembrane space or periplastidial space.
- Outer membranes freely permeable and whereas inner membrane is **selective permeable** or releatively less permeable.

(ii) Stroma (Matrix)

- The space limited by the inner membrane of the chloroplast is called the stroma.
- It is highly proteinaceous.
- The stroma of the chloroplast contains enzymes required for the synthesis of carbohydrates and proteins.
- It also contains small, doublestranded circular DNA molecules called **cp-DNA or plastidome.** and ribosomes.
- The ribosomes of the chloroplasts are smaller (70S) than the cytoplasmic ribosomes (80S). Chlorophyll pigments are present in the thylakoids.

(iii) Lamellar system:

- A number of organised flattened double membrane bound sacs called the thylakoids, are present in the stroma.
- Thylakoids (2-100) are arranged in stacks like the piles of coins called grana (singular: granum) or the intergranal thylakoids. Each chloroplast has 40–60 grana.
- Intergranal thylakoids: flat membranous tubules called the stroma lamellae or fret lamellae connecting the thylakoids of the different grana.
- The membrane of the thylakoids enclose a space called a lumen.
- **The granum is absent in the chloroplasts of algae and bundle sheath chloroplasts of C_4 plants. These chloroplasts are called Agranal chloroplasts.**
- Inner membrane of thylakoid contains **Quantasomes i.e. photosynthetic functional units**.
- Each of them consists of **230 chlorophyll molecules (160 chl a + 70 chl b) and about 50 carotenoid molecules.**

Note:

(1) All the three types of plastids are interchangeable but chromoplasts do not change to other plastids.

(2) **Etioplasts: In the absence of light plant becomes yellowish or white. (AIPMT-2014)**

(2) Mitochondria (Sing-mitochondrion):

- Mitochondria first observed in **striated flight muscles of insect** as granular structure by **Kolliker.**
- The term mitochondria used by **Benda.**
- Unless specifically stained, are not easily visible under the microscope.
- The number of mitochondria per cell is variable depending on the physiological activity of the cells.
- It is also called **power house of cell**.

Origin:

- They have originated from the symbiosis of a prokaryotic organism (aerobic bacteria) with a host cell that was anaerobic and derived its energy only from glycolysis (Endosymbiotic hypothesis).

Shape and size:

- In terms of shape and size also, considerable degree of variability is observed.
- Typically it is sausage-shaped or cylindrical.
- Diameter of mitochondria is **0.2-1.0μm** (average 0.5μm) and length **1.0-4.1μm.**

Number: The number of mitochondria per cell is variable depending on the physiological activity of the cell.

Structure of mitochondria:

- Mitochondria is double membrane bound cell organelle.
- The two membranes are seperated by a broad space that is called **perimitochondrial space (Outer chamber)**.
- **Both the membranes have its own specific enzyme.**
- Inner membrane is folded to form **cristae (Palade)** that increase surface area.

  The two membranes have their own specific enzymes associated with mitochondrial functions.
- Enzymes like **succinate dehydrogenase, ATPase and cytochrome oxidase** are found in inner membrane of mitochondria.
- Mitochondria are rich in **Manganese (Mn).**
- Outer surface of inner membrane is called **C- face** whereas inner surface called **M-face**.

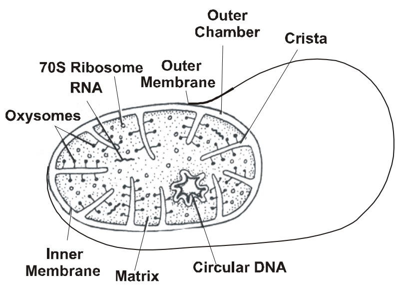


Fig:- Structure of mitochondrion

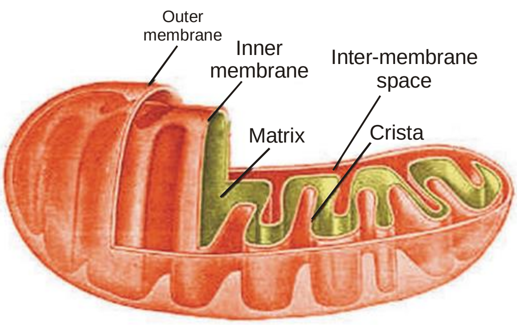


Fig : Structure of mitochondrion (Longitudinal section)

- The inner membrane and cristae bear electron transport chain and particles called **Oxysomes or Elementary particles, F_0–F_1 particles or ETP (Electron transport particles) or ATP synthase particles.**
- These are considered as **functional unit of mitochondria** and they are the site of **oxidative phosphorylation.**
- Head part of oxysomes contains **ATP synthase enzymes** for **oxidative phosphorylation.**

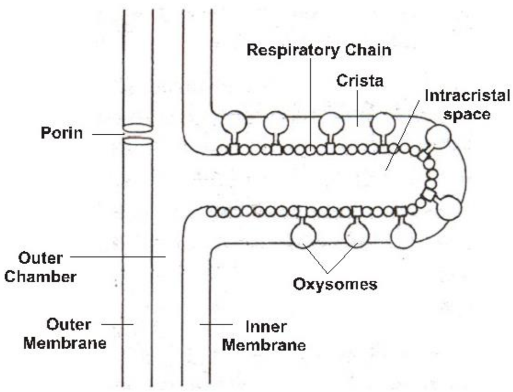


Fig. Inner membrane with oxysome

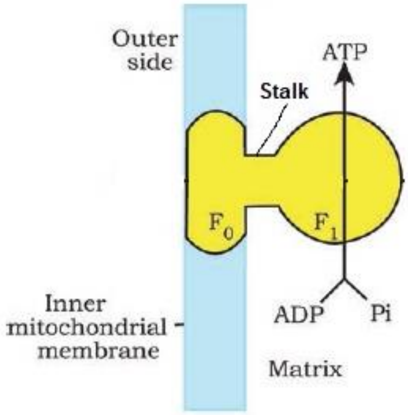


Fig. Diagramatic presentation of ATP synthesis in mitochondria

- The inner compartment is filled with a dense homogeneous substance called the matrix.
- The matrix also possesses single circular DNA molecule, a few RNA molecules, ribosomes (70S) and the components required for the synthesis of proteins.
- **Mitochondrion** is considered as **semi autonomous cell organelle** due to **presence of DNA (rich in G–C ratio), RNA, 70S ribosomes and proteins synthesis systems.**
- **The mitochondria divide by fission.**

Functions of mitochondria

(i) It is the site of aerobic respiration. Most of the ATP are produced by mitochondria during respiration. Thus mitochondrion is called **power house of cell**.

(ii) Enzymes of **krebs cycle, fattly acids synthesis, amino acids synthesis** are found in matrix.

(iii) Mitochondria help in **Vitellogenesis in oocytes**.

(iv) **Heme protein** required for **haemoglobin, cytochrome and myoglobin** is synthesized in mitochondria.

