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Module-I

CYTOLOGY **(L. Cellula = a Small compartment)**

INTRODUCTION: Cell Biology is the branch of biology that deals with the study of structure and functions of cells. OR It is also known as cytology. "The study of structural and functional aspects of cell is called cytology".

The term cell was coined by Robert Hooke. It was first discovered by **Robert Hooke** in 1665. **Schwann** is generally regarded as the 'father of cell Biology' because he described the morphology and physiology of the cell. Each and every plant and animal is made up of a cell or cells. The cells are the building blocks of all the living organisms. The "Cell is the basic (fundamental) unit of the structure and function in an organism." The cell is a smallest unit of a life. It is able to control and perform several functions in all living organisms.

Prokaryotic cells are unicellular organisms including bacteria and archaebacteria, which are composed of a single cell except cyanobacteria (may be multicellular). Eukaryotes are multicellular organisms contain many or more than one cell including humans, which are composed of complex or many cells. The most common parts in the prokaryotic cells and eukaryotic cells are cytoplasm, cell membrane and genetic material.

All living organisms on the planet require a cell to play a vital role by controlling all types of biochemical and metabolic functions inside an organism. **Rudolf Virchow** (1858) states that the cells arise from pre-existing cells, often he called "omnis cellula e cellula". In a broad sense, A cell may be defined as **"a mass of protoplasm containing a nucleus surrounded by a plasma membrane and capable of replication**". i.e self duplication is the most important characteristic feature of the living substance. Protoplasm is covered by cell membrane. It is the living substance found in the cells of plants and animals.

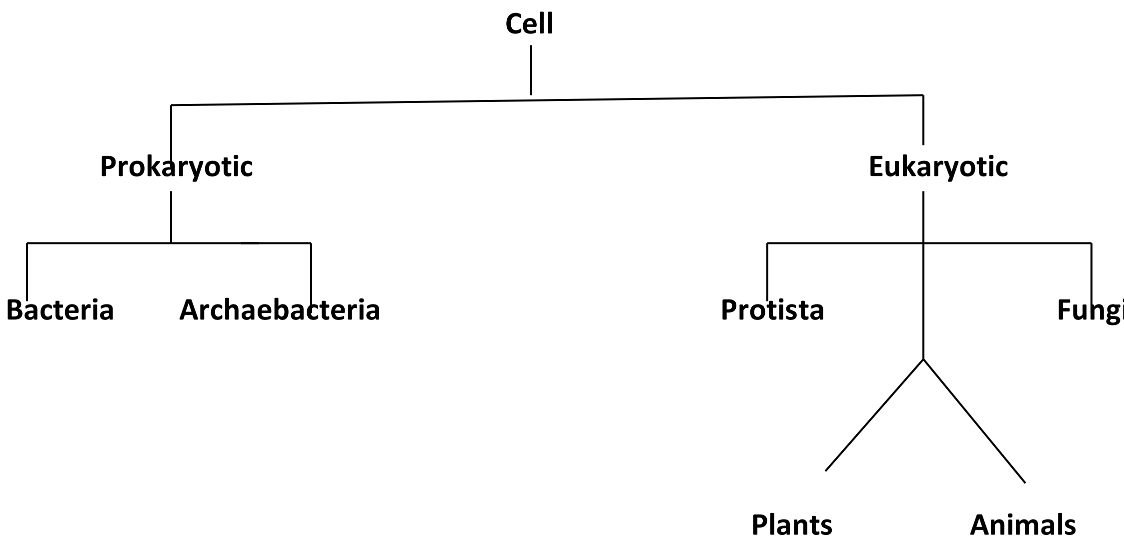
Huxley is defined as the **"protoplasm is the physical basis of life"**. Cell wall is an outer most non-living layer made up of **cellulose**. Cell wall is found only in plant cells and absent in animal cells. A cell is capable of performing all the vital activities of life namely consumption of food, transformation of material, assimilation, storage, removal of waste products, respiration, reproduction etc.

CELL THEORY was proposed by **M.J. Schleiden** (1838) and **Schwann** in 1839. According to the cell theory "**All the living organisms are fundamentally composed of cell or cells and the cells comes from the pre-existing cells**". A new cell generated by the process of cell division of the pre-existing cells.

Salient features of Cell Theory:-

1. All cells are the organisms.
2. The animals and plants are composed of an assemblage of cells.
3. All the cells arise from pre-existing cells only.
4. The cells contain nucleus and the nucleus is composed of hereditary units called chromosomes.
5. All the activities of an organism are the outcome of the activities of its constituent cells.

Types of cells: All the organisms except Viruses possess one or many cells. On the basis of the presence of nuclear membrane, the cells are classified into two types namely, prokaryotic and eukaryotic cell.



Prokaryotes: The cell with incipient nucleus (primitive nucleus) is called prokaryotic cell. An organism with incipient nucleus is called prokaryote.

Ex: All the organisms except Bacteria and Blue green algae

Prokaryotic cell:

Prokaryotic cells are simpler and smaller than he eukaryotic cells. The word prokaryote is derived from Greek word. Prokaryote means before nuclei. These cells lack membrane bound organelles. Prokaryotic cells are unicellular organisms, which reproduce through binary fission. In some cases few prokaryotic organisms also reproduce by budding. Prokaryotic cells have a cell envelope, which generally consists of a capsule, cell wall, cytoplasm, plasma membrane, nucleoid region, ribosome, plasmids, pili and flagella.

Parts of prokaryotic cell and their functions:

Capsule: It is composed of a thick polysaccharide. It is a kind of slime layer which covers the outside of the cell wall. It is used to stick cell together and works as a food reserve and it also protects the cell from dryness and from chemicals.

Cell wall: It is made from the **glycoprotein** called **murein**. Cell wall provides strength and rigidity to the cell and it is permeable to solutes.

Cytoplasm: It helps in cellular growth, metabolism and replication. Cytoplasm is the storehouses for all kinds of chemicals and components that are used to sustain the life of a bacterium.

Plasma membrane: It is also known as cell membrane. It is mainly composed of proteins, phospholipids and carbohydrates which form into fluid-mosaic. Plasma membrane surrounds the bacteria and it is a most important organelle and plays a vital role in controlling the movement of substances in the cell.

Cytoplasm region (or) nucleiod region: An area of the cytoplasm that contains the single bacterial DNA molecule.

Ribosome: They are the smallest part of the cell organelle. Ribosome plays a vital role in protein synthesis as they consist of protein and RNA. They are located freely in the cytoplasm of attached to the RER.

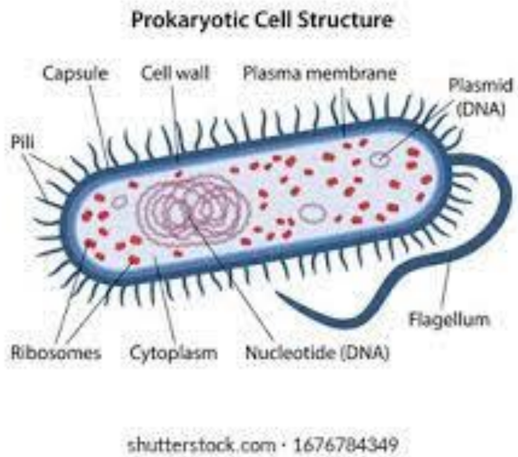
Mesosome: They are the folding present inside the plasma membrane. Mesosome plays a vital role in cellular respirations, replication of DNA, cell division, separation of chromosomes during cell division and also performs the role of Golgi bodies and mitochondria.

Plasmids: They are a small circle of DNA. Plasmid plays a vital role in exchanging DNS between the bacterial cells. Bacterial cells have many plasmids.

Pile: They are short protein appendages which fixes bacteria to surfaces. These pili are smaller than those flagella and are used in conjugation to exchange the genetic information.

Flagella: They are rigid rotating tail. The clockwise rotation moves the cell forward and anticlockwise rotation helps the cell to spin. The rotation is powered by H^+ gradient across the cell membrane.

In prokaryotes, nuclear material is not bounded by definite nuclear membrane. Here, nucleolus and nucleoplasm are absent. The chromatin bodies are scattered throughout the cytoplasm of the cell due to the absence of nuclear membrane. Such a type of nucleus without nuclear membrane is called nucleoid (hereditary material).



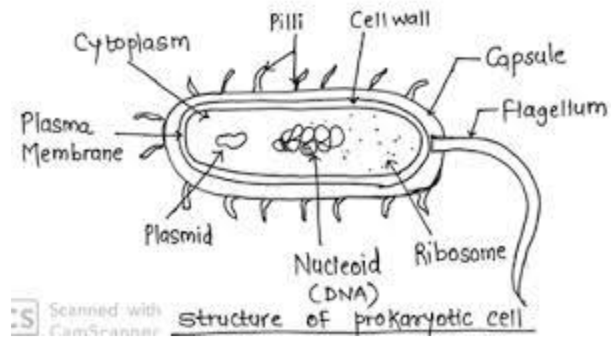
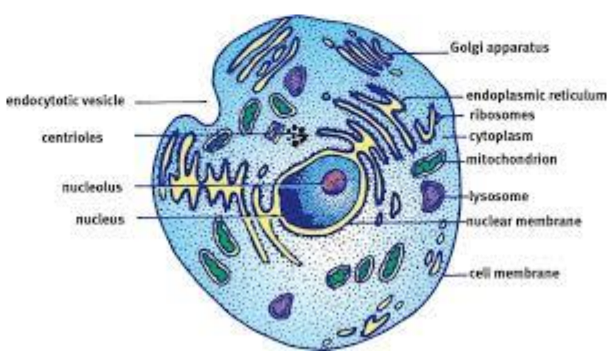


Fig: Prokaryotic cells (Examples- Bacteria, blue green algae, E.coli etc.)

Eukaryotic cell: The cell with definite nucleus is called eukaryotic cell. An organism with true nucleus is called eukaryote. They are complex and larger than the prokaryotic cells. The term eukaryote is derived from Greek word- eukaryote means true nuclei. Eukaryotic cells can be easily distinguished through a membrane bound nucleus. It consists of membrane bound cell organelles. The organelles play a vital role in cell maintenance and other functions. These organelles generally consist of cell, plasma membrane, nucleus, mitochondria, chloroplasts, endoplasmic reticulum, ribosome, Golgi complex, lysosomes, vacuoles, cytoplasm and chromosomes.



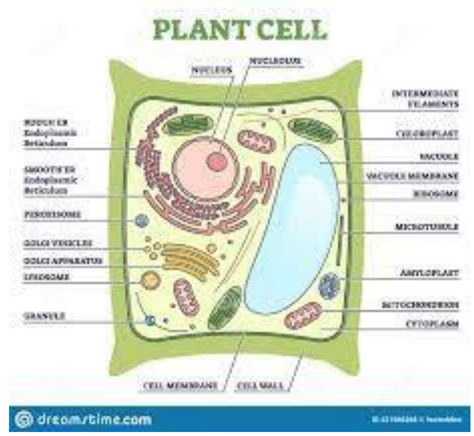


Fig: Eukaryotic cells

Parts of eukaryotic cell and their functions:

Cell wall: It helps in protecting the plasma membrane and plays a vital role in supporting and protecting the cells. It is a thick outer layer made of tough **cellulose**. Cell walls are present in plant cells and are absent in animal cells.

Cytoplasm: It refers to the jelly like material with organelles in it. It is present in plant and animal cells. They consist of inner region of the plasma membrane and also the outer region of DNA. The cytoplasm is made of components, which benefits the cell by keeping the organelles separate from each other. This helps to keep a cell in stable. Cytoplasm also contains some important organelles like, E.R, lysosomes, mitochondria and G.C. Along with these organelles; it also contains chloroplast in plant cells. Every organelle is bound by a fatty membrane which has some specific functions. A cytoplasm plays a vital role in storage and manufacturing of energy. It maintains the cell shape and its consistence and provides suspension to the organelles. All types of cell functions like cell expansion, growth and replication are carried out in the cytoplasm of the cell. All types of cellular activities take place in the cytoplasm. Cytoplasm also helps in the movement of different elements or molecules present within the cell.

Plasma membrane: It is also known as cell membrane. It is present in animal cells, plant cells and even in eukaryotic cells. It is a double layered, thin barrier, surrounding the cell that controls the entry and exit of certain substance. It also refers to a thin, fluid entity that manages to be very flexible and it is stable. It is the living ultra thin biological membrane ranging from 6 to 8 nm and composed of a dynamic layer that chemically comprises a molecule of lipids and proteins that are arranged tin a fluid mosaic pattern. It acts as a protective barrier. This membrane plays a vital role in transportation of materials, cell to cell recognition, enzyme activity and signal transduction. It acts as a boundary and separates the internal and external organelles of a cell.

Mitochondria: Mitochondria convert energy into usable forms, which are used by the cell to perform their cellular functions. This organelle plays a vital role in generating and transforming the energy. Albert von Kolliker recognized the structure of the mitochondria in 1880. It is a power house of the cell. It is responsible for producing energy by breaking down fats and carbohydrates. It converts glucose into energy in the form of ATP. It helps in cellular respiration. It synthesizes ATP from the breakdown of sugars, fats and other fuels in the presence of oxygen. It plays a vital role in oxidative phosphorylation.

Endoplasmic reticulum:

Ribosome: They are biological molecule, which are composed of proteins and RNA. It is a complex and smallest organelle in the sell. It plays a vital role in synthesis millions of protein, which are required for cells to perform several function. These organelles are present in all animal cells and absent in plant cells.