(v) In bacteria the **Mesosomes** bear enzymes of aerobic respiration hence these are called **Chondrioid**. Thus **Mesosome and Mitochondria are analogous organelles.**

(vi) The **gene for male sterility in maize** plants is found in **mt DNA**. Thus it helps in **cytoplasmic inheritance.**

Endomembranous System

- Many membranous cell organelles are co-ordinated in their functions like ER, GB, Lysosome and vacuole so they are considered together as endo membranous system.
- Since the functions of the mitochondria, chloroplast and peroxisomes are not coordinated with the above components, these are not considered as part of the endomembrane system.

3. Enodoplasmic Reticulum (E.R.)

- It was discovered by **Porter and Thompson** and the name Enodoplasmic Reticulum coined by **Porter.**
- It is 3-dimensional and interconnected system of membrane-lined channels that run through the cytoplasm, forms network.
- It divides the intracellular space into luminal (inside ER) and extra luminal (Cytoplasm) compartments.
- It is single membrane bound organelle.
- It is found in plasmodesmata in the form of **desmotubules**.

Structure of E.R.

E.R. is found in three forms

(i) Cisternae: They are flat interconnected sac-like structures. The diameter of each cisternae is **40–50 nm**.

(ii) Vesicles: These are oval or rounded sacs and diameter of each vesicle is **25–500 nm**.

(iii) Tubules: They are tube like extensions that connect cisternae and vesicles. Diameter of each tubule is **50–100 nm.**

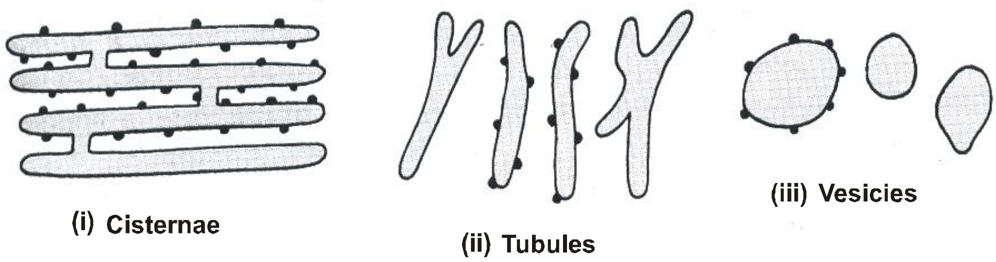


Fig:- Parts of Endoplasmic reticulum

Types of Endoplasmic reticulum

On the basis of nature of its membranes, endoplasmic reticulum is of two types.

(i) RER – Rough Endoplasmic Reticulum

(ii) SER – Smooth Endoplasmic Reticulum

- The ER often shows ribosomes attached to their outer surface. The endoplasmic reticulun bearing ribosomes on their surface is called rough endoplasmic reticulum (RER).
- RER is frequently observed in the cells actively involved in protein synthesis and secretion.
- They are extensive and continuous with the outer membrane of the nucleus.
- In the absence of ribosomes they appear smooth and are called smooth endoplasmic reticulum (SER).
- The smooth endoplasmic reticulum is the major site for synthesis of lipid. In animal cells lipid-like steroidal hormones are synthesised in SER.

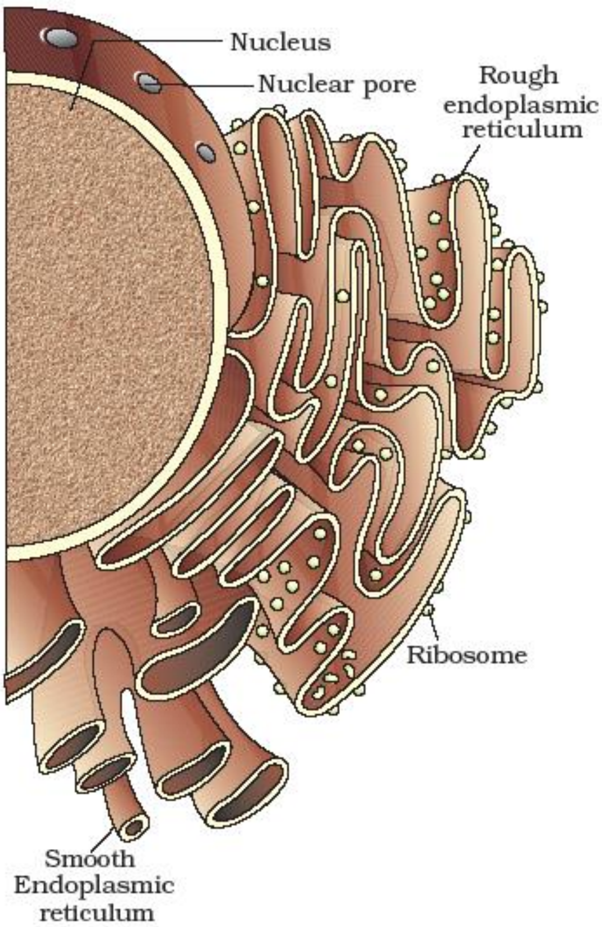


Figure: Endoplasmic reticulum

Differences between SER and RER		
S.No.	**RER**	**SER**
1	It bears ribosomes attached to its membranes	Ribosomes absent on the outer surface of membrane.
2	It consists of cisternae and few tubules	It consists of vesicles and tubules.
3	It takes part in the synthesis of proteins and enzymes **e.g.** pancreas. Liver, Goblet cells	It performs synthesis of glycogen, lipids and steroids. **e.g.**Interstitial cells, Adipose tissue, adrenal cortex, Muscles, Glycogen storing liver cells
4	RER bears ribophorin- I and ribophorin- II for the attachment of ribosomes	Ribophorins are absents.
5	It may develop from nuclear envelope	It may develop from RER.

Functions of E.R.:

(i) It acts as cytoskeleton. It provides mechanical support to the colloidal cytoplasmic matrix.

(ii) It helps in quick intracellular transport.

(iii) It takes part in the formation of nuclear envelope after telophase.

(iv) SER takes part in detoxification of toxic chemicals.

(v) It provides membranes to Golgi apparatus for the formation of vesicles and lysosomes.

(vi) RER provides site for the protein synthesis and secretion, because it has ribosomes on its suface, **Hence RER is frequently observed in the cells actively involved in protein synthesis and secretion.**

(vii) SER synthesizes lipids (phospholipids, chlolesterol), sterols and steroid hormones, visual pigments from vitamin A in retinal cells, Glycogen.

Special Points of ER:

(1) **Microsomes:** They are fragments of RER that are obtained by high speed centrifugation and Fragementation of cell.

(2) **Sarcoplasmic Reticulum (S.R.):** SER that occur in skeletal and cardiac muscles are called SR. It strores Ca^{++} for release during muscles contraction.

(3) **Nissl granules :** RER of nerves cells are called nissl granules.

(4) **GERL :** Golgi associated ER from which lysosomes arise

4. Golgi Complex:

- Camillo Golgi (1898) first observed densely stained reticular structures near the nucleus. These were later named Golgi bodies after him.
- It is extremely **pleomorphic** as its shape and form vary in cells.
- Golgi complex is also Known as **Dictyosome (plant golgi body),** Lipochondria **(Rich in lipids), traffic police of cell,** Idiosome, **Baker's body,** Dalton complex, Golgisome, **export house/middle man of cell.**
- A plant cell has 10 –20 dictyosomes.

Origin:

- Golgi bodies mainly arise from SER.

Structure of Golgi complex

- The shape and size of Golgi complex depend upon the physiological state of the cells. Structurally Golgi complex is composed of four parts

1. Cisternae **2. Tubules** **3. Vesicles** **4. Golgian vacuoles**

1. Cisternae:

- They consist of many flat, disc-shaped sacs or cisternae of 0.5μm to 1.0μm diameter.
- The Golgi cisternae are concentrically arranged near the nucleus.
- In fungi, a dictyosome is unicisternal. Cisternae show asymmetry and polar-two faces.
- Concave or Distal or maturing *trans* face is near cell membrane and cis or convex or Proximal or forming (F) face is towards RER and nuclear membrane.
- The *cis* and the *trans* faces of the organelle are entirely different, but interconnected.

2. Tubules: They form a complex network towards the periphery and *trans* face of the Golgi apparatus. They interconnect the different cisternae.

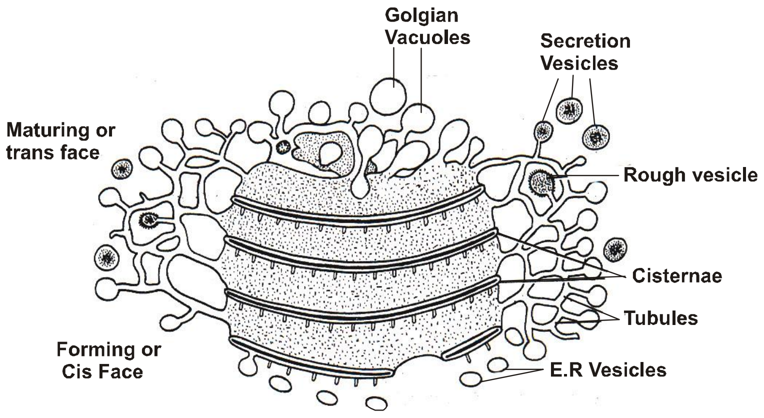


Fig. Structure of Golgi apparatus

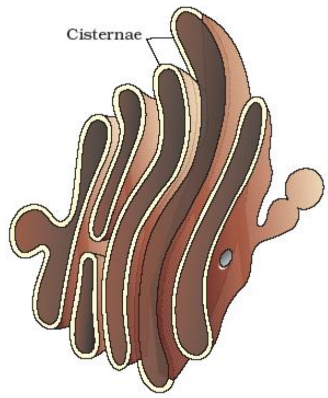


Fig. Golgi apparatus

3. **Vesicles:** They are small sacs that arise from tubules. They are of two types smooth and coated. Out of them smooth vesicles contain secretory substances hence these are called secretory vesicles.
4. **Golgian vacuoles:** These are expensions of cisternae at trans face. Some of them act as lysosomes.

Functions:

(i) Secretion:

- The golgi apparatus principally performs the function of packaging materials, to be delivered either to the intra-cellular targets or secreted outside the cell.
- Golgi complex is a centre of reception, finishing, packaging and secreting for a variety of materials in the cells.
- After modifications materials are packed in vesicles, the latter are budded off from maturing face of Golgi body and released out side the cell that is called **Exocytosis or revevrse pinocytosis.**

(ii) Formation of new cell wall: Pectic compounds of middle lamella and various polysaccharides of the cell wall are secreted by Golgi complex.

(iii) Glycosidation and Glycosylation:

- A number of proteins synthesised by ribosomes on the endoplasmic reticulum are modified in the cisternae of the golgi apparatus before they are released from its *trans* face.
- Golgi complex cause glycosylation of protein synthesized on RER to form glycolipids and glycoproteins.
- Golgi complex cause glycosidation (addition of oligosaccharides to phospholipids of membranes) of lipids.

(iv) Formation of acrosome: Acrosome of sperms is synthesised by Golgi complex during spermiogenesis.

(v) Formation of Lysosome: Vesicles of Golgi complex and ER take part in the synthesis of primary lysosomes **(GERL system)**.

(vi) Vitellogenesis: Golgi complex acts as the centre around which yolk is deposited.

(vii) Root cap cells are rich in Golgi bodies which secrete mucilage for lubrication of root tip.

(viii) Hormones: Production of hormones by endocrine glands is mediated through it.

Note: Materials to be packaged in the form of vesicles from the ER fuse with the *cis* face of the golgi apparatus and move towards the maturing face. This explains, why the golgi apparatus remains in close association with the endoplasmic reticulum.

5. Lysosomes: (Suicidal bags or recycling centres or scavenger of cell)

- These are membrane bound vesicular structures formed by the process of packaging in the golgi apparatus.
- Discovered by De Duve.
- Lysosomes are spherical irregular or rod like, filled with 40 types of enzymes.
- The isolated lysosomal vesicles have been found to be very rich in almost all types of hydrolytic enzymes (hydrolases – lipases, proteases, carbohydrases) optimally active at the acidic pH.
- These enzymes are capable of digesting carbohydrates, proteins, lipids and nucleic acids.
- **Acidic conditions** are maintained inside the lysosomes by **pumping of H^+ or of protons** into them.
- The Lysosomes are absent in prokaryotic cells, RBCs, higher plants. They are abundently found in phagocytic and secreted cells like WBC, Kupffer's cells, histocytes, pancreatic cells, liver cells.

Types of Lysosomes: Lysosomes show **pleomorphism** and are of four types.

(i) Primary lysosomes: These are newly synthesized lysosomes from Golgi complex by GERL system. They contain inactive enzymes.

(ii) Secondary lysosomes (hetorophagosomes or phagolysosomes): It is formed by the union of primary lysosome with food vacuole (Phagosome).

(iii) Tertiary lysosomes (residual bodies or telolysosomes):

- After digestion the products are absorbed in to the cytoplasm.
- The undigested remains are left in the lysosome.
- It is called residual body.
- This moves to the surface and throws the contents by exocytosis.

(iv) Autophagic vacuoles (Autophagosomes or cytolysosomes):

- Complex lysosomes formed by union of many primary lysosomes around old/dead organelle/cell and digest them.
- The phenomenon is also called autophagy or autodigestion.
- Worn out aged or injured cells are also disposed of similarly (apoptosis).
- Hence lysosomes are also called disposal bags.
- Autophagic vacuoles provide nourishment during starvation.