Golgi bodies: They are sac like structures, which are specifically used for storing or preserving all the substances made by the cell. It helps in the movement of transportation of materials within the cell and in synthesis of plant cell wall; hence it is also called as he post office of the cell. It plays as vital role in the modification, transportation and processing of macromolecules which includes proteins and lipids. These organelles are present in all animal cells and absent in plant cells.

Lysosomes: They are spherical organelles, which contains enzymes that help in maintaining the physiologic turnover of cellular constituents. These organelles are present in all animal cells and absent in plant cells. They play a vital role in breaking the food materials and making it easier to digest. It helps in cell renewal and break down old cell parts. Lysosomes play a vital role in removal of dead cells, hence they are named as a suicide bags.

Chloroplast: These are the sites of photosynthesis. Chloroplasts were discovered by Antony Van Leeuwenhoek and Nehemiah Grew. Chloroplasts are important because, if there were no chloroplasts, plants cannot produce oxygen, sugars and starches, which other animals use and eat. They also produced energy in the daylight. They are present only in plant cells and absent in animal cells. Chloroplasts are also found in chlorophyll bacteria, blue-green algae etc.

Vacuoles: They are vesicles that help in the digestion. They are present both in plant cells and in animal cells. In plant cells it helps in maintain its shape and it also stores water, food, enzymes, wastes etc.,

Nucleus: it is present in both plant cell and animal cells. It is a large and present in the center of the cell. It contains DNA and stores all the necessary information, which is required to control all the activities within the cell. Hence it is also called as a brain f the cell or controlling centre of the cell.

Nuclear membrane: It is a double layered. In eukaryotes, chromatin bodies are enclosed by nuclear envelope. The nucleus contains nucleolus, nucleoplasm and chromosomes. It helps In the entry and exits of material into the nucleus. It also separates the nucleus from the other parts of the cell.

Nucleolus: It is located in the nucleus of both plant and animal cell. It plays a vital role in the synthesis of RNA and in the formation of the ribosome.

Chromosomes: The term chromosome is derived from Greek word chromo mean colour and soma means body. Chromosomes are small, coloured thread like structures present in the nucleoplasm of living cells which helps in the inheritance or transmission of characters in the form of genes from one generation to another generation. It is made up of DNA and stored in the nucleus, which contains the instructions for traits and characteristics. Chromosome performs several functions. It helps is self-duplication, help in transmitting or transferring the characters from one generation to another or from parents to offspring. It also controls biological process in the body of an organism. They control cell metabolism by directing the formatting of necessary proteins. They help in cell differentiation during development. A chromosome also helps in determining a sex of an individual.

Centrosomes: They are the small hollow cylindrical shaped organelles, which are composed of nine bundles of micro tubules. They play a vital role in cell division or in the cell cycle. Centrosomes are present only in animal cells and are absent in plant cells. Centosomes are also known as centrioles.

Cell Size: Most of the cells are microscopic in size. Size of the cell varies from 0.1 micron to 1,75,000 micron (175 mm).The smallest cells are those **Mycoplasma gallisepticum**. It measure about 0.1 micron in diameter. The Ostrich egg is the largest sized cell which measures about 175 mm in diameter.

Cell shape: Cells exhibit various forms and shapes. A cell is typically spherical in shape. Cell shape may be **irregular** (Ex: Amoeba), **spherical** (Ex: Noctiluca), **spindle shape** (Ex: Euglena), **cuboidal** (Box shape), **columnar** (Pillar like), **polygonal, oval** (egg shape), **elongated** (Trypanosoma), **flat** (Squamous epithelial cell) etc., The shape of the cells may vary from one organism to another and one organ to another. Even the cell of the organ may vary in shape.

Number: In most of the plants & animals having many cells, hence they are called multicellular organisms. In protozoans there is a single cell hence they are called unicellular organisms. The Body of an average adult man is made up of about 100 trillion cells. (1,000000000000).

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ULTRA STRUCTURE OF ANIMAL CELL

The cell is the basic structural and functional unit of living organisms. The term cell was coined by Robert Hooke. Basically animal cell is made up of three components namely, plasma membrane, cytoplasm & Nucleus.

The cell is surrounded by the plasma membrane. It is filled with a colloidal substance called **cytoplasm.** The cytoplasm contains a spherical body called **nucleus**. The cytoplasm along with the nucleus is called **protoplasm.** In plant cell the plasma membrane is covered by **cell wall.**

Plasma membrane: (Plasmalemma or cell membrane). The plasma membrane is the outermost boundary of the cell. It is a thin, delicate covering of the cell. At the basal end of the cell, it may be folded to form **infoldings**. At the anterior end of the cell provided with number of finger like projections called **microvilli**. The microvilli forms either **phagocytic** or **pinocytic** vesicles into the cytoplasm. It primarily gives mechanical support and external shape to the protoplasm. It is a double layered structure. Plasma membrane is connected with the nuclear membrane through endoplasmic reticulum. It is also capable of growth as the cell enlarges.

Cytoplasm: The cytoplasm is a viscous substance. The mass of the protoplasm lying outside the nucleus is called cytoplasm. It is a colorless, homogenous, translucent, amorphous and colloidal fluid. It also contains **water, salts of Na, K and other metals and organic compounds namely, carbohydrates, proteins, nucleoproteins, nucleic acids and enzymes**. The peripheral part of the cytoplasm is normally non-granular and clear, and s known as **ectoplasm**. Inner portion is granular and less viscous and is known as **endoplasm**. Various cell organelles are found in the cytoplasm of the cell namely, E.R., G.C, mitochondria, ribosomes, lysosomes, etc.,

Animal cell contains centrosome consists of a pair of centrioles. In addition to these structures, the cytoplasm also contains microtubules.

Cytoplasm & also possess non-living **ergastic substances** like strach grains, calcium carbonate, pigments, calcium oxalate crystals, lipids, proteins etc cystolith (Grape like structures of calcium oxalate) Non living inclusions of the cytoplasm of the cell is called **ergastic substances**. These are the products of cell metabolism consists of reserve food material (i.e. strach grains), Secretory products (i.e. Resin & Nectors). & excretory products (i.e. Tannins, alkaloids, mineral crystals] .

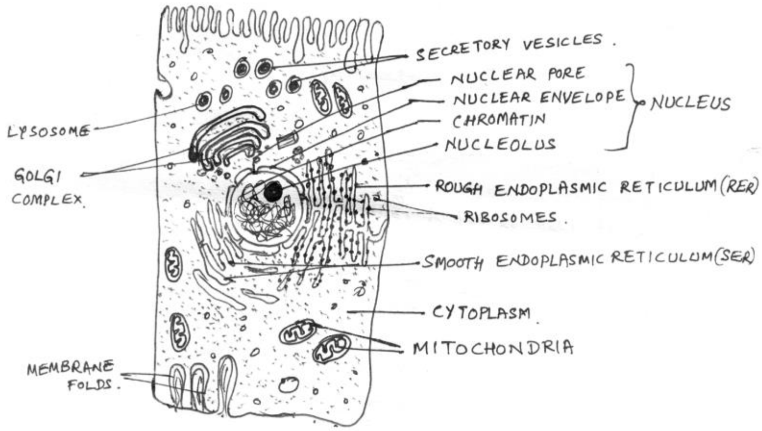

Fig : Ultra Structure of Animal Cell

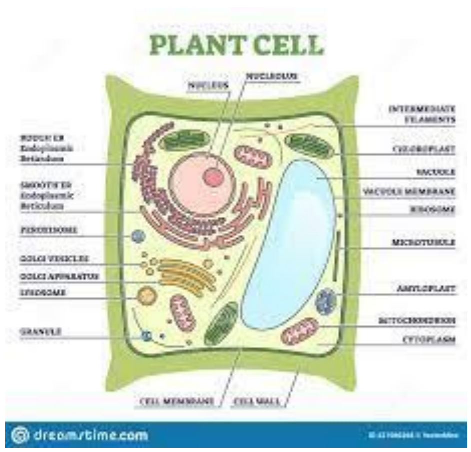

Fig : Ultra Structure of plant Cell

3) Nucleus: Usually the nucleus is located in the centre of the cell and controls all the vital activities of cell. It is bounded by double layered **nuclear membrane** (nuclear envelope) with pores called nuclear **pores**. Nucleus is filled with the nucleoplasm, which contains nucleolus. Chromatin is distributed in the nucleoplasm which acts as a genetic material.

Differences between plant cell and Animal cell

S. No	***Plant cell.***	***Animal cell.***
1.	Cell is bounded by a non-living cell wall made up of cellulose.	Cell wall is absent. Cell is bounded by a living cell membrane.
2.	Shape of the cell is usually round or spherical. (irregular shape – absence of cell wall)	Rectangular shape (fixed shape- presence of cell wall)

3.	Plastids are present and of different types	Plastids are absent.
4.	Vacuoles are present (larger and few in number)	Vacuoles are small and more in number
5.	Centrioles are absent	Centrioles are present
6.	Reserve food is in the form of starch.	Reserve food is in the form of glycogen.

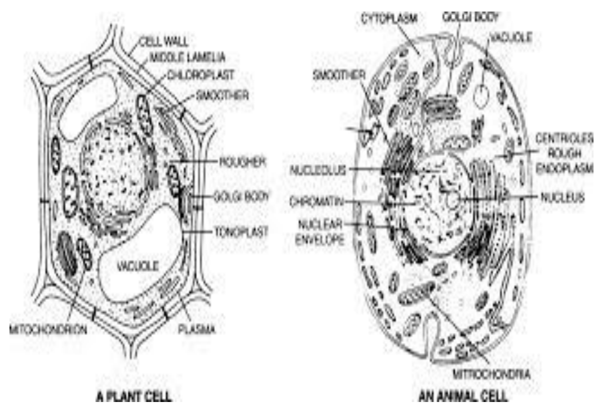

Fig: Structure of plant cell and animal cell

Differences between Prokaryotes and Eukaryotes

Sl. No.	Prokaryotic cell	Eukaryotic cell
1	They are very **minute** in size (primitive forms)	They are comparatively **larger** in size (advanced forms)
2	They are originated about **3.5 billion** years ago	Originated about **1.2 billion** years ago
3	Usually **unicellular** organization	Usually **multicellular** organization
4	Presence of **incipient nucleus** i.e true nucleus is absent	**True nucleus** is present
5	Usually **Smaller in size**, cell size varies from **1- 10 µm**	**Larger size**, usually varies from **10 - 100 µm**. Sometimes very large
6	Membrane bound cell organelles (nucleus, mitochondria, G.C, lysosomes, E.R, chloroplast and peroxysomes) are absent	Membrane bound cell organelles are present. i.e Mitochondria, G.C, lysosomes, E.R, chloroplast and peroxysomes.
7	Genetic material consists of **single chromatin**	Genetic material usually consists of **more than one**

		chromosome
8	Genetic material is freely distributed in the central portion of the cell (**nucleoplasm**)	Genetic material is located in the **nucleus**
9	**DNA is circular** (nucleoid) and only one. It is not associated with histone protein	**DNA is thread like** and more than one. It is associated with histone protein
10	Cell division is of simple **binary fission** (Amitotic)	Cell division is complex with involvement of chromosomes (mitotic) and **meiosis**
11	**Nucleolus is absent**	A well developed **nucleolus is present**
12	**Ribosomes** are small and only and **70S type** (50S+30S)	**Ribosomes** are large and **80S type** (60S+40S)
13	**Cell wall is composed of muco polysaccharides**	**Cell wall** is composed of **cellulose** (in plant) and **chitin** (in fungi). Cell wall is absent in animal cells)
14	Cytoskeleton system is absent	Cytoskeleton is well developed
15	Vacuoles are absent	Vacuoles are present in plant cells
16	**E.R absent** hence protein synthesizing ribosomes freely distributed in the cytoplasm	**E.R present**. Protein synthesizing ribosomes usually attached to E.R
17	Microtubules absent in flagella	Microtubules present in flagella
18	**Flagella with simple arrangement**. (but do not have 9+2 fibrillar pattern)	**Flagella (if present) is very complex** with 9+2 arrangement of microtubules
19	Sexual reproduction absent	Sexual reproduction is present
20	**Cell cycle** duration about **20 -60minutes**	Highly varies, rapidly dividing cells. The **cell cycle** is **24 hours**
	Ex. Bacteria, Cyanobecteria	Ex. Animal cells and pant cells

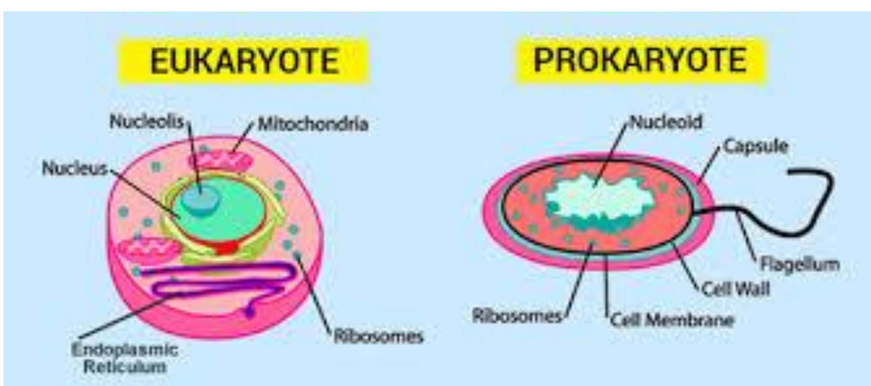

Fig: Structure of prokaryotic cell and eukaryotic cell

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PLASMA MEMBRANE

Introduction: The plasma membrane may be defined as the thin, elastic semi permeable living membrane that serves as a boundary for the cytoplasm. The term plasma membrane was coined by **Nageli** and **Crammer** in 1855. Plasma membrane is also known as cell membrane or plasmalemma. The lipids and proteins are associated with each other in plasma membrane, hence the name lipoprotein membrane.