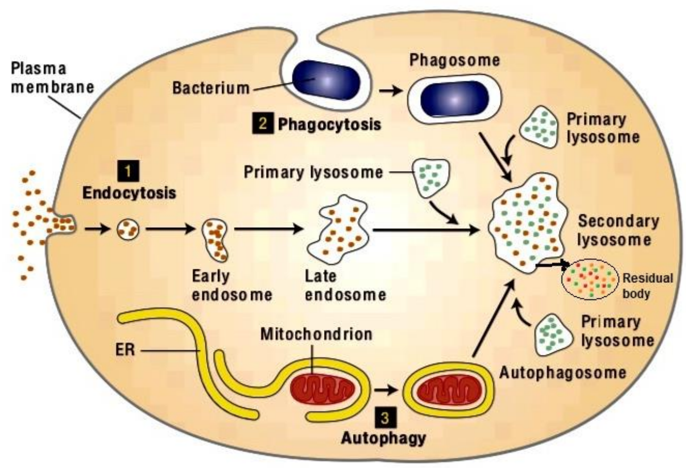


Fig. Types of Lysosomes and their function

Functions:

(1) Intracellular Digestion and Extracellular Digestion

(2) Body Defense (Heterophagy)

(3) Autophagy

(4) Mobilisation of Reserves

(5) Autolysis

5. Vacuoles:

- They firstly described by **Spallangini**.
- Vacuole is the membrane bound space found in the cytoplasm.
- Its membrane is called as Tonoplast which is thinner than plasma membrane.
- In plants, the tonoplast facilitates the transport of a number of ions and other materials against concentration gradients into the vacuole, hence their concentration is significantly higher in the vacuole than in the cytoplasm.
- It contains water, sap, excretory product and other materials not useful for the cell.
- In plant cells vacoule can occupy up to 90% of the volume of the cell.

Vacuoles are of four types.

(i) Food vacuoles:

- In many cells, as in protists, food vacuoles are formed by engulfing the food particles.
- These vacuoles contain digestive enzymes.

(ii) Gas vacuoles (Pseudovacuoles): These are found in some prokaryotes like blue grean algae where they perform buoyancy regulation.

(iii) Contractile vacuole:

- It is found in some protists like **Amoeba**, Paramecium and Chlamydomonas.
- It expands to receive water this process is called diastole.
- When it contracts to expell water outside. It is called systole.
- It performs osmoregulation and **excretion**.
- Contractile vacuole is analogous organ to liver.

(iv) Sap vacuoles:

- It contains sap or water.
- In plants single large central vacuole is present whereas in animal cell several small vacuoles are found.
- Sap is non living content of cell.
- Sap contains sugar, amino acid, Tannin, esters, phenols, enzymes, calcium oxalate, organic acid - (acetic acid and fumeric acid), resin, gum, minerals (Ca, Mg, Mn, Na, K), pigments (Anthocyanin, Anthoxanthin).
- Sap also maintains osmotic pressure of cell.
- pH of vacuolar cell sap is acidic and hypertonic. Most common element and organic acid in sap vacuole are K^+, acetic acid.

6. Ribosomes: (Protein factories)

- Ribosomes are the granular structures first observed under the electron microscope as dense particles by George Palade (1953).
- They are composed of ribonucleic acid (RNA) and proteins and are not surrounded by any membrane.
- These are smallest, submicroscopic ribonucleoproteins particles or palade particles or engine of the cell or protein factories.
- The number of Ribosomes is 20000–30000 in prokaryotic cell and 10^4 –10^5 in eukaryotic cell.
- Ribosomes are found in both prokaryotic and eukaryotic cells except **mature RBC and mature sperm.**

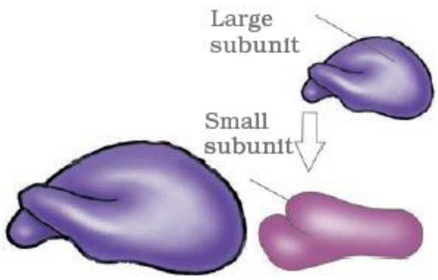


Fig. Ribosome

Types of ribosomes

(i) Cytoplasmic ribosomes **(ii) Organelle ribosomes**

(i) Cytoplasmic ribosomes:

- In prokaryotes, they freely lie in cytoplasm and 70S type whereas in eukaryotes, they are freely attached to ER and nuclear membrane and 80S type.

(ii) Organelle ribosomes:

- These are found in organelle of eukaryotic cells like mitochondria, plastids, and nucleus.
- Size and density of the ribosomes depends upon sedimentation coefficient in the ultra centrifuge. It is mesured in Svedberg units (S).
- The two subunits of 80S ribosomes are 60S and 40S and the two subunits of 70S ribosomes are 50S and 30S. **0.001 M Mg^{++}** concentration is required for the association of two subunits as a result intact ribosome is formed.

30S + 50S = 70S

40S + 60S = 80S

- If the concentration of Mg^{++} increased 10 times then two ribosomes fuse to form dimer (70S + 70S = 100S dimer, 80S + 80S = 120S dimer).

Chemical composition of Ribosomes:

70S Ribosomes		80S Ribosomes	
1.	rRNA (60-65%), protein (35-40%)	1.	rRNA (40-44%), protein (56-60%)
2.	30S sub unit – 16S rRNA and 21 proteins	2.	40S subunit – 18S rRNA and 33 proteins
3.	50S subunit – 23S and 5S rRNA and 347 proteins	3.	60S subunit – 28S, 5.8 and 5S rRNA and 40 proteins

Functions

- Ribosomes are the sites of protein synthesis.
- Free ribosomes form structural and enzymatic proteins that are used inside the cell whereas attached ribosomes forms proteins for transport.

7. Centrioles:

- Centrosome is an organelle usually containing two cylindrical structures called centrioles.
- They are membraneless structures.
- They are surrounded by amorphous pericentriolar materials.
- The clear cytoplasm **(Zone of exclusion)** around centriole is called **centrosphere or kinoplasm or cytocentrum.** Both centrioles are commonly called **Diplosomes.**
- Centriole does not bear intracellular compartment.
- Centrioles are usually found in all the animal cells except Amoeba.
- Centrioles are absent in higher plants. Although centriole is found in those plants that bear flagellate stage in the life cycle. **e.g. Many green algae, Bryophytes, pteridophytes, cycads.**
- Both the centrioles in a centrosome lie perpendicular to each other in which each has an organisation like the cartwheel.
- Each centriole is composed of 9 peripheral triplet fibrils of microtubules but in the central part these are absent. Thus centriole has **9 + 0** arrangement of tubules.
- The size of each peripheral triplet fibril is 25nm and It consists of three **subfibrils** – **C, B, A** from outside towards innerside.

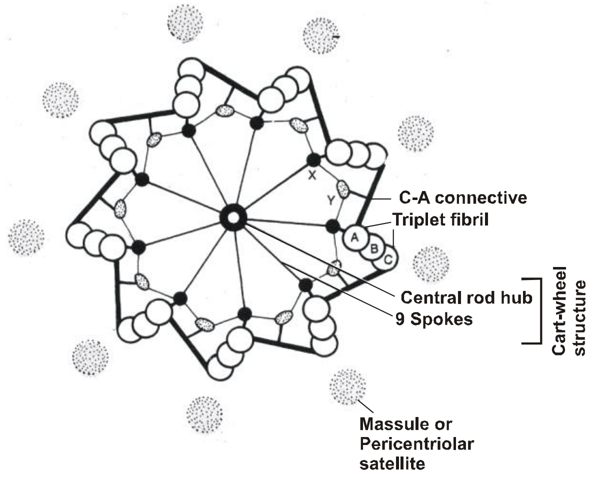


Fig :- Ultrastructure of centriole in T.S.