Occurrence: Plasma membrane is the outer limiting membrane in all animal cells. But in plant cells and bacterial cells, it is located below the cell wall. It serves as a barrier for the flow if some components into and out of cells. Thus it determines the composition of cytoplasm in the cell.

Size: Plasma membrane is about $75A^0$ in thickness in almost all the plant cells, animal cells and bacterial cells. (A^0 or one Angstrom unit= 10^{-8} cm (1/1000000000 cm).

The plasma membrane is a thin elastic skin-like membrane covering a cell. It is a structural and functional component of both prokaryotic & Eukaryotic cells. It measures about 120 $A^{\mathbf{0}}$ in thickness. It is an outermost layer of plant and animal cell. It is present below the cell wall in plant cell.

Models of plasma membrane: There are several models proposed by different scientists to put forth different models of plasma membrane. Some of the important models are as follows.

1. Trilaminar model (Unit membrane
2. Bilaminar leflet model (Sand witch model)
3. Lattice model
4. Micellar model
5. Fluid Mosaic model

The detail account of plasma membranes is as follows.

1. **Trilaminar model (Unit membrane):** This model was proposed by **Robertson** in 1959. According to this model, the plasma membrane is made up of three layers namely an outer protein layer, a middle lipid layer and an inner protein layer. The middle layer is $35A^0$ thick and an outer and inner protein layer measures about $20A^0$ each. Such a trilaminar membrane is called unit membrane. According to Robertson all biological membranes are unit membranes and this concept is called unit membrane hypothesis. Plasma membranes of prokaryotes and eukaryotes are unit membranes. Again the membranes of E.R, Golgi complex, Mitochondria, lysosomes, plastids and nucleus are unit membranes.

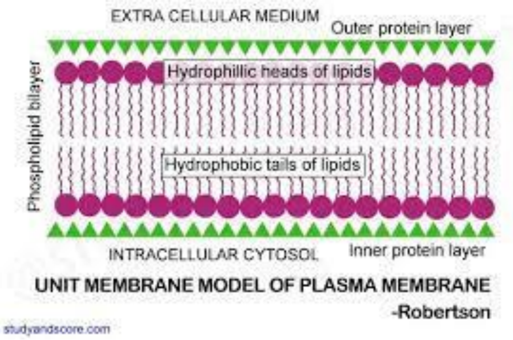


Fig: Unit membrane

2. **Bilaminar leaflet model (Sand witch model):** This model was proposed by **Danielli** and **Davson** in 1934. According to this model, the plasma membrane is made up of two layers. These two layers of lipid molecules coated with protein. Each lipid molecule has a hydrophobic tail and a hydrophilic head. The hydrophobic tails of the two layers face each other and the hydrophilic head facing towards periphery.

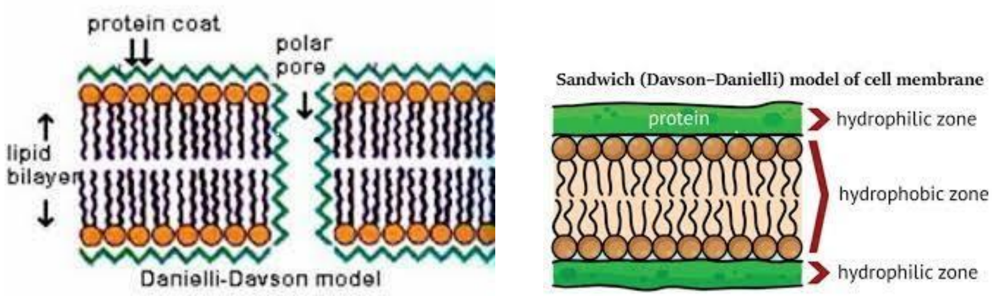


Fig: Bilaminar leaflet model

3. **Lattice model:** This model was proposed by **Wolpers in** 1941. According to this model, the lipids and proteins are arranged in layers but a lattice or network like structure. Proteins form a kind of mechanical frame work. The lipid component is distributed between the meshes of protein frame.

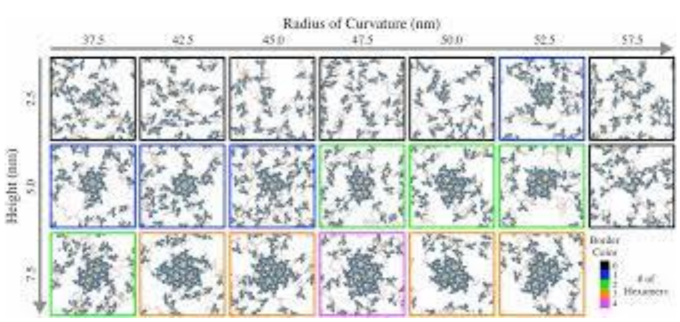
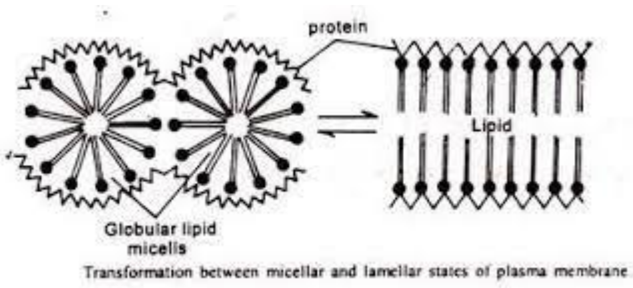


Fig: Lattice model

4. **Micellar model:** This model was proposed by **Hiller & Hoffman** in 1953. According to this model, the molecules in the membrane are not arranged in layers but they are arranged in the form of globular sub units called **micelles**. The lipid molecules are the building blocks of the membrane and the protein globules are arranged on either side.



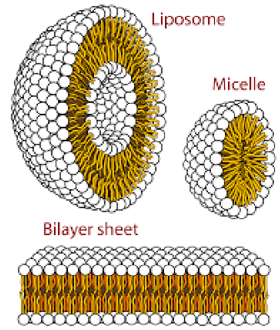


Fig: Micellar model

5. Fluid Mosaic model of plasma membrane

The fluid mosaic model was proposed by S.J. Singer & G.L. Nicholson in 1972. This model is widely accepted all over the model. The plasma membrane is composed of about 43.6 % phospholipids, 49.2% proteins and 7.2% carbohydrates. According to this model, the phospholipid molecules are arranged in two layers forming a bilaminar structure as shown in the figure. In the fluid mosaic model the lipids, proteins and carbohydrates are arranged as shown in the figure.

1. **Arrangement of lipids**: The phospholipids are arranged in the form of double layer or bilayer(Bimolecular leaflet). Hydrophilic ends (hydrophilic head) facing the periphery (directed outwards) and hydrophobic ends (hydrophobic fatty acid tails or non polar end) facing the centre.
2. **Arrangement of proteins:** Protein globules are dispersed in these lipid layers. Extrinsic proteins are scattered on the inner outer layer forming a mosaic. **"The proteins molecules are distributed on the outer surface of the bilaminar structure are called peripheral or extrinsic proteins"**. While the **"protein molecules are embedded (inserted) within the bilayer is called intrinsic proteins".** Intrinsic proteins are located within the lipid layer. Some proteins extend fully and project on both sides such type of proteins are called transmembrane proteins. Proteins show mobility and behave like icebergs floating in the sea. Hence it is also known as fluid mosaic model of plasma membrane.
3. **Arrangement of carbohydrates**: The carbohydrates are associated with either the lipids or proteins forming glycolipids and glycoproteins respectively.

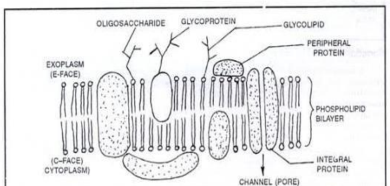
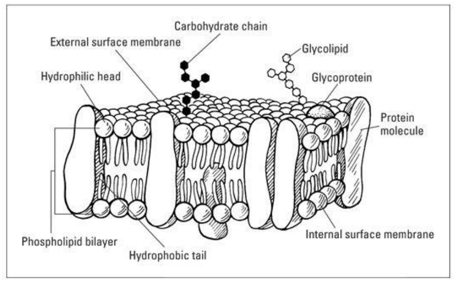


Figure 3.7 A simplified diagrammatic sketch of the Fluid-Mosaic Model of biomembrane (after Singer and Nicolson 1972).



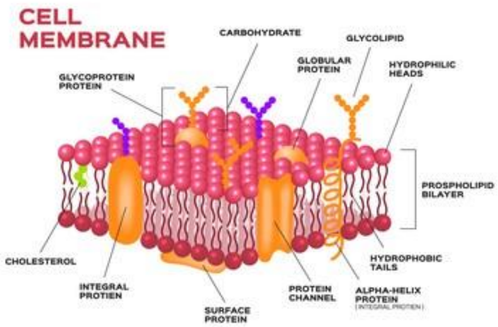


Fig: Fluid Mosaic Model of Plasma membranes

Functions of plasma membrane: Plasma membrane modified to perform specific functions. Namely, transport of oxygen, water materials.

1. **Diffusion**: ('downhill movement'): Movement of molecules and water from the region of higher concentration to a region of lower concentration till the equilibrium reached. i.e O_2 and CO_2 transport across the membrane.
2. **Osmosis**: Plasma membrane acts as a semi permeable membrane. Here the flow of solvent molecules from a region of higher concentration to a region of lower concentration through the semi permeable membrane" (greater solute concentration).
3. **Active transport**: ('uphill movement'): The movement of molecules (ions, solutes) against a concentration gradient by the expenditure of energy (ATP).
4. **Phagocytosis**: (**cell eating**): "Ingestion (Engulfing) of solid particles with high molecular weight by the plasma membrane is called phagocytosis".
   Ex: Amoeba, Entamoeba, In man WBCs, Macrophages etc.,
5. **Pinocytosis**: (**cell drinking**): "Ingestion (Engulfing) of liquid particles (droplets) with high molecular weight by the plasma membrane is called pinocytosis".
6. **Microvilli**: which helps to increase the area for an absorption.
7. **Desmosomes**: Modified plasma membrane found between two adjacent cells help in adhesion.
8. **Plasmodesmata**: Extensions of plasma membrane between two adjacent cells help in communication and exchange of materials.

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ENDOPLASMIC RETICULUM (ER)

INTRODUCTION: Endoplasmic reticulum is a cell organelle found in the endoplasmic portion of the cell hence the name ER. It is a complex network of membrane bound vacuities in the cytoplasm of the cell. The term endoplasmic reticulum refers to a vast network of membrane enclosed tubules, vesicles and sacs n the cytoplasm.

Discovery of ER: The ER was discovered by **K. R. Porter**, Claude and Thompson in 1945, but the term Endoplasmic reticulum was given by Porter in 1953.

Definition: The membrane-bound intracellular network of cisternae and tubule is called Endoplasmic reticulum. (Endoplasmic reticulum is a complex network of membrane bound vacuities in the cytoplasm of the cell).

Occurence: Endoplasmic Reticulum is absent in prokaryotes (bacteria and blue green algae). It is found in all the eukaryotic cells except mature RBC, eggs, embryonic cells.

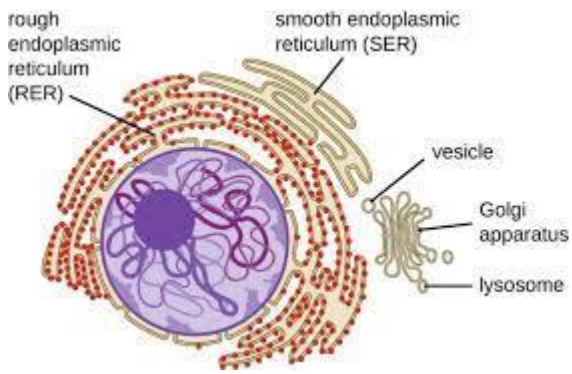
Location: It is extending between nuclear membrane and plasma membrane.

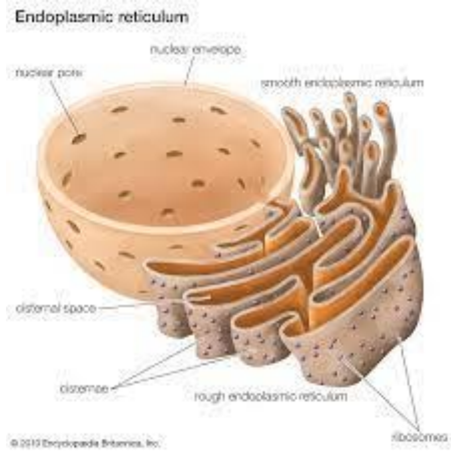
STRUCTURE: It is also bounded by double layered membrane similar to the plasma membrane. Each membrane measures about 50 A^0 to 60 A^0 in thickness. ER membrane is continuous with the plasma membrane, and nuclear membrane. The ER consists of three components; namely cisternae, tubules and vesicles. All of them are filled with a fluid called endoplasmic matrix.