- A is spherical or tubular shaped whereas B and C are C–shaped. A consists of 13 protofilaments.
- A linker connects two peripheral triplet fibrils in such a way that A subfibril of a peripheral triplet fibril is connected with C sub fibril of adjacent peripheral triplet fibril. This linker is called **C– A linker**.
- In the central part a proteinecious **Hub** is present. Nine radial spokes arise from Hub.
- The main function of centriole is locomotion and the role of centriole in cell division is secondary function.
- Centriole is surrounded by amorphous structures called **massules or perecentriolar satellite.** Massules act as nucleating centre for the growth of microtubules during Aster formation. Occurs in **S-phase.**

- Thus new centriole arises from pre-existing centriole in S phase without presence of DNA due to massules Centrioles take parts in synthesis of Basal bodies, cilia, flagella, spindle poles.
- Distal centriole of sperm synthesizes Axial filament of sperm.
- Proximal centriole of sperm stimulate cleavage in fertilized egg after fertilization.

8. Cilia and Flagella

- The basic structure of cilia and flagella is similar. Engleman gave structure of cilia or flagella**.**
- Cilia and flagella are hair-like outgrowths of the cell membrane.
- The electron microscopic study of a cilium or the flagellum show that they are covered with plasma membrane.
- Structurally cilia or flagella is composed of four parts.

(a) Basal body

- Both the cilium and flagellum emerge from centriole-like structure called the basal bodies.
- It is also known as **Blepharoplast, Basal granule or kinetosome.**
- The arrangement of microtubules is **9 + 0** similar as centriole. It forms cilia and flagella.

(b) Rootlets

- They originate from outer surface of basal part of cilia or flagella. Each of them consists of bundles of microfilaments.
- They provide mechanical support to the basal body.

(c) Basal plate

- It lies between basal body and shaft. One subfibril is disappeared from peripheral triplet in this plate.
- Two central singlet fibrils originate from basal plate.

(d) Shaft:

- It is elongated part composed of three parts.

(i) Covering membrane (Extension of plasmalemma) (ii) Matrix (iii) Axoneme

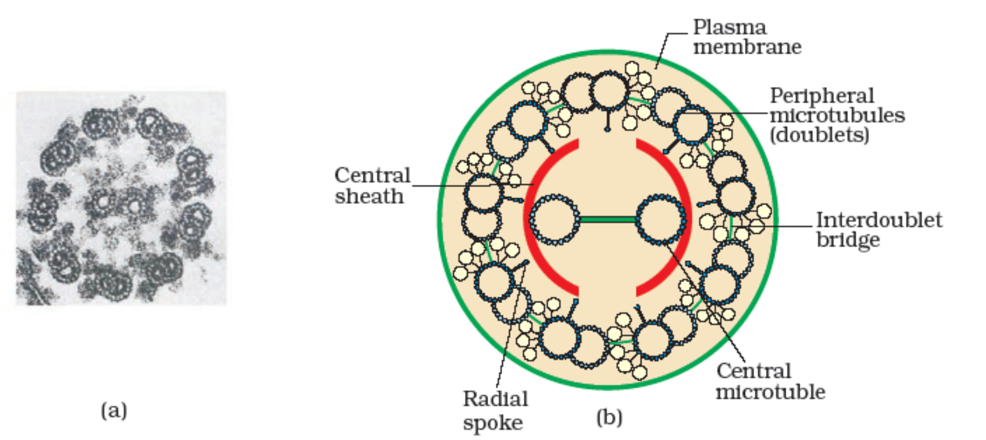


Figure : Section of cilia/flagella showing different parts : (a) Electron micrograph (b) Diagrammatic representation of internal structure

- Axoneme is the main part which possesses a number of microtubules running parallel to the long axis.
- **Nine peripheral doublet fibrils** are **tilted at 10º. Nine peripheral doublet fibrils and two central singlet fibrils** are composed of **tubulin protein.**
- Such an arrangement of axonemal microtubules is referred to as the 9+2 array.
- The central tubules are connected by bridges and is also enclosed by a central sheath, which is connected to one of the tubules of each peripheral doublets by a radial spoke. Thus, there are nine radial spokes.
- Each peripheral doublet fibril contain **subfibrial A and B.**
- A subfibril has two side arms or **lateral arms** composed of **dynein protein**. Out of them outer arm has hook. **Inner arm show ATPase activity**. It also generates force for the movement of cilia thus it is considered as locomotory motor for cilia.
- Two peripheral doublet fibrils are connected by **A–B linker** composed of **nexin protein.**
- A spoke originates from each subfibril A and grows towards central part.
- The tip of each spoke is swollen that is called head which is connected with central proteinaceous sheath by transitional junction.
- Cilia and flagella are different in number, length, distribution and function.

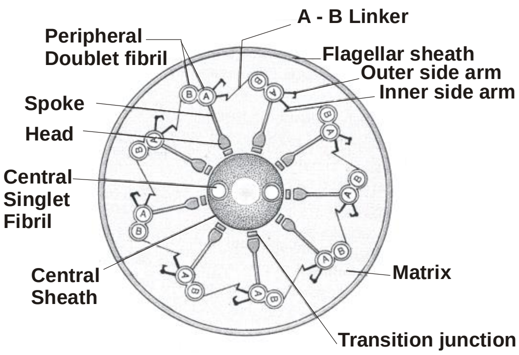


Fig :- Ultrastructure of flagellum in T.S.

Differences between Cilia and Flagella		
S.No.	**Cilia**	**Flagella**
1.	Only Eukaryotic cell has Cilia.	The prokaryotic bacteria also possess flagella but these are structurally different from that of the eukaryotic flagella.
1.	No of cilia is 3000–14000.	No. of Flagella is 1–4 .
2.	Length is 2–10μm.	Length is about 150μm.
3.	They are found at most of the part of organ/body.	It is present at one end of an organ/body.
	Cilia are small structures which work like oars, causing the movement of either the cell or the surrounding fluid.	Flagella are comparatively longer and responsible for cell movement.
4.	They beat in coordinate manner that is either synchronous (isochronous beat simultaneously) or matachronous (beat one after other).	They beat independently.
5.	They show pendular movement	They show undulatory motion.
6.	Cilia perform locomotion, aeration, Feeding, circulation.	Flagella perform Locomotion only.

9. Micorobodies

- Many membrane bound minute vesicles called microbodies that contain various enzymes, are present in both plant and animal cells.
- These are smallest single membrane bounded organelles that participate in oxidation reactions other than those of respiration.

  It is a following types–

(i) Sphaerosomes (Oleosomes):

- They originate from SER.
- These are abundant in cotyledon and endosperm of oily seeds.
- The major function of sphaerosomes is synthesis and storage of fat.