1. **Cisternae**: These are elongated, flattened, un-branched sac-like structures. They are arranged in the form of parallel bundles. They are interconnected and may be covered with ribosomes. Their diameter is **40 to 50 m. micron.** They are found in secretary cells.

2. **Tubules**: These are smooth walled, elongated, highly branched tube- like structures. They do not possess ribosomes on their surface. The diameter of tubules measures about **50 to 100 mm in diameter.** They are usually found in non secretary cells like striated muscle cells. They arise from the cisternae.

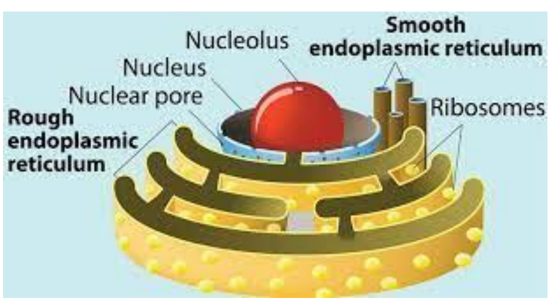
3. **Vesicles**: These are spherical or ovoid, sac-like structures and measures about **25 to 500 mm in diameter.** They are rich in pancreatic cells. They are found at the end of cisternae and tubules. Many vesicles are found dispersed in the cytoplasm.

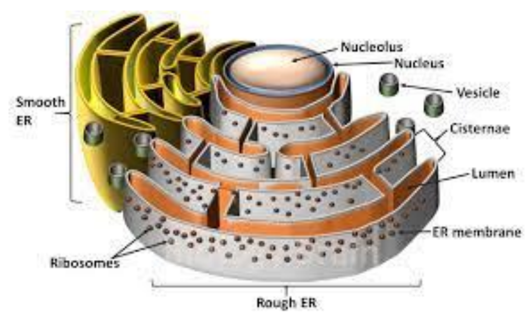




Types of Endoplasmic Reticulum: Based on the presence or absence of ribosomes on their membranes, the ER is classified into two types namely RER and SER.

1. ***Smooth or Agranular Endoplasmic Reticulum (SER)***: Endoplasmic reticulum without ribosomes is called Smooth Endoplasmic Reticulum. Endoplasmic reticulum do not provides the space for the attachment of ribosomes, hence it gives rise to the smooth surface. Its main units are tubules & vesicles. It is responsible for synthesis of steroids. The ER present in retinal cells is called myeloid bodies. The ER present in muscle cells is called Sarcoplasmic reticulum.
   Ex: Cells of adrenal cortex.





2. **Rough or Granular Endoplasmic Reticulum (RER)**: Endoplasmic reticulum with ribosomes is called Rough Endoplasmic Reticulum. Endoplasmic reticulum provides the space for the attachment of ribosomes, hence it gives rise to the rough surface. Mostly it is found in cisternae. It is mainly involved in protein synthesis.
   Ex: liver cells, goblet cells, plasma cells and Pancreatic cells.

FUNCTIONS:

1. It provides **mechanical support** (supporting structure) to the cell. It forms the cytoskeleton to the cell.
2. It acts like a **circulatory system** of the cell. (i.e. transport of proteins, hormones, ions etc.,) i.e It acts as a passage to transport of secretary substances.
3. RER helps in the **synthesis of proteins**.
4. It retinal cells, SER produce visual pigments from Vitamin A.
5. ER helps in **detoxification** (i.e. Removal of toxins using cytochrome P-450 from cell. It occurs in ER of liver cells).
6. SER helps in the synthesis of **steroid hormones, cholesterol, ascorbic acid** etc.,
7. It activates the mitochondria to synthesize the ATP molecules.
8. In muscle cells, SER modified into sarcoplasmic reticulum, which store and release $Ca2+$ for muscle contraction.
9. SER produce organelles like Golgi apparatus, lysosomes, vacuoles.
10. In liver cells, SER bears enzyme bodies called glycosomes for glycogen metabolism (glycogenesis and glycogenolysis).
11. It is permeable in nature.
12. It takes part in the formation of nuclear membrane during cell division.

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GOLGI COMPLEX (Golgi Apparatus)

INTRODUCTION: Golgi complex is a cell organelle found in the cytoplasm of the cell. Golgi complex is also known as Golgi bodies, Golgi material, dictyosomes, lipochondrion, canalicular system or Golgi apparatus. Golgi complex is a complex cytoplasmic structure made up of cisternae, a network of tubules with vesicles and vacuoles It helps in membrane transformation, secretion and production of complex biochemicals.

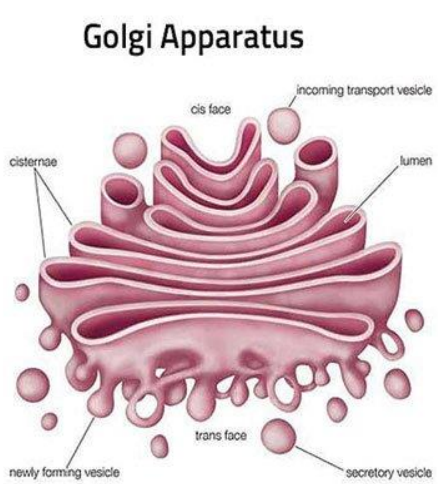
Discovery of Golgi apparatus: It was discovered by Italian scientist **Camillo Golgi** in 1898 in the nerve cells of new born Owl.

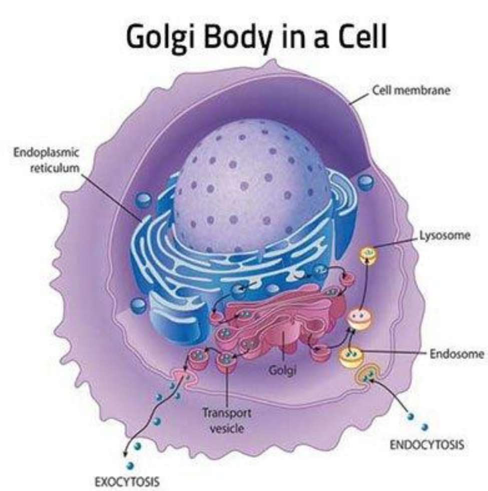
Definition: "Golgi complex is defined as a cluster of smooth membranes associated with the endoplasmic reticulum".

Occurrence: Golgi complex is absent in prokaryotic cells. It is present in all eukaryotic cells except RBC's of mammals, mature sperms, sieve tubes of plants, sperms of bryophytes and pteridophytes.

Location: In animal cells the G.C. is generally seen near the nucleus. In animal cells Golgi complex is either single or consists of a single connected complex. The localized organelle is compact. It generally occurs at one end between the nucleus and the periphery.

In plant cells, Golgi apparatus is formed of a number of unconnected units called dictyosomes. Their number is highly variable-from one in certain simple algae to 25000 in rhizoidal cells of Chara. Commonly there are 10-20 dictyosomes per plant cell. A liver cell may possess up to 50 units of Golgi apparatus called Golgisomes.





STRUCTURE: Golgi complex is a group of flattened tubes or sacs, arranged one above the other in the form of stalk of bundles. The shape and size of Golgi complex are not fixed. They depend upon the physiological state of the cells. Each sac is covered by membrane similar to the plasma membrane. A typical plant dictyosome is 0.5-1.0 nm in diameter. Usually Golgi complex is made up of four components namely, cisternae, tubules, vesicles and vacuoles as shown in the figure.

1. **Cisternae(Lamellae)**: These are elongated flattened sacs filled with fluids or matrix and piled one upon the other in the form of **stacks**. They are arranged in parallel bundles one above the other (2 to 8 in a stack). In a stack, the adjacent cisternae are separated by a distance of 200 -300A^0. The cisternae are slightly curved to give a definite polarity to the Golgi apparatus. Hence the cisternae have **convex** and **concave** surfaces. The convex side is called forming face while the concave side of the apparatus is known as maturing (trans-face) face. The membranes of the maturing face are 7-8 nm in thickness while those of the forming face are about 4 nm in thickness. The cavity measures about 60-90 A^0.

   The forming face receives (transitional) vesicles from endoplasmic reticulum. Their contents pass through various cisternae with the help of coated vesicles and inter-cisternal connectives. They ultimately reach the maturing face where they are budded of as secretion, coated or Golgian vesicles or vacuoles. While passing through the apparatus, bio-chemicals are variously transformed.

2. **Tubules**: They form a complicated network towards the periphery and maturing, face of the apparatus. Actually tubules arise due to fenestrations of the cisternae. They have a diameter of 30-50nm. The tubules interconnected the different cisternae.

3. **Vesicles**: They are small droplet-like sacs of 20-80 nm in diameters. These are closely associated with cisternae. They are of two types, smooth and coated. They develop either by budding or by constriction of the ends of the cisternae. The coated vesicles have a rough surface. The smooth vesicles have a smooth surface. They contain secretary substances and are hence known as secretion vesicles.

4. **Golgian vacuoles**: These are large spacious round sacs associated with the edges of cisternae. These are formed by the expansion of the cisternae which have become modified to form vacuoles. The vacuoles develop from the concave or maturing face. Golgian vacuoles contain amorphous or granular substance. Some of the golgian vacuoles function as lysosomes. The cavity measures about 60 to 200A^0.

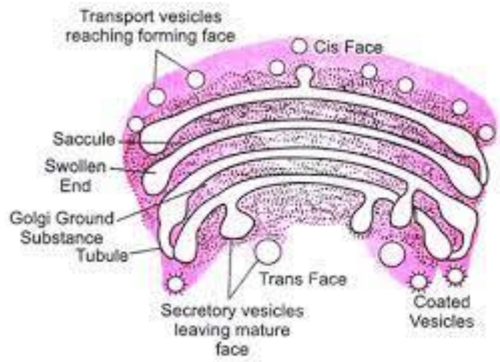


Figure : GOLGI APPARATUS IN SECTION

Fig: Golgi complex

FUNCTIONS: G.C performs several functions.

1. **Secretion:** It serves as a **packing center** for the cell. i.e. it forms Secretary Vacuoles (Vesicles) used to pack enzymes, proteins, carbohydrates Etc.,
2. **Formation of Acrosome:** Golgi complex is responsible for the formation of **acrosome** of the sperm. It helps in the penetration of sperm into the ovum.
3. **Formation of lysosome:** Lysosomes are formed from Golgi complex.
4. **Glycoproteins and Glycolipids:** It helps in the formation of glycoproteins and synthesis of phospholipid.
5. **Formation of new cell wall:** Golgi complex helps in the formation of **cell plate** during cell division.
6. **Complex carbohydrates:** It helps in the synthesis and secretion of polysaccharides.
7. **Transformation of membranes:** G.C involves in the formation of plasma membrane.
8. **Glycosylation:** Glycosylation is the formation of linkages with carbohydrate units. Glycocylation produces complex carbohydrates such as glycoproteins, mucopolysaccharides, glycolipids, glycogen etc.

9. It helps in the synthesis and secretion of polysaccharides.
10. G.C involves in the formation of plasma membrane.
11. It is involved in the metabolism of sulphate.

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LYSOSOMES (Suicide bags of cell)

Introduction: **"**A tiny single membrane bound vesicle enclosed with hydrolytic enzymes found in the cytoplasm of the cell is called lysosomes. These are the spherical bodies found in the cytoplasm of the cell. Lysosomes are also regarded as "**suicide bags of a cell**". It was first discovered by **Christian de Duve** in 1955.

Occurrence: The lysosomes are found only in all eukaryotic cells and absent in prokaryotic cells. These are distributed throughout the cytoplasm of the cell.

Types of lysosomes: There are four types of lysosomes. Such as follows.

1. Primary lysosome: Newly formed vesicle enclosed with hydrolytic enzymes are called primary lysosomes.

2. Secondary lysosome: The phagosome (vesicle containing ingested material) is combined with primary lysosome to form secondary lysosome. Digestive vacuoles-pinosomes and phagosomes

3. Residual bodies: Secondary lysosomes with undigested food (waste products) are called residual bodies.

4. Autophagic vacuoles (Auto lysosomes): This is a structure containing parts of the cell itself. i.e. parts of the ER, mitochondria. It helps in intracellular digestion. During starvation, sometimes lysosomes destroy or eat of its own cell, hence lysosomes are also known as suicide bags.

Size and Number: Number and size also vary from one organ to another. Generally they occur in more number in the secretary ells. **Ex:** Liver and pancreatic cells.