(ii) Peroxisomes (uricosomes):

- They are found in both plant and animal cells.
- A photosynthetic cell contains 70–100 peroxisomes.
- They contains oxidative enzymes like urate oxidase, D-amino acid oxidase, α-hydroxy acid oxidase and β-hydroxy acid oxidase.
- **Catalase** performs detoxification of H_2O_2. In plants, peroxisomes are the site of **photorespiration**.
- Peroxisomes also take part in β-oxidation of fat.

(iii) Glyoxysomes:

- These are largest microbodies.
- They were observed from endosperm of germinating castor bean seeds. These are common in Neurospora. Germinating oily seeds of castor, groundnut and cucumbers, Yeast.
- These are the sites of **β-oxidation of fat** and **Glyoxylate cycle** they are highly specialized peroxisomes.

(iv) Transosomes:

- They were observed in **ovary follicle cells of Birds (Aves)**.
- **Transosome** is **triple layered organelle** that helps in yolk formation.

(v) Lomasomes:

- They lie between cell membrane and cell wall and were discovered in **fungi**.
- They help in cell proliferation and elongation for diffusion of substances required in cell wall formation.

10. Cytoskeletal structures

- An elaborate network of filamentous proteinaceous structures present in the cytoplasm is collectively referred to as the cytoskeleton.
- The cytoskeleton in a cell are involved in many functions such as mechanical support, motility, maintenance of the shape of the cell.
- In eukaryotic cell, these are of three types

  (i) Microtubules

  (ii) Microfilaments

  (iii) Intermediate filaments

Property	Microtubules (Tubulin Polymers)	Microfilaments (Actin filaments)	Intermediate filaments
Structure	Hollow tubes; wall consists of 13 columns of tubulin molecules	Two interwined strands of actin, each a polymer of actin subunits	Fibrous proteins supercoiled into thicker cables
Diameter	25 nm with 15 nm lumen	7 nm	8 - 12 nm
Protein subunits	Tubulin, consisting of α–tubulin and β–tubulin	Actin	One of several different proteins of the keratin family, depending on cell type.
Main functions	Maintenance of cell shape. Cell motility (as in cilia or flagella) Chromosome movements in cell division Organelle movements	Maintenance of cell shape Changes in cell shape Muscle contraction Cytoplasmic streaming Cell motility (as in pseudopodia) Cell division (cleavage furrow formation)	Maintenance of cell shape Anchorage of nucleus and ceratin other organelles Formation of nuclear lamina

Nucleus

- It was first seen by **Anton Von Leeuwenhoek** in **RBC of salmon fish**.
- It was discovered by **Robert Brown (1831)** in **orchid's root cell**.
- Material of the nucleus stained by the basic dyes and chromatin name was given by **Flemming**.
- **J. Hammerling** proved the role of nucleus in heredity, growth and morphogenesis. **He proved that nucleus is the master organelle of the cell.**
- Interphase stage is a best stage to study about the nucleus due to having highly extended and elaborated nucleoprotein complex known as chromatin, nuclear matrix and nucleoli (One or more spherical bodies).
- It is **largest extracytoplasmic component of cell** that controls morphology, function and heredity.

Occurence:

- It is found in all eukaryotic cells except mature mammalian erythrocyte and in mature sieve tube of higher plant.
- In prokaryotic cell the nucleus is without distinct nuclear membrane that is called **nucleoid**.

Number:

- Usually single nucleus is found in a cell.
- **In *Paramecium* two nuclei are present.**
- Multinucleated condition is found in some organisms this condition is called **syncytium** (arises due to fusion of cells) **E.g.** ***Ascaris*** or **coenocytic** (due to repeated nuclear divisons without cytokinesis) **E.g.** ***Vaucheria, Rhizopus***.

Shape and size: The size of nucleus is **5 – 25μ**..

- The size of the nucleus depends on the volume of cell, amount of DNA protein and metabolic activity of cell.
- In a cell there is a definite **nucleo-cytoplasmic ratio** (given by **Hertwig)**.

Nucleocytoplasmic index = $\frac{(V_n)}{(V_c)-(V_n)}$ Vn = Volume of nucleus

Vc = Volume of cell

- It is largest components of cell. It is usually spherical shape. It may be oval or elliptical or Disc shaped.

Structure of Nucleus

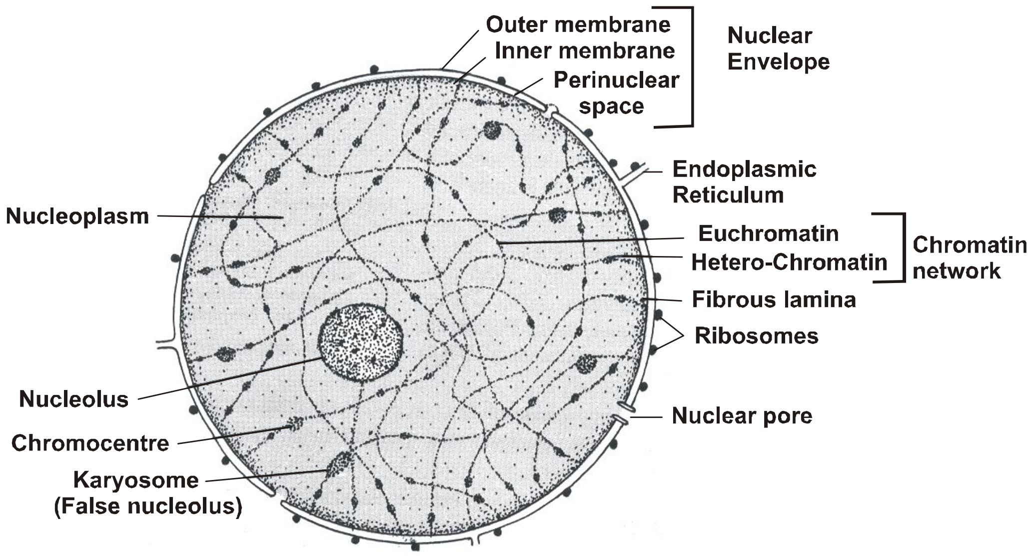


Fig:- Ultrastructure of interphase nucleus

Nucleus consists of following parts

(1) Nuclear membrane:

- Electron microscopy has revealed that the nuclear envelope is consist of two parallel membranes.
- The two membranes are seperated by a space of (10 to 50 nm) called the perinuclear space.
- The perinuclear space forms a barrier between the materials present inside the nucleus and that of the cytoplasm.
- The outer membrane usually remains continuous with the endoplasmic reticulum and also bears ribosomes on it.
- At a number of places the nuclear envelope is interrupted by minute pores, which are formed by the fusion of its two membranes.
- These nuclear pores are the passages through which movement of RNA and protein molecules takes place in both directions between the nucleus and the cytoplasm.

(2) Nucleoplasm (Karyolymph): The nuclear matrix or the nucleoplasm contains nucleolus and chromatin. It is jelly like fluid, its pH is 7·4 ± 0·2. It is reservoir of nucleosides, enzyme of DNA and RNA synthesis.