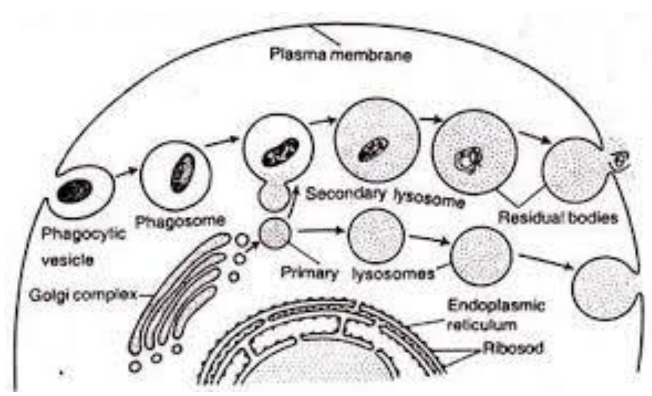
ULTRA STRUCTURE OF LYSOSOMES: Lysosomes are the small, single membrane bound vesicles enclosed with hydrolytic enzymes. They are distributed throughout the cytoplasm of the cell. The membrane is made up of lipoprotein. Lysosomes contain about 24 types of hydrolytic enzymes, namely acid deoxy ribonuclease, acid ribonuclease, acid phosphotase, acid phospholipase etc.,

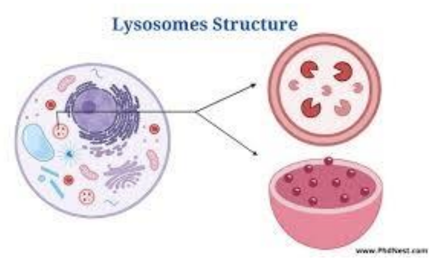
It is believed that these enzymes are synthesized by the cell and packed by Golgi bodies. If the enzymes are released outside the lysosomal membrane, the cell itself would be digested (autolysis), hence it is also called suicide bag. These cell organelles are abundant in uterus. During the starvation, the lysosome digests of its own cell.

Origin: It is believed that lysosomes are derived from E.R, G.C and plasma membrane

FUNCTIONS OF LYSOSOSOME:

1. Lysosomes are concerned with **intracellular digestion**.(digestion of food materials that enters into the cell by **phagocytosis** and **pinocytosis**).
2. They digest the reserve food content of the cell during starvation.
3. Lysosomes are suicidal bags, some times which destroys of eats of its own cell.
4. It helps to digest the unwanted RBC, mitochondria or bacteria.
5. Lysosomes eat or digests the tail during metamorphosis of tadpole larva. (Lysosomes are responsible for the disappearance of tail during metamorphosis of tadpole into adult frog.
6. It plays an important role in **acrosomal activity** of spermatozoan. i.e it helps in the penetration of sperms into ovum.
7. Lysosomes destroy old and malfunctioning cells by autophagy.





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CHLOROPLAST

INTRODUCTION: Plastids are discovered by Schimper in 1885. They are found only in plant cells. Plastids are of three types. Such as follows.

1. **Chloroplast:** These are green color plastid. They take part in photosynthesis.

2. **Chromoplast:** These are colored plastids except green. This is responsible for coloration of flowers and fruits and help in attracting insects for pollination.

3. **Leucoplast:** These are colorless plastids. They store reserve food materials.

CHLOROPLAST (Gr. Chloron=Green)

Chloroplast is a largest cell organelle found in the cytoplasm of a plant cell. It is absent in prokaryotes and animal cells. Generally it is a spherical or oval shaped structure. The chloroplasts are located mainly in the mesophyll cells. Each cell has 20 to 40 cells. The chloroplast is surrounded by two membranes i.e., an outer and an inner membrane. It is filled with fluid called stroma or matrix. It contains proteins, DNA, ribosomes and various enzymes required for carbon fixation.

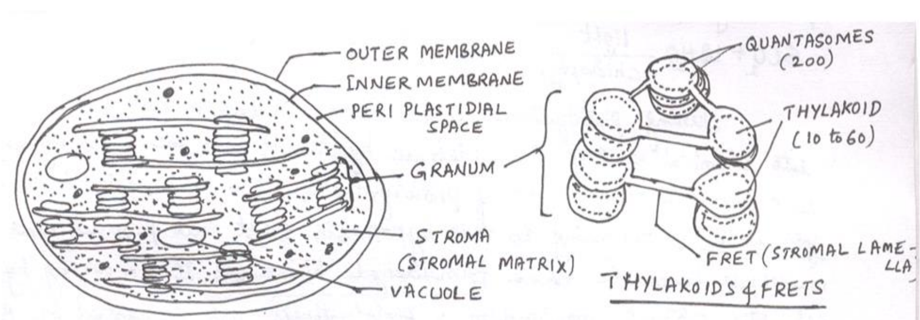

Fig: Structure of chloroplast

STRUCTURE OF CHLOROPLAST: "The disc-like structures with double membrane and arranged one above the other in the form of a stack is called Thylakoids" (Lamellae). "A stack of thylakoids is called a granum". (Thylakoids are organised into bodies called grana). "The thylakoids of granum are interconnected by tubular connections called frets" (intergranal membrane).

"The granum contains number of photosynthetic units called quantasomes". Each granum is made up of 10 to 60 thylakoids. Each thylakoid contains 200 quantasomes. Thylakoids are involved in photochemical reactions.

Quantasomes are the functional units (photosynthetic units) made up of a group of pigment molecules required for carrying out photochemical reactions. Chlorophyll pigments are found in the quantasomes. The chloroplast gives the green colour to the plant and helps to absorb or capture the radient energy from the Sun and it is converted into Chemical energy during photosynthesis.

Photosynthetic pigments: "Photosynthetic pigments are very sensitive to light. They absorb radient energy from sun and convert it into chemical energy".

[**LHCs----Light Harvesting Complex)**

Photosystem: The photosynthetic pigments like chlorophylls and carotenoids are arranged on the thylakoid membranes as the functional units or sets. These are called photosystems or pigment systems (PS). The existence of photosystems was suggested by R.Emerson in 1957. A photosystem can absorb all wave-lengths of light within the visible spectrum and especially between 400-500 and 600-700 nm ranges.

FUNCTIONS:-

1. Chloroplasts contain chlorophyll which helps in photosynthesis.
2. Chromoplasts posses colored pigment for coloration in flowers and fruits.
3. Leucoplasts are colorless and help in the storage of food in the form of starch.

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RIBOSOMES

INTRODUCTION: Ribosomes are the small dense granular and spherical structure. The ribosomes were first discovered by Palade in animal cells (1955). In plant cells ribosomes were first discovered by Robinson and Brown in Beans roots (1953).

OCCURENCE: Ribosomes occurs in both prokaryotic and eukaryotic cells. Ribosomes are distributed freely in the cytoplasmic matrix of cell or found attached on the E.R and nuclear membrane. These are also found in the mitochondrial matrix and chloroplast.

TYPES OF RIBOSOMES: According to their size and sedimentation coefficient (s), two types of ribosomes are recognized, such as follows.

1. 70 S Ribosomes – 50 S + 30 S unit
2. 80 S Ribosomes – 60 S + 40 S unit

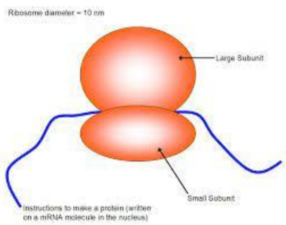
   (S=Svedberg unit)- It is the sedimentation coefficient which indicates how fast a cell organelle sediments in an ultracentrifuge.

NUMBER: Number of ribosomes also varies from one cell to another cell. Bacterial cell contains 10,000 ribosomes. Eukaryotic cell contains 1 to 10 million ribosomes.

ULTRA STRUCTURE OF RIBOSOMES: Ribosomes are small dense spherical granules found in the cytoplasm or on the surface of RER. During protein synthesis many ribosomes aggregate to form polyribosomes and remain attached on m-RNA molecule.

FUNCTIONS:

1. Ribosomes are the sites of protein synthesis hence they are called protein factories.
2. They provide the necessary space and the enzymes required for protein synthesis.
3. During protein synthesis, the m-RNA molecule binds to a ribosome to form m-RNA-ribosome complex. (Where the protein synthesis takes place).



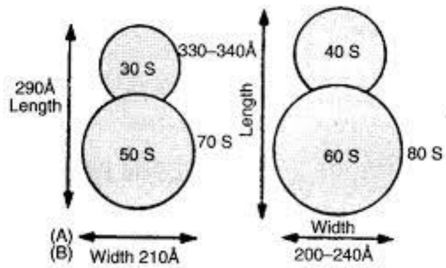
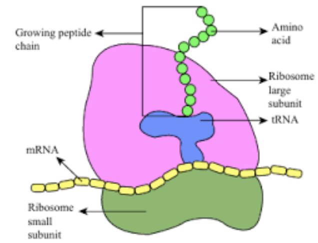
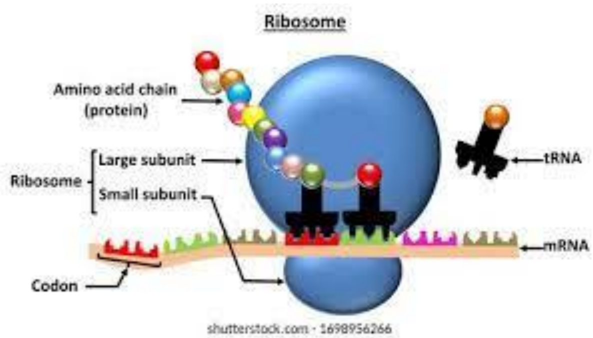
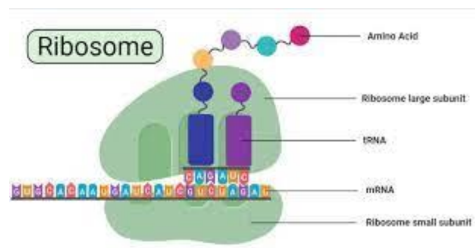


Fig. Ribosomes : (A) Prokaryotic, (B) Eukaryotic







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CENTRIOLES

INTRODUCTION: Centrosome is a cell organelle concerned with cell division. It is also known as **cell centre**. It was discovered by **Van Beneden** in 1887.

Occurence: Centrosomes are found in all eukaryotic animal cells and in the cells of some lower plants like algae, fungi, bryophytes, ferns and gymnosperms. They are absent in higher plants (angiosperms), prokaryotes, diatoms and yeast. Amoeba also does not contain centrosome.

The centrosome is located in the centre of the cell near nucleus in the cytoplasm. In metazoan it lies outside the nucleus, but in protozoa it lies inside the nucleus.

ULTRA STRUCTURE OF CENTRIOLES: The centrosome is cylindrical in shape. It measures about o.15 to 0.25 micron in diameter and 0.3 to 2.0 micron in length.

The centrosome consists of two components, namely centrosphere and centrioles. The dense area of the cytoplasm present around the centrioles is called centrosphere. Each centrosome contains one or two darkly staining granules called **centrioles**. (Each centrosome has two cylindrical components called centrioles). The interphase cell contains only one centriole. But when cell division begins the centriole divides into two.

Each centriole is in the form of a cylinder opening at one or both ends. These two centioles are arranged at **right angles** to each other and they are bound by amorphous region. The wall of each centriole is formed of nine triplet microtubules. Each triplet is formed of three microtubules. They are named as A, B and C from the inner side.. The triplets are arranged like the vanes of a pin wheel. The triplets remain lightly tilted.

A microtubule of one triplet is connected to the C microtubule of another triplet by a dense material called linker. The A-C linkers cause the tilt of the triplets. The proximal end of the centriole has a cart wheel structure. It consists if a central rod or hub and nine spokes. Each spoke is connected to the A microtubule of the triplet.

Near the outer end of each spoke, there is a thickening called X. There is another thickening called Y located between the X thickenings. The Y thickening is connected with the X thickenings and linkers.

The microtubules of centriole are formed of three important chemical substances, namely, tubulin (protein), Lipid and ATPase enzyme.

FUNCTIONS:-Centriole has the following functions:

1. Centrosomes play an important role in the **initiation of *c*ell division** in animals.
2. The centrioles help in the formation of **spindle fibres** during cell division.
3. In spermatozoan, the distal centriole develops into the axial filament of flagellum.
4. During cell division centrioles of centrosome establish **polarity in animal cell.**
5. Modified centrioles are involved in the formation of locomotory organelles such as **cilia** and **flagella**. (The basal bodies of cilia and flagella develop from the centrioles).

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Module-II

MITOCHONDRIA(Gr.mito=thread, chondrion=granule)

INTRODUCTION: The mitochondria are thread-like granular cytoplasmic organelles. They contain many enzymes and coenzyme which are responsible for energy metabolism hence, mitochondria are also known as **power houses** or **chondriosomes** of the cells.
The mitochondria were first discovered by **Flemming and Kolliker** in 1882.The term mitochondrion was coined by **Benda** in 1898.

OCCURENCE: Mitochondria are absent in prokaryotic cells and found in all eukaryotic cells like both plant and animal cells.

ULTRA STRUCTURE OF MITOCHINDRIA:

Shape: Mitochondria may be filamentous or granular, rod-shaped, club shaped, ring shaped, rounded, saucer in shape.

Size: The Size of the mitochondria is variable. The length of the mitochondria varies from 3 to 10 microns and their width from 0.2 to 1.0 micron. The smallest mitochondrion is seen in yeast. The largest mitochondria are found in the oocytes of Amphibians.

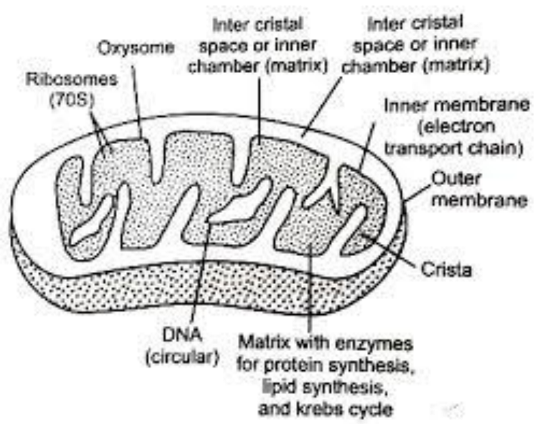
Number: The number of the mitochondria are also varies from one species to another species and cell to cell depending upon the metabolic activity of the cell. They occur in large number in where the cell requires great amount of energy. **Ex:** Abundant number of mitochondria in Liver and kidney cells. Usually the plant cells have lesser number of mitochondria than in animal cells. The giant Amoeba (Choas choas) contain 50,000 mitochondria whereas the Sea urchin's egg contain 1,40,000 to 1,50,000 mitochondria. The mitochondria are generally distributed throughout the cytoplasm of the cell.

Structure: The mitochondria are covered by the double layered membranes, namely, an outer and inner mitochondrial membranes. Outer membrane is smooth where as inner membrane is folded. Each membrane measuring about $60A^0$ in thickness. The space between the outer and inner mitochondrial membrane is called mitochondrial space measuring about 80 to $100A^0$.

Mitochondria is filled with a fluid called mitochondrial matrix. Inner mitochondrial membrane is provided with numerous finger-like projections called cristae. Surface of the cristae contains electron transfer particles (ETP) called elementary particles or F_1 particles or Racker's particles oxysomes. Each particle consists of a base piece, a stem, and a head. They are regularly arranged at a distance of $100A^0$. Matrix contain protein, lipid, RNA, phospholipids, cholesterol, sulphur, copper, vitamins, more than 70 enzymes and coenzymes. Mitochondria contain one or more DNA called mitochondrial DNA. It is circular in shape.

FUNCTIONS:-

1. Mitochondria provide energy needed for the various activities of the cell, hence the mitochondria are also known as "**power house of the cell".**
2. It helps in the **synthesis of proteins and lipids.**
3. It helps in the **synthesis of steroid hormones**. i.e conversion of cholesterol to steroid hormones in the adrenal cortex are catalyzed by the mitochondrial enzymes.
4. They store ATP molecules which are popularly known as **energy currencies** of the cell**.**
5. Mitochondria are the **respiratory centers of the cell**. During oxidation the food stuffs like carbohydrates, fats and proteins are breakdown into CO_2 and H_2O and release the energy in the form of ATP molecules. Hence the mitochondria are also regarded as **power house** of the cell.
6. It helps in the **accumulation of calcium.**
7. **Conversion of Ornithine to citruline** in mitochondria during **urea cycle.**



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NUCLEUS

INTRODUCTION: Nucleus controls all the vital activities of the cell. First it was discovered by Robert Brown in Orchid cell in the year 1871.

Occurence: It is found in all the eukaryotic cells but absent in prokaryotic cells. Usually it is located at the centre of the cell.

ULTRA STRUCTURE OF NUCLEUS: Nucleus is an important component in the cell. It is bounded by double membrane. i.e It is surrounded by outer and inner nuclear membrane(nuclear envelope). The space is present in between outer and inner nuclear membrane called peri nuclear space.

Number: The number of nucleus is also varies from one cell to another. Generally each cell contain a single nucleus, when they are uni nucleated cell. When the cell is made up of two nuclei called bi nucleated cell. If it is made up of more than two nuclei it is said to be multi nucleated cells.

Size: Size of the nucleus is also varies i.e smallest size in mycelia (fungi), largest in oocyte cell.

Shape: Usually the shape of the nucleus is spherical in structure but kidney shaped in Paramecium, Horse-shoe shaped in Vorticella.

The nucleus is composed of four components, namely

1. Nuclear membrane
2. Nucleoplasm
3. Chromatin network
4. Nucleolus

Nuclear membrane: The nucleus is surrounded by double layered membrane called an outer and an inner nuclear membranes measuring about $90A^0$ thickness. The space is present between an outer and an inner nuclear membrane called peri nuclear space. It measures about $100A^0$ to $700A^0$ wide. The nuclear membrane is provided with numerous pores called nuclear pores. The nucleus is connecting plasma membrane through E.R Through nuclear pores and E.R it communicate with plasma membrane.

Nucleoplasm: The nuclear membrane is enclosed by the fluid called nucleoplasm. It provides the space for enzymes, nucleic acids (DNA & RNA), proteins and minerals.

Chromatin network:-It is elongated thread like structure and arranged in the form of network like structure. It carries hereditary materials from one generation to other.

Nucleolus: It is a small dense granular and spherical structure present in the nucleus. It was discovered by Fontana in 1874. It is composed of ribosomal RNA, proteins and some enzymes. Nucleolus if the active sites of RNA synthesis. The nucleolus is the biogenesis of ribosomes.

FUNCTIONS:

1. Nucleus controls all the activities of the cell. Hence it is also known as master molecule.
2. It helps in the metabolic activities of the cell.
3. The nuclear membrane allows free exchange of ions between the nucleus and the cytoplasm.
4. Through the nuclear pore an exchange of macromolecules between cytoplasm and nucleus (nucleo-cytoplasmic exchange)
5. Nucleus contains DNA, which acts as a genetic material plays an important roe in inheritance and gene expression.

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CHROMOSOMES (Gr.Chroma = colour; soma = body)

Introduction: **Robert Brown** (1831) discovered nucleus. Hof meister observed darkly stained bodies in pollen mother cells of Tradescantia. Fleming identified (1882) the involvement of the darkly stained bodies in cell division. The term chromosome was coined by **Waldayer** in 1888. Morghan showed the importance of chromosomes in living organisms. The chromosomes are clearly visible in during metaphase of cell division. The chromosomes are stained with haematoxylin, accetocarmine, acetorcein or feulgen. The genes found in chromosomes plays an important role in heredity, mutation, variation and evolution,. Hence, the chromosomes are regarded as "**vehicles of heredity**".

Definition: "The microscopic thread-like structure found in the nucleus of a cell is called chromosomes". (Chromosomes are the nuclear components with a specific organization, individuality and function with the capacity of self duplication or replication).

Size: The size of the chromosomes is measures in terms of micrometers. Average length of the chromosomes varies from 0.5 to 30 µm. The diameter varies from 0.2 µm to 3.0 µm. The chromosomes of the plants are generally larger than chromosomes of animals.

Chromosome number:

Number of chromosomes are varies from species to species. The number of chromosomes for a given species is constant. Every species has a basic set of chromosomes in its gamete; it is called the haploid set (n). The number of chromosomes in haploid set for a species is constant. The diploid number of chromosome is represented as 2n.

Sl.No.	Name of plant	Haploid (n)	Diploid (2n)
1	*Aluminum cepa*	8	16
2	*Raphanous sativus*	9	18
3	*Oryza sativa*	12	24
4	*Pisum sativum*	7	14

Sl.No.	Name of Animal	Haploid (n)	Diploid (2n)
1	*Homo sapiens*	23	46
2	*Ascaris*	1	2
3	*Rana pipiens*	13	26
4	*Dog*	39	78
5	*Drosophila* (fruit fly)	4	8
6	*Gorilla*	24	48

Genome:

The total number of genes present in haploid set of chromosomes constitutes a genome. When male and female gamete of a species fused, a **diploid zygote** is formed. It consists of two haploid sets of chromosomes one set of chromosomes comes from the maternal side (egg) and other from the paternal side (sperm).

Structure of metaphase chromosome (Chromosome morphology):

Under the electron microscope, metaphase chromosome morphology reveals the following structures (number, structure, shape and types of chromosomes).

Chromatid (sister chromatids):

1. Each chromosome is made up of a pair of elongated, cylindrical identical structures called chromatids or sister chromatids.
2. The chromatids are produced by the replication of a single chromosome (So identical in structure).
3. The metaphase chromosome has two chromatids which are cylindrical or rod shaped, parallel to one another and held at a point called the centromere.

Centromere:

1. The two identical chromatids are held together by a single rounded body called centromere. (Centromere is the point at which both the two identical chromatids are found attached with each other).

Primary constriction:

1. A small constriction is found on each chromatid is called primary constriction.
2. Sometimes primary constriction is also known as Centromere.

Kinetochore:

1. The centromere of each chromosome is associated with protein complex called kinetochore.
2. Kinetochore provides the space (site) for the attachment of spindle fibre during cell division.

Secondary constriction:

1. A secondary construction is another narrow region on a chromosome.
2. It occupies a definite position. It is not found in all chromosomes.
3. Secondary constriction is associated with nucleolus, hence it is also known neither as NOR (Nucleolar organizing region).

Satellite (Trabant):

1. The terminal end of the chromosome extending beyond the secondary constriction is called satellite". It may be round or elongated.
2. The chromosomes with satellite called sat-chromosomes.

> **SAT – Chromosomes:** These are chromosomes with a rounded or elongated structure beyond the secondary constriction is called satellite. SAT stands for Sine Acido Thymidire i.e., region without Thymidilic acid which means without DNA in the satellite

Telomere:

1. The telomere is present at the tip of the chromosome and avoids or prevents the fusion of terminal ends of chromosomes. (The blunt tips of a chromosome are called telomeres).
2. It is necessary for the proper replication of chromosomes.

Chromonema (Chromatin fibre):

1. The main thread-like structure of the chromosome is called chromonema.
2. It is made up of nucleoproteins capable of coiling and uncoiling.
3. Each chromatid is made up of a single chromonema.
4. It is composed of necleic acid and DNA combines with proteins.
5. Nucleosomes are the structural units of chromatin fibre.

6. At certain regions the chromosome is tightly coiled less active and takes up more stain. It represents the heterochromatin regions.
7. At certain other regions the chromonema is loosely coiled, highly active and takes up less stain. It represents ecuhromatin regions.

Chromomeres:

1. The region of chromonema appears as beaded like structures called chromomeres.
2. The coiling results in the formation of many beaded structures called chromomeres.

Chromatin:

1. The stainable material of the chromosome is called chromatin.
2. “The condensed (highly coiled) and deeply stained state of the chromatin is called hetero chromatin”.
3. The diffuse (lightly coiled and stained) state of the chromatin is called Euchromatin”.

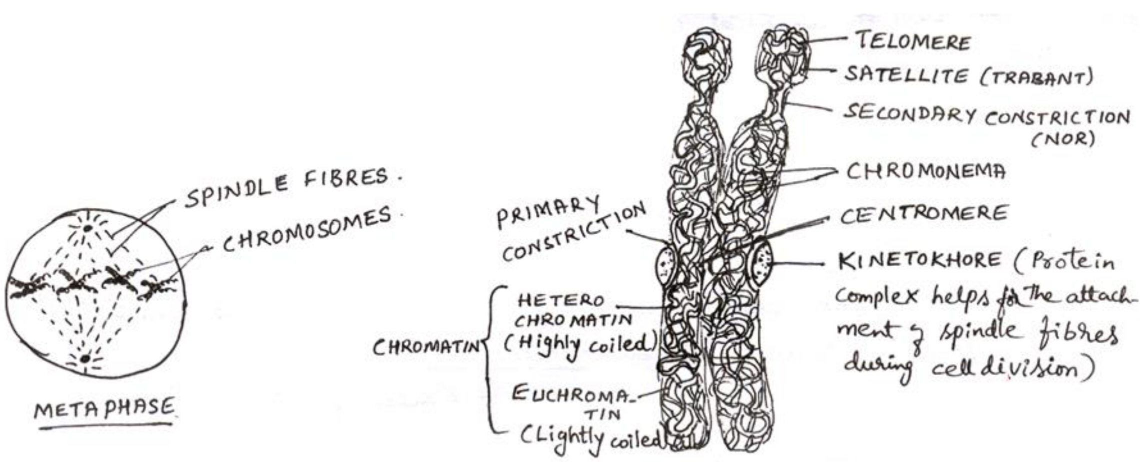


Fig: Metaphase chromosome.

Differences between heterochromatin and Euchromatin

Sl.No	Heterochromatin		Euchromatin

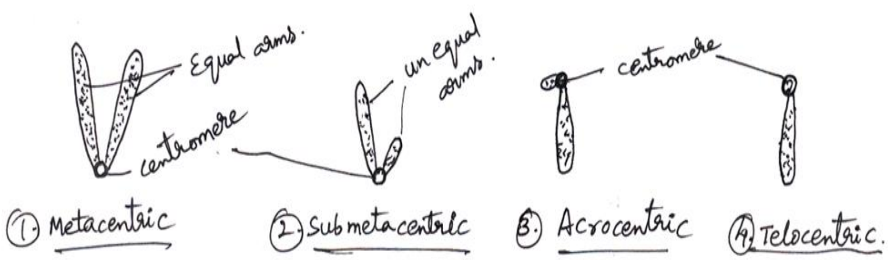
1	The condensed state of chromatin called heterochromatin.	1	The diffuse state of the chromatin is called Euchromatin.
2	Stains deeply	2	Stains lightly
3	They represent tightly coiled regions	3	They represents lightly (Diffuse) coiled regions.
4	Replicate late	4	Replicate early.
5	Relatively inactive	5	Relatively active

Classification of chromosomes based on the position of Centromere:

Based on their position of centromere, the chromosomes are classified into 4 types such as follows:

1. **Metacentric chromosome:** The metacentric chromosomes assume V-shaped during anaphase. The centromere is present at the centre leads to form two equal arms.
   Ex: Amphibians, Trillium and Tradescantia
2. **Submetacentric chromosome:** It is L or J - shaped structure. The centromere is located near the centre or slightly away from the median position of chromosome leads to form two unequal arms.
   Ex: Human beings

3. **Acrocentric chromosome:** Assumes 'j' shape during anaphase. The centromere is located at one end thus giving a very long arm Short arm.
   Ex: Grass hoppers
4. **Telocentric chromosome:** It assumes rod shape during anaphase. The centromere is located at the tip of the chromosome. Chromosome will have only one arm.
   Ex: Protozoans



Based on the number of centromere: On the basis of the number of centromere, the chromosomes are classified into the following types.