- Its peripheral part is dense jelly like fibrous part that lies below nuclear membrane it is called **fibrous lamina or nuclear lamina.**
- Nuclear lamina provides strength to the nuclear membrane. It also performs reformation of nuclear membrane during Cell division.

(3) Chromatin network:

- It consists of **DNP (Deoxyribonucleoprotein).**
- It is stained by **Acetocarmine** after that two types of regions are formed.
  - **(i) Euchromatin**
  - **(ii) Heterochromatin**

Differences between Euchromatin and Heterochromatin		
S.No.	**Euchromatin**	**Heterochromatin**
1.	It is light stained	It is dark stained.
2.	It is fibrous	It is granular.
3.	Its diameter is 10-30nm	Its diameter is 100nm.
4.	It bears active genes.	It does not possess active genes.
5.	Crossing over is quite common	It inhibits crossing over.

(4) Nucleolus: It was discovered by **Fontana.**

- The nucleoli are spherical structures present in the nucleoplasm.
- It is absent in RBC, sperm, Yeast, muscle fibres, young embryo cells and Procaryotes.
- It is largest part of nucleus (35%) and it is dense, DNA free subcellular structure and content of nucleolus is continuous with rest of the nucleoplasm is it is not membrane bound structure.
- Usually **1–4 nucleoli,** are found in a nucleus of diploid cell. At least one nucleolus is found. **1600 nucleoli** have been reported in the oocytes of ***xenopus*** **(An amphibian).**
- Nucleolus is a site for active ribosomal RNA synthesis. Larger and more numerous nucleoli are present in cells actively carrying out protein synthesis.

Origin : Nucleolus is connected with **NOR (Nucleolar organizer Region)** of chromatin. **NOR** synthesizes nucleolus at the end of cell division.

Functions of Nucleolus

(1) It is site of r-RNA synthesis.

(2) It synthesizes ribosomes therefore, it is called ribosome factories.

(3) It takes part in the synthesis of spindle during cell division.

Functions of Nucleus

1. It stores genetic information in its DNA molecules that can be passed on the daughter cells.
2. Nucleus controls all metabolic activites of the cell.
3. All variations are caused by changes in genetic material present in the nucleus.
4. It helps in cell differentiation by allowing certain particular sets of genes to operate.

5. It directs the synthesis of some structural proteins and chemicals required for cell growth and maintenance with the help of RNA.

Chromosomes

- These were Discoverd by **Hofmeister (1848)** in pollen mother cells of ***Tradescantia* (Rhoeodiscolor)**.
- They represent **physical basis of inheritance**.
- Plants generally have larger chromsomes than animals and amongst plants, monocots have bigger chromosomes than dicots.
- A single human cell has approximately two metre long thread of DNA distributed among its forty six (twenty three pairs) chromosomes.
- The interphase nucleus has a loose and indistinct network of nucleoprotein fibres called chromatin (contains DNA, histones protein, nonhistones protein and RNA).
- During cell division, dehydration and condensation of chromatin network take place as a result chromatin is converted into chromosomes.
- Every chromosome (visible only in dividing cells) essentially has a primary constriction or the **centromere** on the sides of which disc shaped structures called **kinetochores** are present.
- **Metaphase stage** is best stage to observe **size, shape, morphology etc. of chromosomes**.
- On the basis of position of the centromere, chromosomes are of following types.

  (i) Metacentric : Centromere is found in middle and at anaphase chromosome is **V-shaped.**

  (ii) Sub-metacentric : The position of the centromere is subcentral. Anaphasic stage **L-shaped.**

  (iii) Acrocentric : The position of the centromere is subterminal. Anaphasic stage **J-shaped.**

  (iv) Telocentric : Centromere terminal, anaphasic stage is **I- shaped.**

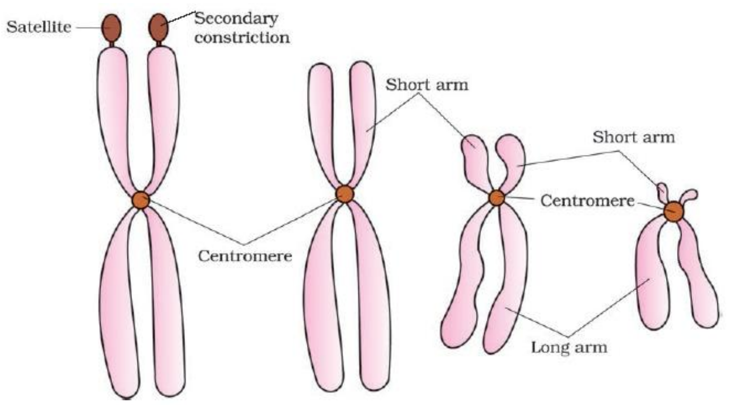


Fig. Types of chromosomes based on the position of centromere

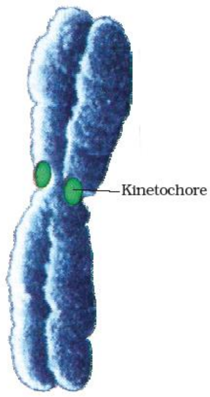


Fig.Chromosome with kinetochore

No. of chromosome in organisms		
	Name of organism	**Chromosome no.**
1.	*Homo sapiens*	2n=46
2.	*Drosophila melanogaster* (Fruit fly)	2n=8
3.	*Pisum sativum* (Pea)	2n=14
4.	Maize	2n=20
5.	Wheat	2n=42

Ultrastructure of Chromosome:

Eukaryotic chromosome contains following parts

(i) Pellicle: Outermost thin covering of chromosome.

(ii) Matrix: It consists of proteins, lipids and RNA in which chromonemata remain embedded.

(iii) Chromonema: There is two chromonemata when chromosome has two chromatids. Chromonemata is coiled structure.

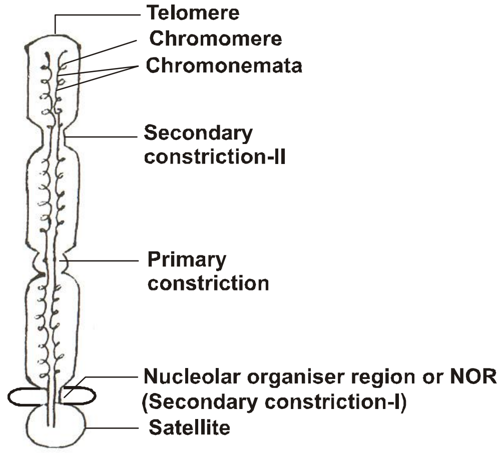


Fig:- Structure of chromosome

(iv) Centromere (Primary constriction): Narrow non stainable area where two chromatids are joined.The surface has disc or **kinetochore** on either side for attachment of microtubules belonging to chromosomal fibre.