Monocentric: Chromosome with one centromere is called monocentric chromosome.

Dicentric: Chromosome with two centromeres is called dicentric chromosome.

Tricentric: Chromosome with three centromeres is called tricentric chromosome.

Polycentric: Chromosome with many centromeres is called polycentric chromosome.

Acentric : Chromosome without centromere is called acentric chromosome.

Kinds of chromosomes:

Mainly there are two types of chromosomes. Such as follows.

1. **Autosomes: (Somatic or Body chromosomes):**
"The chromosomes, which are responsible for controlling the body characters and are not involved in the determination of sex is called autosomes."

Autosomes are concerned with the growth of an organism and genes which are situated on autosomes determine the body characters. There are 44 Autosomes in human beings (44A)

2. **Allosomes:(Sex chromosomes):** Chromosomes other than autosomes are called allosomes. These chromosomes are responsible for the determination of sexes, either male or female.

Allosomes are the sex chromosomes. These decide the sex of individuals. There are two sex chromosomes designated as X and Y. The females will have two X chromosomes where as males will have one X and one Y chromosome.

i.e, XX in Woman and XY in Man

Ex: Homo sapiens will have $2n = 46$, the chromosome complement of man is represented as 44A + XY and that female are represented as 44A + XX. Female gametes are produced during **Oogenesis** (Process of the formation and maturation of eggs called oogenesis) will have 22A + X hence only one type of eggs are produced. This is called **homogametic condition.**

During **Spermatogenesis** (Process of the formation and maturation of sperms called spermatogenesis), males produce haploid sperms of two different chromosomal complements namely 22A + X and 22A + Y. This is called **Heterogametic**.

Karyotype: The study of number, shape, size of metaphase chromosome. **It** is the set of chromosomes contained in the nucleus of a species it reveals the number, size, shape and type of chromosome. This karyotype is prepared by observing metaphase chromosome.

Idiogram: The graphic representation of chromosomes emphasizing all the features of a karyotype is called the idiogram.(The diagrammatic representation of karyotype is called the ideogram). In this the homologous pairs of chromosomes are arranged in the order of decreasing length.

Functions of chromosomes:

1. Chromosomes are the **vehicles of heredity**, because they carry hereditary information from one generation to next generation.
2. Autosomes determine body characters and allosomes determine the sex of an individual.
3. Chromosomes control all cellular functions.
4. Chromosomes help in protein synthesis.
5. Change in the chromosome number and genes lead to the development of new species.

CELL CYCLE AND CELL DIVISION

Concept of cell cycle : The sequence of events that occurs between the formation of cell and its division into daughter cells is called cell cycle. **"The series of changes that takes place in a newly formed cell which involve in growth and division to form two daughter cells is called cell cycle".** It consists of two stages, a non dividing growing interphase or I phase and a short dividing mitotic or M - phase.

Cell Cycle: "A series of events that prepares a growing cell to divide its components equally between two daughter cells is called cell cycle". [The term "Cycle" refers to the renewal or return to an initial state].

1.Interphase (L. inter - between, Gr. Phasis - aspect): Biochemical activities occur in this stage. It was formerly known as 'resting stage or preparatory phase '. The period between two mitotic divisions is called interphase. It was once known as resting stage or preparatory phase. But, in fact it is a period of great activity. Interphase lasts for 10 - 20 hours. It is further divisible into three stages namely G1 phase, S phase and G2 phase.

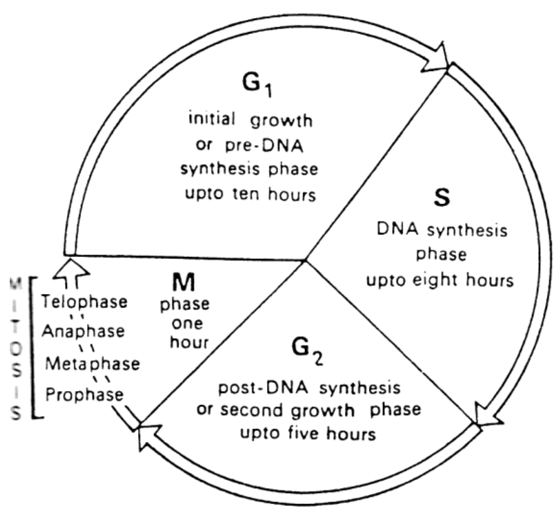


Fig. B2.23 Diagrmmatic representation of cell cycle showing different stages of mitosis in an animal cell.

G_1 phase: It is the post mitotic phase and takes place at the end of cell division. The newly formed cells accumulate the chemical energy and prepare themselves for the synthesis of DNA. Synthesis of RNA & Protein takes place.

S phase (synthetic period)**:** It is the synthesis phase. During this phase, duplication or replication of DNA and centriole takes place. The duplication of DNA results in the duplication of chromosomes.

G2 phase: It is the pre mitotic gap phase. The synthesis of RNA and protein continues in this phase. Formation of macromolecules for spindle formation and the cell prepares itself to go into the mitotic phase. Here, synthesis of energy - rich compounds that provide energy for mitosis also takes place.

Sequence of phases: $G_1 \rightarrow S \rightarrow G_2$

2. Mitotic phase (M- phase): M - phase follows the interphase and represents the last phase of actual division. This phase lasts for a short period when compared to interphase. During this phase two important processes takes place simultaneously i.e Karyokinesis and cytokinesis. Karyokinesis results in the separation of chromosomes into two equal groups and cytokinesis results in division of cytoplasmic components into approximately two halves. After M-phase, a cell may either enter interphase to repeat the cell cycle or G_0 - phase to arrest the cell cycle. The cells in G_0- phase may grown in size and get differentiated.

CELL DIVISION & TYPES

1) Mitosis or indirect cell division or equational cell division.

2) Meiosis or reductional division.

CELL DIVISION AND TYPES

Cell Division: "The process by which a cell divides into daughter cells is called cell division". The cell division actually consists of two separate process i.e. karyokinesis and cytokinesis.

- **A.** **KARYOKINESIS:** (Gr. Karyon = nucleus) "The division of the cell nucleus into daughter nuclei is called karyokinesis".
- **B.** **CYTOKINESIS:** (Gr. Kytos = cell) "The division of cytoplasm is called cytokinesis"

Types of cell division: There are two types of cell divisions namely, mitosis and meiosis.

1) MITOSIS (Indirect cell division):

Mitosis was first observed by **Strasburger** in 1875 in plant cells and later **W. Fleming** described the mitosis in animal cells in the year 1879. The term mitosis was coined by Fleming in 1882.

Definition: *"The process of the formation of two daughter cells from one parent cell in which daughter cells are similar to that of parental cell in all respects. i.e. same number of chromosomes, genes and same amount of cytoplasm is called mitosis".*

OR

"Mitosis is a cell division in which replicated chromosomes are distributed to the daughter cells in such a way that they come to have exactly the same number of chromosomes as the parent cell".

OR

Mitosis has been defined as a type of cell division which ensures the constancy of chromosome number and equal distribution of genetic material to the successive generations of cells. Therefore it is also called **equational division**.

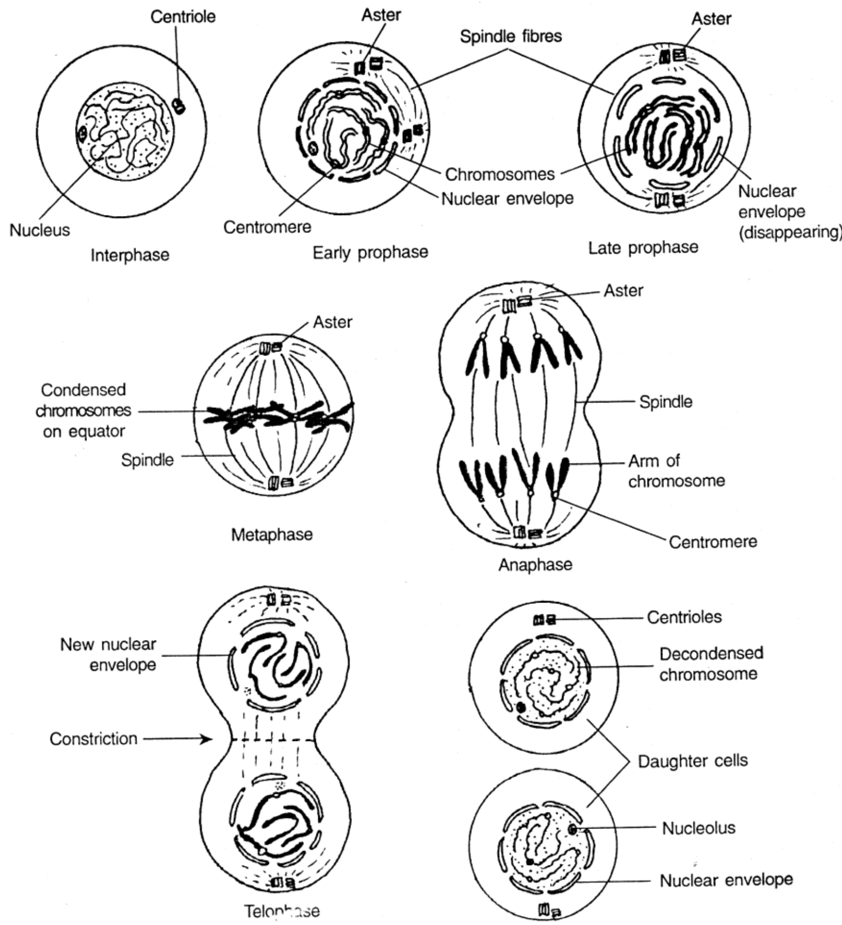
Occurrence: Mitosis occurrence in somatic cells or Body cells. Therefore it is also known as somatic cell division. In plants mitosis occurs in meristematic tissues of roots and tip of the stem.

Mitosis includes two divisions namely, Karyokinesis and Cytokinesis.

A. **Karyokinesis:** "The division of nucleus is called Karyokinesis". *It* is somewhat elaborate period when compared to cytokinesis. Division of cytoplasm is called cytokinesis. There are four stages (phases) in mitosis. Namely, Prophase, Metaphase, Anaphase and telophase.

1. **PROPHASE :**

- Prophase is the first stage of mitosis.
- It begins as soon as the interphase is over.
- Condensation of chromosomes. i.e The long, thin, thread-like chromosomes becomes coiled or folded to become shorter and thicker. This process is called Condensation.
- Each chromosome is made up of **two chromatids** (threads) attached to the centromere.
- Already duplicated centrioles move towards the opposite poles and form asters.
- Chromosomes move towards nuclear membrane
- Disappearance (disintegrate) of nucleolus and nuclear membrane.



Telophase

Different stages of mitosis in an animal cell

2. **METAPHASE :**

- Metaphase is the second stage of mitosis.
- The chromosomes are highly condensed, thick and short.
- The chromosomes are arranged in an equatorial plate or line.
- Chromosomes attached to the spindle fibres with the help of centromere.
- The arms of the chromosomes oscillate freely.

3. **ANAPHASE :**

- Anaphase is the third stage involved in the mitosis.
- The two chromatids of each chromosome separate completely to become daughter chromosomes.
- Centromere of chromosomes breaks down by the pulling or dragging of spindle fibres.
- The daughter chromosomes move towards the opposite poles (The two daughter chromosomes move away from the equator to the opposite poles).
- The movement of chromosome is by the contraction of spindle fibres.

- Depending upon their position of centromere the chromosomes appear as V, J or Rod - shaped structure.

4. **TELOPHASE :**

- Telophase is the last stage involved in the mitosis.
- The daughter chromosomes arrive or reach at the opposite poles where they become thread like again and forms chromatin network.(The daughter chromosomes arrive or reach at the poles).
- The spindle fibres disintegrate and disappear.
- Reappearance of nucleolus and nuclear membrane.
- End of the telophase, formation of two daughter nuclei.

B. **CYTOKINESIS :**

The division of cytoplasm is called cytokinesis. A furrow develops in the middle of the cell. It deepens till the cytoplasm is divided into two equal parts. It thus forms two daughter cells.

- Cytokinesis begins in late anaphase.
- In animal cells, formation of cleavage or furrow.
- Constriction develops in the middle of the cell.
- When the constriction deepens the cell becomes dumb-bell shaped.
- Formation of two daughter cells.

Differences between plant cell and Animal cell

Sl.No.	Plant cell	Animal cell
1.	Centrioles are absent & hence no asters are formed.	Centrioles are present, and they produce asters.
2	A cell plate is formed.	No cell plate is produced
3	No constriction of the cell during cytokinesis.	Cytokinesis occurs by furrowing or constriction of the cell.
4	It occurs in the undifferentiated or meristematic tissues	Mitosis occurs in tissues of animal cell.