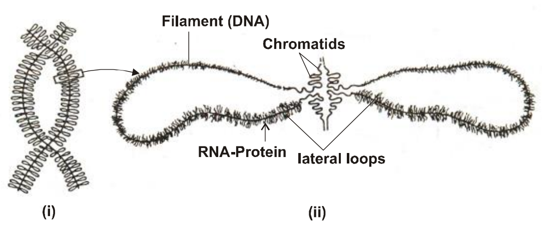
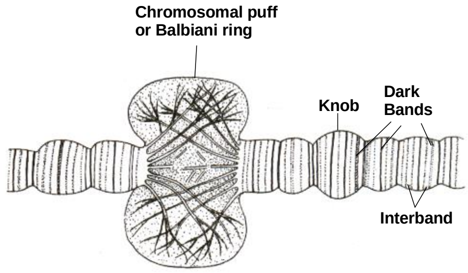
(v) Secondary constriction: They are narrow areas of two types. **NOR and joints. NOR or nucleolar organiser region is secondary constriction-I** capable of forming **nucleolus in telophase. It is found on chromosome number 13, 14, 15, 21, 22. Joints or secondary constriction-II** are areas involved in breaking and fusion of chromosome segments.

(vi) Sometimes a few chromosomes have non-staining secondary constrictions at a constant location. This gives the appearance of a small fragment called the satellite.

(vii) Satellite: It is knob like part distal to NOR. The chromosome that bears satellite is called **SAT (Sine acid Thymonucleinico) chromosome.**

(viii) Telomeres: These are nonsticky terminal ends of chomosome or seal ends of chromosomes. They prevent the sticking of one chromosome with other. They are rich in guanine base. Telomerase enzyme is (required for replication of) this part of chromosome.

Special type of chromosomes

S.No.	Lampbrush chromosomes	Polytene chromosomes
1.	They firstly observed by **Flemming.**	They discovered by **Balbiani.**
2.	These are found in yolk rich **primary oocytes of Amphibians like Newt (*Triturus*), spermatocytes of many animals, giant nucleus of *Acetabularia*.**	They were observed in the cell of **salivary glands** of **Chironomus larva** of **Dipterian insect**. These are also found in **malpighian tubules, endosperm, antipodal cells and salivary glands of Drosophila.**
3.	They are found in **permanent diplotene stage of meiosis**.	They are found in **permanent prophase stage**.
4.	The size upto **5.9 mm (5900μm)**.	The size of polytene chromosomes is **2000μm.**
5.	Special Characteristic: The axis of lamp-brush chromosome is composed of **DNA** and **matrix of RNA and proteins Its lateral loops help in synthesis of RNA and yolk.**	Special Characteristic: They become **giant** due to **endomitosis or endoduplication**. **Large swellings** are found on some places of each strand that are called **puffs (Balbiani rings)**. In puffs DNA is uncoiled for rapid transcription of RNA.
	 Fig:- (i) Lampbrush chromosome (ii) One loop of a lampbrush chromosme	 Fig:- Structure of polytene chromosome

Karyotype:

- Chromosomes have some specific features
  (a) Number of chromosomes
  (b) Relative size
  (c) Position of centromere
  (d) Length of arm
  (e) Secondary constriction
  (f) Satellites.
- All such features by which a particular set of chromosomes (chromosomal complement) can be identified, is called **karyotype** of a species or it is chromosomal complement of organism providing description of various aspects of all the chormosomes like number, relative size, position of centromere, length of arms and centromeric ratio, secondary constriction and satellites.

Idiogram:

- A diagrammatic representation of karyotype of a species showing morphological chraracteristics of the chromosome is called idiogram.

Resonate the concept

(1) Virus is acellular and connecting link between living and non living.

(2) Smallest cell– *Mycoplasma laidlawii* (PPLO) (0.1 -0.3μm)

(3) Largest unicellular eucaryotic cell - *Acetabularia* alga - (10cm).

(4) Longest animal cell –Human nerve cell (90cm).

(5) Longest plant cell –Ramie (*Boehmaria*)–55cm, jute fibre–30–90cm, hemp–1metre.

(6) Largest animal cell–Ostrich egg cell (170mm×150mm)

(7) Small cell has higher surface volume ratio than the larger cell.

(8) Number of different materials may be deposited in the wall.

(a) Lignin: It is formed by polymerisation and dehydrogenation of aldehydes and alcohols of coniferyl and coumaryl. It reduces the water content of the wall matrix and increases its hardness. The deposition of lignin on the cell wall is called **lignification** that provides strengthening to the cell wall.

(b) Suberin: It is fatty substance that makes the wall impermeable. It reduces the transpiration rate in plants. It is found in the cork and casparian strips of endodermal cells. The deposition of suberin is called suberisation.

(c) Cutin: It lies as a distinct layer on the outside of the epidermal cell wall. It is fatty substance that reduces the rate or epidermal or surface transpiration. Other substances may also be deposited in the cell wall such as silica **(E.g. grasses)**, minerals waxes, tannins, resins, gums.

(9) Spectrin, a helical extrinsic protein used to attach with intrinsic protein at the inner side of membrane and make cytoskeleton with microtubule and microfilament

(10) Porins the intrinsic protein found in the outer mitochondrial and bactrial membrane

(11) Permease, translocase etc. act as carriers for the transport of materials.

(12) Through ESR (electro spin resonance), it is revealed that **flip-flop mechanism is absent in protein molucules**

(13) Other than phospholipids the cell membranes have cholesterol, cerebrosides, gangliosides and sphingomyelins.

(14) Gas vacuoles protect the cell from UV radiation.

(15) Anthocyanin is water soluble pigment. It provides colour to the petals of flowers (Blue, Purple or violet, Black and Pink colour).

(16) The Na^+ ions of sap vacuole maintain turger pressure.

(17) K^+ are abundantly present is sap of sap vacuole.

(18) **Chaperons :** These are specific proteins that help in folding and transport of proteins into organelles and are synthesized on ribosomes.

(19) Cilia or flagella are absent in Red algae, Blue green algae or cyanobacteria, Angiosperms, Pinus, Arthropods.

(20) Cilia or flagella performs power stroke and recovery stroke for locomation .

(21) Flagella are either whiplash type (smooth surface) or Tinsel type (hairy surface). The microscopic hairs are called flimmers

(22) Chemically nucleolus contains 10% rRNA, 5% DNA and 85% non histone proteins.

(23) It is believed that **Ca^{++} ions** are responsible for the maintenance of organisation of nucleolus.

(24) The **structural and functional unit of chromatin** is **nucleosome**.

(25) Chemical composition of chromosome

DNA–40%, Histone –50%, Non-histone proteins–8.5%, RNA–1.5%, trace amount of Ca^{++}, Fe^{++}, Mg^{++}, lipids.

(26) **Acentric chromosome : Chromosome without centromere.**

(27) **In human chromosomes are metacentric, submetacentric and Acrocentric. But telocentric chromosome are absent.**

(28) Nucleus is largest extra cytoplasmic inclusion.

(29) Fluidity of cell membrane is due to non-polar ends of phospholipids.

(30) **Protoplast:** It includes all the living constituents of the protoplasm. Naked cell without cell wall is also called protoplast.

(31) **Calmodulin:** Calcium protein complex often associated with microtubules and microfilaments, taking part in motility and regulation of certain enzyme systems.

(32) Cells of WBC, skin cell, oral mucosa are taken for Karyotyping.