Significance of mitosis:

1. Mitosis maintains the constant chromosome number.
2. Chromosomes carry the hereditary units or genes from parents to offsprings.
3. In unicellular organisms (Ex: Amoeba, Euglena), mitosis results in the formation of new offspring. Here mitosis is a method of reproduction.
4. In multicellular organisms (Ex: Man, Fishes, Frog, Snakes, Birds etc.,) mitosis helps in growth and development.
5. Mitosis also helps in replacement of damaged and dead cells (It produces new cells for the healing of wounds and for regeneration).
6. For instance in man, cell replacement is necessary in skin, hairs, and nails and in blood.
7. It plays an important role in tissue culture.

MEIOSIS (Gr. Meiom = to reduce; to make smaller)

INTRODUCTION: Meiosis was discovered by **J.B. Farmer** and **Moore** in 1905. The term meiosis was coined by Former and Moore. Meiosis occurs during gamete formation in the gonads (Germ cells or organs). In this case the chromosomal number is reduced to half in daughter cells. Hence it is also called reduction division.

It involves production of gametes. Meiosis takes place only in diploid germinal tissues. These are found in gonads. The male gonads are called testes and the female gonads are called the ovaries. They produce haploid gametes i.e the sperm and the ovum

Meiosis is a continuous process which includes two complete divisions resulting in the formation of four haploid cells.

Definition: "The process by which formation of four daughter cells from one parent cell, in which the daughter cells receive only half of the chromosomes from the parent cell" is called meiosis.

OR

Meiosis is defined as "the cell division occurring in diploid cells (germ cells), in which the daughter cells receive only haploid number of chromosomes".

Meiosis undergoes two divisions. Such as follows;

1) First meiotic division (Meiosis I)
2) Second meiotic division (Meiosis II)

MEIOSIS -I : (Heterotypic, reductional division): During this process the diploid parent cell divided into two daughter cells which are haploid.

KARYOKINESIS-I: Karyokinesis of Meiosis-I includes four stages namely, prophase-I, Metaphase-I, Anaphase-I and telophase -I.

PROPHASE-I: It is the longest stage in meiosis and important events occur during this stage. The prophase - I is divided into five sub stages, namely Leptotene, Zygotene, Pachytene, Diplotene and Diakinesis.

1. **Leptotene** (Leptonema) **:** (Gr. Leptos=thin thread):

- It is the first stage in the prophase I of meiosis I.
- The chromosomes are elongated, thin, thread like structures and uncoiled.
- Each chromosome appears as a **string of beads**.
- The chromosomes are double stranded but indistinct **looks** like a single stranded structure.
- Each chromosome consists of two chromatids.
- The chromosomes are aggregated in one end of the nucleus forming a bouquet (**bouquet stage).**
- The centrioles repel to form asters and move towards opposite poles.

2. **Zygotene** (Zygonema) **:** (G. Zygon = adjoining):

- It is the second stage in the prophase I of I meiotic division.
- Pairing of homologous (paternal and maternal) chromosomes.(The process of pairing of homologous chromosomes is called **Synapsis**).
- **Condensation of chromosomes**. As a result the chromosomes shorter and thicker.
- Each paired homologous chromosomes are called bivalent. Since each paired chromosome bears of two chromotids.
- A bivalent is made up of four chromatids hence it is therefore called a **tetrad.**
- The number of bivalent is always equal to the haploid number of chromosomes.
- The two chromatids of same chromosome are called sister chromatids and those belonging to different chromosomes of a homologous pair are termed as non-sister chromatids.

3. **Pachytene**(Pachynema) : (Gr. Pachus = thick):

- This is the third stage in the prophase I of meiosis.
- **Synopsis is completed** during this stage. Chromosomes become thick and short.
- Due to the continuous condensation (gets coiled) of chromosomes becomes shorter & thicker and distinct.
- **Crossing over** (genetic recombination) occurs during this stage. [Mutual exchange of hereditary material of the two parents between the two homologous chromosomes]
- Due to the crossing over it appears **X – shaped** structure called **chiasmata** (cross piece).
- Each bivalent consists of four strands therefore it is referred to as tetrad stage.

- A mutual exchange of chromosomal material between the non-sister chromatids of homologous chromosomes takes place. This genetic exchange is called crossing over. It is an exchange of DNA segments. It results in recombination of genes.
- Breakage and reunion of chromatid segments assisted by enzymes like endonucleases, polymerases and ligases.
- The points of interchange are 'x' shaped and are called **chiasmata.**

4. **Diplotene** (Diplonema) **:** (Diplo = Double) :

- The chromosomes repel from one another due to force of attraction.
- Since the chromosomes are still held at the chiasmata (X-shape, 8 –Shpaed, O–Shaped). Because of repulsion, the chiasmata are shifted towards the ends of the bivalent & this process is called terminalization. (**Terminalization of chromosomes**)
- Attraction between homologous chromosomes disappears.
- Repulsion between homologous chromosomes begins.
- Repulsion results in terminalisation of chiasmata.
- Formation of asters and spindle fibres.

5. **Diakinesis** : (Gr. Dia= across ; Kinesis = movement):

- This is the last stage in prophase I of meiosis I.
- The chromosomes become **shorter thicker** (to their maximum).
- Disappearance (disintegration) of nuclear envelope & nucleolus.
- Formation of asters and spindle fibres.
- The chromosomes are released into the cytoplasm and contact with spindle fibres. **The chiasmata disappear.**
- **Terminalization is completed** at this stage.

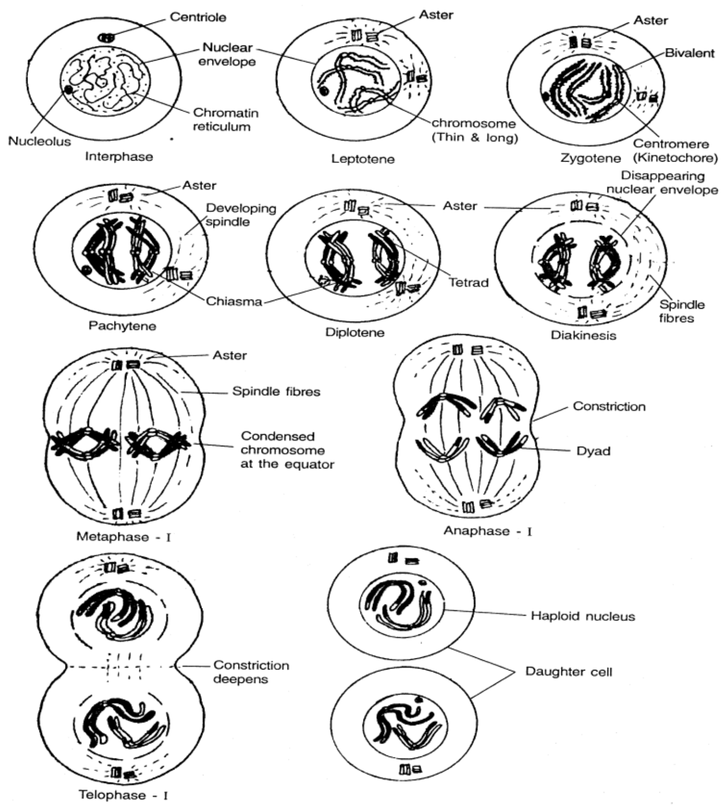
METAPHASE - I :

- Orientation (Arrangement) of chromosomes in an equatorial plane.
- Spindle fibres attached to the centromeres of each chromosome.
- The centromere lies towards the poles and arms present towards the equator (This type of arrangement is very Important; it ensures the reduction of chromosome number).
- Centrioles form asters at two poles.

ANAPHASE - I :

- Each homologous chromosome with two chromatids moves towards opposite poles.
- Spindle fibres contracts and bivalent chromosomes moves towards the opposite poles.

- The separated chromosomes are called dyads because each of them consists of chromatids.
- The homologous pair of chromosomes more towards the opposite poles.
- At the end of anaphase I two groups of chromosomes are produced with each group having half the number of chromosomes present in the parent cell.



Different stages of Meiosis I in an animal cell.

TELOPHASE - I:

- The haploid (n) chromosomes reach the opposite pole and become long, thread like & uncoiled.
- Nuclear envelope is formed around each group of chromosome. The nucleolus does not reappear and to form two daughter cells.

CYTOKINESIS- I:

- It occurs by furrowing in animal cells and by cell plate formation in plant cells.
- In many plant cells cytokines does not occur and the haploid cells directly pass into meiosis II.

INTERPHASE- II:

This is an interval between the first and second meiotic division. It differs from interphase - I in the fact that the chromosomes (DNA) do not replicate.

MEIOSIS II (Second meiotic division):

It occurs soon after the first, There is no further duplication of chromosomes. and the events of meiosis II resemble (similar) those of mitosis. Two daughter cells divide into four daughter cells. It consists of following stages.

KARYOKINESIS - II

PROPHASE II:

- Again the chromosomes becomes condensed(condensed) .
- Formation of centrioles and spindle fibres.
- Disappearance of nuclear envelope and nucleolus.

METAPHASE II:

- The chromosomes are arranged on **equatorial line** with the help of spindle fibres.
- The two chromatids of each chromosome got separated by division of centromere.

ANAPHASE II:

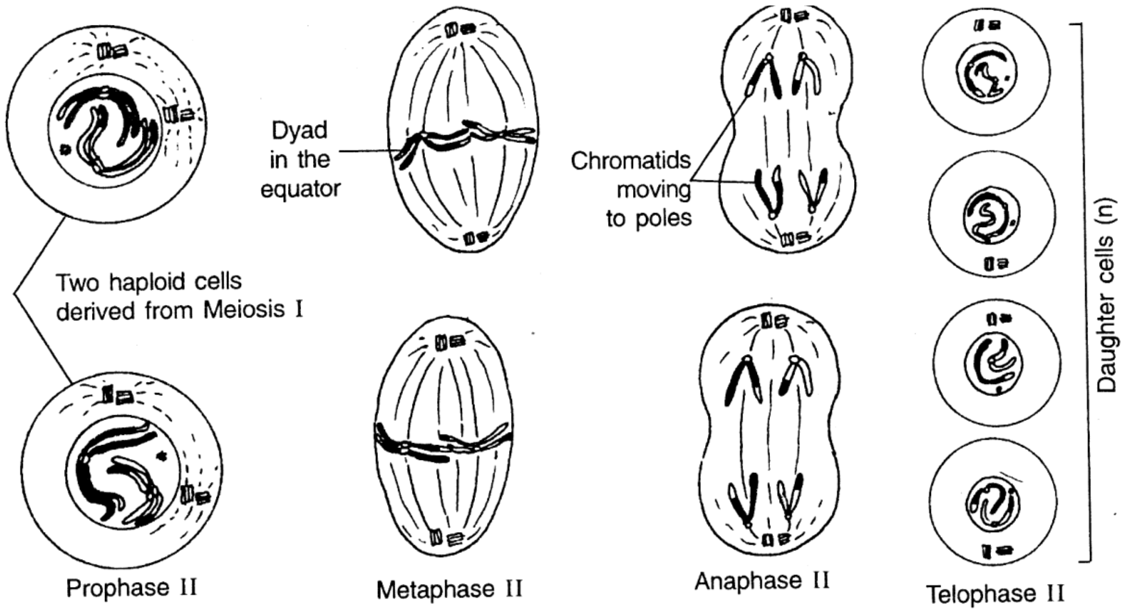
- Centromeres split and the chromatids separate into sister chromosomes.
- The sister chromosomes are then pulled towards the opposite poles.
- The separated chromatids become daughter chromatids and move towards the opposite poles. (Each may now be called chromosome)

TELOPHASE II:

- The two groups of chromosomes uncoil and become thread like.
- Again nuclear membrane and nucleolus reappears.
- Disappearance of spindle fibres.

CYTOKINESIS II:

- The division of cytoplasm occurs; it results in the formation of four haploid daughter cells.
- The number of chromosomes is the same as produced by meiosis I. Hence meiosis II is called homotypic division.



Stages of Meiosis II

Significance of meiosis:

1. Meiosis is responsible for the formation of haploid gametes.
2. It helps to maintain constant number of chromosomal number in each and every species.
3. It results in crossing over and recombination of genes. This brings variations & variations are raw materials for the process evolution.
4. It results in the formation of gametes.
5. It carries the hereditary characters from both the parents.

<u>Differences between Mitosis and Meiosis.</u>

Sl.No.	Mitosis	Meiosis
1	It occurs in **somatic cells** (i.e, diploid, haploid,polyploid cells)	It occurs in **germ cells** (i.e, diploid, polyploid cells only)
2	It consists of **single nuclear division**	It consists of two **successive nuclear divisions**.
3	It is an **equational division** (i.e, daughter cells have the same chromosome number as parent cell)	It is a **reductional division**.
4	Prophase is less complicated and **not divided into substages.**	Prophase I is complicated and has **five substages**.
5	Chromosomes are not **clearly visible** in	Chromosomes are visible.

	prophase	
6	**Synapsis is absent**	**Synopsis occurs in Zygotene**
7	**Crossing over is absent**	Crossing over occurs in **Pachytene** stage.
8	Unpaired chromosomes arranged on equator at metaphase	Paired chromosomes arranged on equator at metaphase I.
9	Chromatids separate at anaphase	Whole chromosomes (with two chromatids) separate at anaphase I.
10	Separating chromatids are identical (same)	Separating chromatids are recombined due to crossing over
11	Both homologous chromosomes are present in the daughter cells	Only one of each pair of homologous chromosomes present in the daughter cells.
12	Produces **two daughter cells**	Produces **four daughter cells**.